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DIGITAL FARM INDEX (DFI): REGIONAL DISPARITIES IN THE DIGITALISATION OF AGRICULTURE IN ROMANIA

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Abstract

The paper analyzes the state of digitalization in Romanian agriculture, aiming to assess regional gaps in farms' digital maturity. The study pursues two objectives: to develop and validate the Digital Farm Index (DFI) based on Eurostat data for 2023, and identify regional profiles of technology adoption in commercial farms (Standard Output > €100,000). The research is guided by two hypotheses: technology distribution is uneven across regions, and agricultural specialization influences the type of digitalization. Calculated using asymmetric weights, the indicator aggregates four dimensions: connectivity (20%), precision agriculture (35%), robotics (25%), and management systems (20%). The results confirm the hypotheses and indicate distinct regional profiles. The North-West region records the highest DFI score (25.50), while the Center region leads in automation (38.04%), mainly due to the livestock sector. The North -East region stands out at the managerial level (9.27%), whereas South-West Oltenia faces severe connectivity gaps (22.54%). Comparatively, the national DFI reaches 20.89 when calculated based on the number of farms and 25.83 when calculated based on hectares, demonstrating the concentration of digital technologies in large-scale holdings. The study concludes that agricultural policies should be tailored to specific regional realities rather than based on uniform approaches.

Key words**:** *Agriculture 4.0, Digital Farm Index (DFI), regional disparities*

INTRODUCTION

The transition toward the Agriculture 4.0 paradigm presents a major stage in the transformation of agro-food systems at the global level, being characterized by the extensive integration of Internet of Things (IoT) technologies, Big Data analytics, and autonomous solutions into agricultural production processes (Verdouw et al., 2021) [13].

At the European level, the objectives set out under the Digital Decade 2030 outline ambitious strategic directions aimed at accelerating the digitalization of rural areas and enhancing the competitiveness of the agricultural sector (European Comission, 2021) [5]. Nevertheless, the specialized literature suggests the existence of significant digital disparities, manifested not only between Member States but also internally, among agricultural regions characterized by different levels of technological development. (Say et al., 2018) [9]. In this context, the mere availability of digital technologies does not automatically lead to improved performance of agricultural holdings, which highlights the need for multidimensional instruments capable of assessing the digital maturity of farms. Moreover, when viewed through the lens of clasical and contemporary theories of economic growth and development, technological innovation goes beyond the status of a simple quantitative factor, representing, in essence, the main driver of the structural and qualitative transformations of economic systems (Ștefan, 2012) [12]. In Romania, the process of agricultural digitalization is currently in a stage of consolidation. Although recent bibliometric studies indicate an intensification of scientific interest in the digitalization of agriculture (Stoica et al., 2022) [10], the specialized literature points to the absence of adequate composite indicators for quantifying technological progress at the regional level. Digital transformation in the Romanian rural space represents a well-founded prerequidite,

being closely dependent on the capacity to participate in the digital economy and on the adaptation of human resources to new requirements (Buțu et al., 2024; Ionițescu et al., 2023) [2,7]. At the European level, the literature emphasizes the importance of structural and technological factors in explaining differences in agricultural performance, while technical endowment and resource management play a decisive role in achieving efficiency objectives (Coca et al., 2023) [3].

At the same time, the implementation of digital decision-support systems faces barriers related to the economic size of the farm (Bodescu et al., 2022) [1], while the integration of Big Data flows is becoming a strategic necessity for improving the efficiency of agricultural management (Cofas, 2023) [4]. Although there is significant potential for the adoption of smart technologies, the process of agricultural digitalizations is confronted with major structural challenges, with technological upgrading becoming an essential instrument for increasing sectoral competitiveness (Șerban et al., 2025) [11]. The analysis of regional disparities shows that the level of digital infrastructure and the structural speficicities of each region determine the pace of technological adoption at the territorial level (Popescu et al., 2025) [8]. For commercial holdings with a Standard Output exceeding €100,000, digitalization tends to become an important determinant of competitiveness and economic sustainability.

Starting from these premises, the main objective of the research is to develop and apply a rigurous model for evaluating digital maturity, operationalized through the Digital Farm Index (DFI). Built on a methodology based on asymmetric weights, designed to reflect the specific agronomic impact of the four pillars of digital adoption, and using Eurostat data for 2023 [6], the proposed index makes it possible to test hypotheses regarding the distribution and determinants of technology adoption at the regional level. In this regard, the study investigates the existence of pronounced territorial asymmetries between regions with high digital performance and regions characterized by structural constraints. Moreover, by comparatively assessing the index according to the number of farms versus the utilized agricultural area, the paper analyzes the influence of productive specialization and economic size on the typology of adopted technologies and explores the role of connectivity as a potential structural barrier to the implementation of advanced precision agriculture solutions.

This integrated approach provides a detailed diagnosis of territorial vulnerabilities and contributes to the specialized literature by proposing a clear and replicable analytical framework for monitoring digital transformation in emerging agricultural economies. Through the comparative analysis of the eight NUTS 2 development regions, the study highlights the need to design differentiated agricultural policies capable of responding to the structural specificities and level of digital maturity of each region, thereby facilitating the reduction of technological disparities and the strengthening of the agricultural sector's competitiveness.

MATERIALS AND METHODS

The research is based on the analysis of data derived from the Eurostat database, using updated datasets for reference year 2023 regarding the adoption of technologies in the agricultural sector. In order to ensure the economic relevance of the results and to capture the behavior of holdings with a high innovation potential, the analysis is carried out exclusively on commercial farms with a Standard Output exceeding €100,000. This methodological choice makes it possible to reduce the distortions generated by subsistence agriculture and to focus the analysis on the segment of holdings that possess the technical and financial capacity required to implement advanced digital solutions. The analysis is conducted at the level of Romania's eight NUTS 2 development regions, thus enabling a comparative assessment of territorial differences in the process of digital technology adoption.

The evaluation of the digital maturity of agricultural holdings was carried out through the construction of a composite indicator, the Digital Farm Index (DFI), structured around four essential dimensions of the technological modernization process. The dimensions analyzed include: (1) connectivity, assessed through the level of internet access among holdings; (2) precision agriculture, reflected by the use of global navigation satellite systems (GNSS) and sensor-based technologies; (3) robotics and automation, capturing the adoption of drones and autonomous equipment; and (4) digital management systems, measured through the use of Farm Management Information Systems (FMIS) applications. For each dimension, the basic indicators were taken directly as percentages of commercial farms in each region that use the respective technologies, or as percentages of the agricultural area managed through technologies.

To ensure the territorial comparability of the raw data provided by Eurostat, the basic indicators for each dimension were calculated in percentage terms. Specifically, the number of farms, or the agricultural area in hectares, using a given technology was divided by the total number of commercial farms, or to the total agricultural area, in the respective region, and the result was multiplied by 100. In this way, percentage values were obtained, reflecting the actual degree of penetration of each technology.

Given that all four indicators used in the construction of the DFI are expressed on the same percentage scale, with values ranging from 0 to 100, the application of a prior statistical normalization procedure was not necessary. However, unlike traditional approaches based on simple averages, the present methodological framework employs a system of asymmetric weights. Accordingly, the composite indicator Digital Farm Index (DFI) was determined through the weighted aggregation of the four pillars, according to the following relationship:

$$DFI = (P_1 \times 0.20) + (P_2 \times 0.35) + (P_3 \times 0.25) + (P_4 \times 0.20)$$

where:

P_1 represents the share of farms with internet access;

P_2 represents the share of farms using precision agriculture technologies;

P_3 represents the share of farms using robotics and automation solution;

P_4 represents the share of farms using digital farm management systems (FMIS).

This methodological choice of differential weighting was adopted on the premise that not all dimensions of digitalization have the same capacity to generate direct effects on the technical and economic performance of agricultural holdings. Internet connectivity, although indispensable, primarily represents a basic infrastructural condition, which is why it was assigned a weight of 20%. By contrast, precision agriculture was considered the pillar with the most direct agronomic impact on input optimization, cost reduction, and the increased efficiency of resource use, which justifies the highest weight, namely 35%. Robotics and automation were assigned a weight of 25%, reflecting their significant contribution to the efficiency of operational processes, especially in specialized holdings. Digital management systems (FMIS) were weighted at 20%, given their role in integrating technological information and supporting managerial decision-making, although their impact on production is more indirect compared with technologies applied directly in the field or within automated processes. Therefore, the weighting structure used aims to differentially reflect the estimated contribution of each dimension to the digital maturity of agricultural holdings.

The weights used reflect a conceptually grounded analytical choice and do not claim to establish a universally valid hierarchy for all types of agricultural holdings. The same calculation procedure was applied both to indicators reported in relation to the number of agricultural holdings and to those reported in relation to the utilized agricultural area (UAA), in order to capture the differences between technology adoption at the farm level and the territorial extent of digitalization.

Another methodological innovation of this study lies in calculating the DFI from a dual

perspective: (1) in relation to the number of agricultural holdings and (2) in relation to the utilized agricultural area (hectares). This dual approach is essential for isolating the effect of economic size and for capturing structural differences, namely whether technology is adopted on a broad scale across farms in general or whether it is concentrated primarily in large-scale holdings.

The resulting values were subsequenlty subjected to a comparative regional analysis, with the aim of identifying the predominant patterns of technology adoption and testing hypotheses regarding the influence of agricultural specialization, for example livestock farming versus crop production, on the structure of digitalization process. The proposed methodology provides a clear and replicable analytical framework capable of supporting the folumation of evidence-based regional agricultural policies aimed at reducing digital disparities and accelerating technological convergence.

RESULTS AND DISCUSSIONS

The results obtained from processing Eurostat data (2023) reveal a national configuration characterized by pronounced technological fragmentation among commercial farms in Romania. The analysis targets the segment of holdings with a Standard Output exceeding €100,000, and the results indicate that digitalization does not represent a homogeneous process, but rather one marked by divergent regional priorities. Before aggregating the indicators into a composite index, the analysis of the individual components (Table 1) highlights a differentiated territorial distribution of digital innovation, in which basic infrastructure and advanced technologies evolve at distinct paces.

Table 1. Regional adoption rates of digital technologies in Romanian commercial farms (SO > 100,000 €)

Region Nuts 2	Farms with internet access (%)	Precision agriculture adoption (%)	Robotics and automation (%)	Farm management systems (%)
North -West	60.25	15.53	28.57	4.35
Center	51.63	9.24	38.04	3.26
North - East	53.17	18.05	21.46	9.27
South -East	55.46	15.34	8.26	7.37
South Muntenia	53.20	16.84	11.78	5.72
Bucharest- Ilfov	46.15	7.69	7.69	3.85
South –West Oltenia	22.54	17.61	11.27	2.11
West	48.98	12.24	10.88	4.08

Source: authors' own processing based on Eurostat data, 2023.

The analysis of the regional distribution of digitalization indicators at the level of commercial holdings highlights a spatial configuration marked by pronounced heterogeneity, defined by divergent investment priorities and specialization profiles. The raw data show that the modernization process of Romanian agriculture is characterized by a heterogeneous technological configuration across the analyzed regions.

Connectivity currently represents the main structural barrier fragmenting the national agricultural landscape. The sharp contrast between the North-West Region (60.25%) and the South-West Oltenia Region (22.54%) indicates the existence of structural digital disparities at the level of basic infrastructure. This discrepancy of more than 37 percentage points suggests that, in the absence of stable access to communication networks, a substantial share of commercial farms in the southern area is excluded from the benefits of integration into cloud-based ecosystems or real-time data transfer, thereby severely limiting the scalability potential of digital innovations.

With regard to robotics and automation, the data confirm the hypothesis that the regional production profile acts as a catalyst for the typology of technologies adopted. The particular situation of the Center Region, which records an adoption rate of 38.04%, represents an indicator of the maturity of the

commercial livestock sector in this territory. In the context of intensive livestock farming, investments have been directed primarily toward the automation of production processes, such as autonomous milking or feeding systems, thereby generating a distinct technological profile compared with regions dominated by crop farms, where interest in robotic solutions remains, for the time being, marginal.

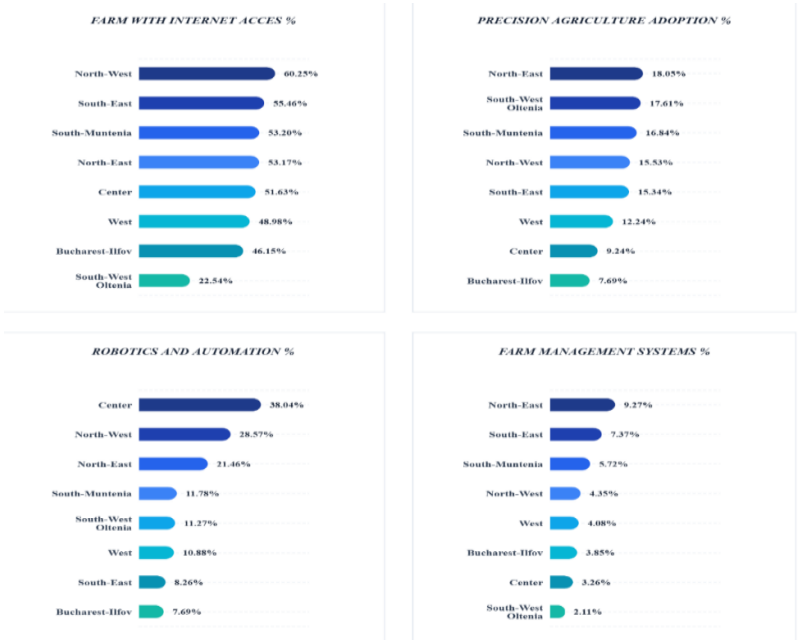

Fig. 1. Regional adoption rates of digital technologies in Romanian commercial farms (SO > 100,000 €)
Source: authors' own processing based on Eurostat data, 2023.

The analysis of the digital management (FMIS) and precision agriculture pillars highlights the North-East Region as the benchmark for the professionalization of data-driven decision-making. Although it does not hold the leading position in the connectivity pillar, this region ranks first in the use of farm information management systems (9.27%) and precision technologies (18.05%). This convergence indicates a transition toward a data-driven management model, specific to large-scale crop holdings seeking rigorous input optimization. A paradoxical situation can be observed in the South-West Oltenia Region, where the adoption rate of precision agriculture (17.61%) contrasts sharply with the deficit in internet infrastructure. This situation suggests a model of digitalization focused on smart hardware, such as GNSS systems with partially offline functionality, which, although improving the efficiency of mechanized operations, remains vulnerable due to the lack of integration into complex data flows. The analysis of the figure shows that the digitalization of commercial farms in Romania remains a selective process, concentrated mainly in certain categories of holdings and regions. The North-West provides the infrastructural base, the Center dominates physical automation, while the North-East stands out in terms of managerial maturity. This asymmetric distribution fully justifies the need for differentiated agricultural policies capable of addressing the specific bottlenecks of each region in order to ensure sustainable technological convergence.
For a deeper understanding of the structural impact of digital technologies, the analysis was extended from the number of holdings to the utilized agricultural area (UAA). This perspective highlights a process of technological concentration, in which, although the share of digitalized farms may appear relatively modest, their contribution to the total agricultural area is considerably higher. The results confirm that large-scale holdings represent the main drivers of modernization, generating a disproportionate effect on the dynamics of digital transformation within the agricultural sector.

Table 2. Share of utilized agricultural area (UAA) managed through digital technologies in Romanian commercial farms

Region Nuts 2	Farms with internet access (%)	Precision agriculture adoption (%)	Robotics and automation (%)	Farm management systems (%)
North -West	66.44	21.24	23.09	7.37
Center	51.96	11.88	24.83	4.21
North - East	59.93	25.22	21.46	13.61
South -East	64.73	26.62	10.79	12.57
South Muntenia	61.77	26.53	16.00	10.43
Bucharest- Ilfov	45.52	9.37	11.81	0.00
South –West Oltenia	30.99	25.01	13.77	3.58
West	56.98	20.79	11.52	8.03

Source: authors' own processing based on Eurostat data, 2023.

Extending the analysis from the level of individual holdings to the utilized agricultural area (UAA) provides an essential structural perspective, revealing a much broader spatial footprint of digitalization than is suggested by the mere share of the number of farms.

This approach confirms the manifestation of a scale effect in Romanian agriculture, where large commercial holdings act as the main vectors for the diffusion of Agriculture 4.0 technologies, generating economies of scale and optimizing production processes over extensive areas.

The analysis of the connectivity pillar at the area level reflects a strengthening of digital infrastructure in the plain regions and the western part of the country.

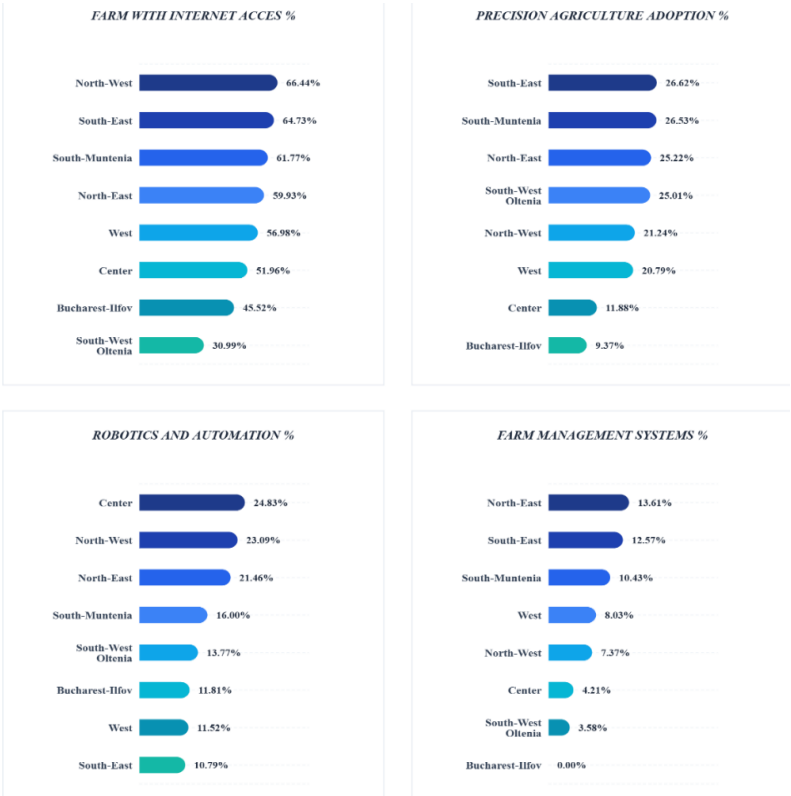

Fig. 2. Share of utilized agricultural area (UAA) managed through digital technologies
Source: authors' own processing based on Eurostat data, 2023

The North-West Region maintains its leading position, with internet coverage across 66.44% of the agricultural area, followed closely by the South-East (64.73%) and South Muntenia (61.77%). This generalized increase in connectivity indicators reported per hectare compared with those reported per farm suggests that large farms have managed to overcome rural infrastructure barriers through their own investments in dedicated

communication solutions. In constrast, the gap remains visible in South-West Oltenia, where only 30.99% of the area benefits from internet access, confirming the persistence of a major territorial vulnerability.

A particularly relevant dynamic can be observed in the precision agriculture pillar, where the hierarchy shifts in favor of the large cereal-growing areas in the south. The South-East (26.62%) and South Muntenia (26.53%) regions take the lead, demonstrating that GNSS – and sensor-based technologies are integrated primarily into large crop farms, where precision in the application of inputs per hectare becomes a critical factor of competitiveness. The technological upgrading effort in South-West Oltenia is also noteworthy, as precision systems are used across one quarter of its agricultural area (25.01%), despite the major connectivity deficit mentioned above.

With regard to robotics and automation, the hectare-based data provide a more nuanced view of the profile of the Center Region. Although it remains the leader (24.83% of UAA), a convergence can be observed with the North-West (23.09%) and North-East (21.46%) regions. This indicates that, although robotization is driven primarily by livestock farming at the level of individual holdings, from a spatial perspective automation is beginning to cover significant areas also in advanced crop and horticultural sectors as well. The farm management systems (FMIS) pillar confirms the managerial maturity of the North-East Region, where 13.61% of the regional agricultural area is managed through specialized software. This value, reinforced by the solid performances of the South-East (12.57%) and South Muntenia (10.43%) regions, highlights the strategic orientation of large-scale holdings toward the digital control of costs and production flows. In conclusion, the hectare-based analysis demonstrates that digitalization in Romania has a much deeper territorial impact in large-scale crop production areas.

This reality is reflected in the first-place ranking of the North-East Region in the DFI calculated at the level of utilized agricultural area, with a score of 28.90. While at the farm level digitalization appears to be a fragmented process, the spatial perspective reveals a concentration of innovation in the major agricultural poles, highlighting the need for policies that also support the technological transition of medium-sized holdings in order to reduce the current technological polarization. The comparison between the data presented in Table 1 (farms) and Table 2 (utilized agricultural area) highlights a series of relevant trends concerning the structure of the digitalization process in Romanian agriculture. A significant increase in the indicators can be observed when they are reported in relation to area. In the South-East region, although only 15.43% of farms use precision agriculture technologies, these farms manage 26.62% of the regional agricultural area. This discrepancy confirms that, in plain areas, GNSS- and sensor-based technologies are adopted primarily by large crop farms, where the optimization of inputs over extensive areas generates significant economies of scale. Unlike precision agriculture, the robotics pillar presents a distinct configuration. Although 38.04% of farms use automation solutions (Table 1), the corresponding area amounts to only 24.83%.

(Table 2) This result confirms the livestock-specific profile of the region, where robotization is concentrated in intensive holdings managing a high number of animals on relatively smaller agricultural areas.

The North-East Region highlights an efficient use of digital management technologies, as the share of agricultural area managed through FMIS systems (13.61%) significantly exceeds the share of farms using these solutions (9.27%). This result indicates that large commercial holdings have advanced toward a data-driven agricultural management model, using digitalization to optimize performance over extensive areas.

The region with the lowest level of connectivity (30.99% of UAA), South-West Oltenia, displays a relatively high rate of precision agriculture adoption at the area level (25.01%). This configuration suggests an orientation toward investments in smart hardware technologies, such as autoguidance systems, which make it possible to

compensate for the limitations of digital infrastructure and contribute to the digitalization of a significant share of the agricultural area.

Digital Farm Index (DFI) for Agricultural Holdings

The calculation of the composite Digital Farm Index (DFI) at the level of agricultural holdings highlights the hierarchy of digital maturity within Romania's commercial agricultural sector. As it is determined through the application of asymmetric weights, which favour technologies with major agronomic impact, such as precision agriculture and robotics, the DFI score reflects the actual level of digitalization at the regional level and provides an integrated perspective on the territorial distribution of the technological transformation process (Figure 3). The results presented in Figure 3 highlight a configuration of digital maturity that confirms the influence of structural profiles and regional investment priorities. At the national level, the average DFI calculated on the basis of the number of farms is 20.89. The North-West Region ranks first nationally, with a DFI score of 25.50, reflecting a relatively high and balanced level of digital adoption, supported both by a solid infrastructural base, namely connectivity, and by a high degree of integration of automation solutions.

An important shift in the hierarchy can be observed in second place, occupied by the North-East Region with a score of 24.27. Owing to the new methodology, which gives greater weight to digital management systems (FMIS) and precision agriculture, this region surpasses the Center Region. The latter ranks third, with a score of 23.72, its digital profile being driven almost exclusively by the robotics pillar, which is specific to livestock specialization, but constrained by weaker performances in the field of precision agriculture.

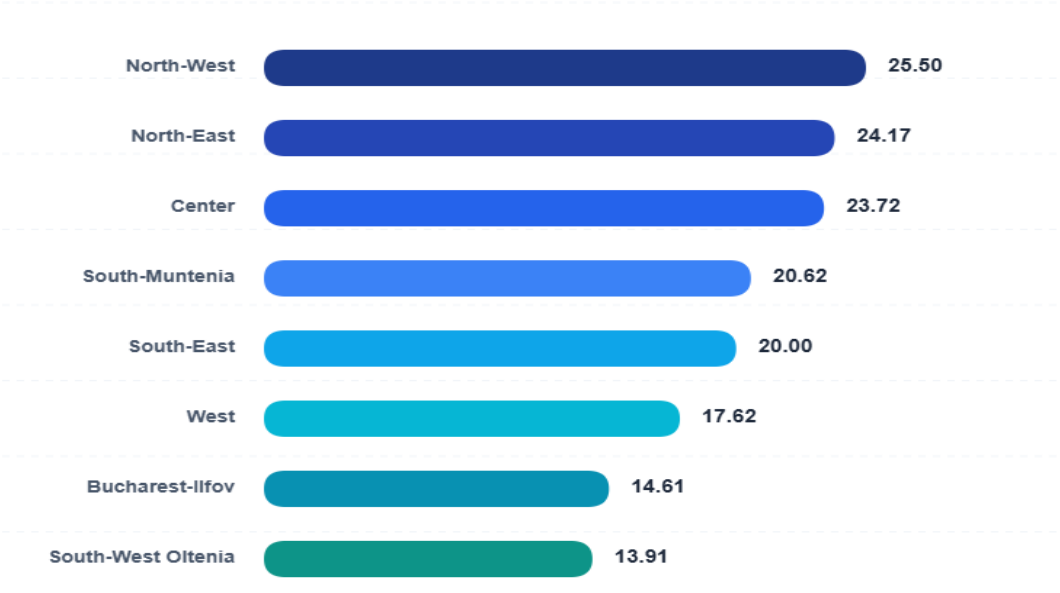

Fig. 3. Digital Farm Index for agricultural holdings
Source: authors' own processing based on Eurostat data, 2023

In the middle range of the ranking are the South-Muntenia (20.62) and South-East (20.00) regions, both of which are situated very close to the national average. In these regions, the adoption of precision technologies contributes to supporting the digitalization process; however, the overall integration of the four pillars remains more

limited across the broader mass of farmers compared with the leading regions. The West (17.62), Bucharest-Ilfov (14.61), and South-West Oltenia (13.91) regions record the lowest levels of the DFI. In the case of the South-West Oltenia Region, the low score reflects the major connectivity deficit, which acts as a constraint on the integration of complex digital solutions.

Therefore, the results confirm that the digital maturity of commercial farms in Romania is not distributed uniformly. The DFI calculated at the farm level shows that, despite the existence of certain ”islands” of technological excellence, the critical mass of holdings still faces structural and investment-related constraints in the adoption of advanced technologies.

Digital Farm Index (DFI) for Utilized Agricultural Area (UAA)

The calculation of the composite index in relation to the utilized agricultural area (UAA) fundamentally changes the perspective of the analysis, highlighting the actual extent of technologies across managed agricultural land. Reporting the weighted pillars to area makes it possible to isolate the scale effect and brings to light the gap between technology adoption at the unit level (farm) and its spatial magnitude hectares (Figure 4).

The results presented in Figure 4 highlight a visible intensification of digitalization when the analysis is reported in relation to agricultural area. The national average of the DFI increases significantly from 20.89 at the farm level to 25.83 at the hectare level. The difference of nearly five points indicates that high-performance digital technologies are adopted primarily by large-scale holdings, which manage extensive areas and generate a disproportionately large impact on the technological transformation of the agricultural sector.

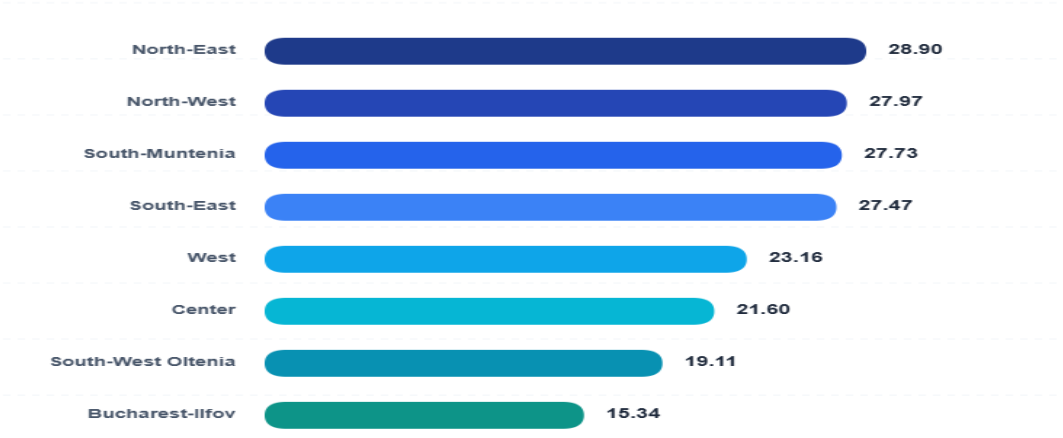

Fig. 4. Digital Farm Index (DFI) by utilized agricultural area (hectares)
Source: authors’ own processing based on Eurostat data, 2023.

The North-East Region consolidates its leading position at the national level, with a DFI score 28.90, confirming that digital innovation is integrated across an extensive agricultural area. This result reflects the region’s superior performance in the precision agriculture pillar, which carries a weight of 35% in the index, as well as in the digital management pillar. The North-West Region remains at a very high level, ranking second with a score of 27.96, thereby demonstrating a balanced spatial diffusion of all four technological pillars. However, the most remarkable dynamic is observed in the large cereal-growing areas of the south: South-Muntenia (27.73) and South-East (27.47) rise sharply in the ranking and exceed the national average. These results highlight that, although the number of digitalized farms in these areas is lower, satellite-guidance systems and

sensor-based technologies, namely precision agriculture, are applied across vast agricultural areas.

A downward reconfiguration can be observed in the Center Region (21.60), which loses competitive advantages when the analysis shifts from farms to hectares. This decline validates the hypothesis that robotics in the Center Region is specific to intensive livestock holdings, whose land footprint, measured in hectare, is much smaller compared with crop farms in the Southern and Eastern parts of the country. At the lower end of the ranking are the West (23.16), South-West Oltenia (19.11), and Bucharest-Ilfov (15.34) regions. Even in the case of South-West Oltenia, an improvement in the hectare-based score can be observed compared with th efarm-based score, supported by hardware-based self-guidance technologies, although the regions remain constrained by the lack of internet infrastructure.

Therefore, the UAA- based DFI analysis demonstrates that the digitalization of commercial agriculture in Romania is profoundly asymmetric. Costly and advanced technologies are strongly concentrated in large-scale holdings that use precision agriculture to generate economies of scale, leaving the rest of the agricultural sector in a state of technological vulnerability.

CONCLUSIONS

The present research has made it possible to substantiate a multidimensional analysis of digital maturity in Romania's commercial agricultural sector, offering a rigorous perspective on the way technological innovation is territorially distributed. By developing and applying the composite Digital Farm Index (DFI), based on an innovative system of asymmetric weights, the study has gone beyond the simple statistical monitoring of technology adoption and has proposed an analytical instrument capable of capturing the structural mechanisms that influence the pace of digital transformation at the regional level. Synthesizing the results obtained, the conclusions of the research can be structured along several levels of impact:

First, the results confirm the existence of significant territorial asymmetries in the process of digitalizing commercial agriculture in Romania. The analysis has shown that the presence of internet connectivity, although it constitutes a basic infrastructural condition, is not sufficient in itself to achieve a high level of digital maturity. The contrast between regions with superior performance and those still at an early stage, such as South-West Oltenia, indicates the existence of structural disparities that affect the coherent integration of technologies with major agronomic impact and limit technological convergence at the national level.

Second, the study confirms the role of productive specialization as a major determinant of the regional technological profile. The distinct configuration of the Center Region, which stands out through high levels in the robotics pillar, highlights the orientation of investments toward solutions specific to intensive livestock holdings. By contrast, regions dominated by large-scale crop production tend to rely primarily on precision agriculture technologies and digital management tools (FMIS), demonstrating that technological adoption is closely shaped by the operational needs of the dominant production profile.

The central aim of the paper lies in the precise quantification of the scale effect, achieved through the comparative analysis of indicators reported in relation to the numer of holdings versus the utilized agricultural area (UAA). The results show that digitalization has a much stronger territorial expression when reported in relation to area: the national average of the DFI increases significantly, from 20.89 when calculated on the basis of the number o farms to 25.83 when calculated on the basis hectares. This substantial difference validates the hypothesis that costly digital innovations are strongly polarized, being concentrated in large-scale agricultural units capable of making optimal use of economies of scale.

From a regional perspective, the DFI rankings indicate differentiated digital profiles. The North-West Region holds the first position in te ranking calculated at the level of

agricultural holdings (DFI: 25.50), reflecting a balanced combination of the four pillars of digitalization across the broader population of farmers. By contrast, the North-East Region leads the analysis reported in relation to utilized agricultural area (DFI: 28.90), confirming the extensive integration of precision agriculture and management systems across vast agricultural areas. These results show that digital leadership manifests in distinct forms: either through technology penetration across a large number of medium-sized farms, or through its concentration on the extensive areas managed by the major actors in the market.

In conclusion, the paper underscores the urgent need to regionalize agricultural policies aimed at digital transformation. The results support the abandonment of uniform national strategies in favor of support measures tailored to the specific vulnerabilities and advantages of each region, namely urgent investments in communication infrastructure for disadvantaged areas, such as South-West Oltenia, as well as managerial integration programs and targeted support for medium-sized farms in polarized regions. In this context, the Digital Farm Index represents a robust and flexible analytical instrument that can be extended in future research through the inclusion of variables related to digital skills, economic performance, or the ecological sustainability of agricultural holdings, thereby providing support for an equitable transition toward Agriculture 4.0.

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CONSUMER PERCEPTION OF FOOD SECURITY DURING BULGARIA'S ACCESION TO THE EUROZONE

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Abstract

Bulgaria have joined the European union in 2007 alongside Romania. Ever since the process of accession have been completed the country was on track to join the eurozone and adopt the Euro as its currency, foregoing the longstanding (since 1880) national currency of Bulgarian LEV. After the fulfilment of conditions to join the Eurozone Bulgaria is adapting the Euro on the 1st of January 2026. This transition has consumers concerned about price increases for foods and consumer goods. Bulgaria, since its accession to the EU have gradually transitioned form net food exporter to net food importer with a high ratio of fresh fruits and vegetables, livestock products and processed foods currently being imported. The goal of this study is to analyse consumer's perception of their food security during the initial period of adopting the Euro as a national currency in Bulgaria. The study is conducted among consumers form the Southeast region of the country. To achieve this goal the following tasks are completed: to collect survey data from consumers on their perceived levels of food security; to draw conclusions based on statistical analysis of the collected data; and to suggest guidelines for future surveys to facilitate the continued data collection and analysis. The conducted survey results prove that consumers have felt the inflationary process of currency transition at a much higher rate than the actual recorded values – 13% vs. 3.8%. The perceived inflation does not affect the food security of most households, as almost two thirds if surveyed consumers will not change anything about their food purchasing patterns. A further study is needed to access the consumer perception when more time have passed.

***Key words*:** *food prices, consumer perception, inflation, monetary transition*

INTRODUCTION

The analysis of the discourse of food security in the European Union requires a deeper look at how macroeconomic changes, including currency integration, increase the vulnerability of regional supply chains (Matejkova et al., 2024; Trasca et al., 2025) [11, 15].

In particular, the institutional frameworks need to be assessed to comprehend how the domestic policy responses alleviate the effects of a price volatility on the availability of essential products (Ivanova, L, 2006; Zawojska & Siudek, 2025) [7, 16].

Price stability is one of the core pillars of this integration because any monetary policy fluctuations can have a disproportionate impact on the most vulnerable groups of people and undermine the food security of households (Dovgal, 2022) [5].

In this regard, the fact that strategic measures are implemented to optimize monetary transmission mechanisms and increase the technological modernization of production becomes crucial to the anchoring of long-term inflationary expectations (Dovgal, 2022) [5].

The 2020s-era shift to sustainability, innovation, and domestic supply chain strengthening has marked the development of Bulgarian food production. The National Development Program of Bulgaria 2030 steers such an evolution and significantly emphasizes the establishment of structural and sectoral balance in the field of agriculture. One of the key elements of this plan is the National Plan of Recovery and Sustainability that makes the green Bulgaria and sustainable agriculture one of the primary objectives of the present decade. These reforms will be aimed at bringing the Bulgarian agrarian sector to the international commitments in terms of the Sustainable Development Goals, the European Green Deal, which is encouraging farmers to implement technological and digital solutions to enhance climate and environmental performance. The sector vision of 2030 will be to position

Bulgaria as a leader of bioproducts production, specializing in food, cosmetic, and pharmaceutical products based on Bulgarian raw materials. This project focuses on producing high-quality and clean food and preserving the thematic sector of the industry to healthy living, bioeconomy, and biotechnology. The strategic map of 2021-2027 focuses on the means of increasing access to end-users to the clean production, processing, and storage of certain Bulgarian ingredients to achieve this vision.

The creation of small and family farms has become one of the key priorities in the European Union because they constitute about 80-90 percent of the formations of the agricultural sector (Toma et al., 2021) [14]. The present-day EU policies are currently geared towards enhancing the competitiveness of such farms to protect the regional food systems against international supply shocks and drastic price fluctuations, even though such farms were traditionally oriented towards the personal or local market needs (Brankov and Matkovski, 2022; Toma et al., 2021) [3, 14]. It is especially important since the prices of agricultural input and energy doubled in 2020-2022, and it immediately endangered the economic sustainability of smaller producers who are frequently net-sellers of agricultural goods (Bureau & Swinnen, 2017; Kornher et al., 2024) [4, 8]. To realize the economic potential of these farms, the national interventions have to take care of the risks of changing climatic conditions and increasing production costs in order to ensure stable food supply (Matejkova et al., 2024; Toma et al., 2021) [10, 14].

Under the wider EU context, the effect of increase in food prices has tipped the core issue on the food supply into the affordability of food. Although the EU is mostly well-endowed with enough agricultural reserves and is also a net exporter, the soaring food prices since 2021 have greatly reduced the purchasing power of low-income earners in some of the Member States. The 2022 Versailles Declaration and the Common Agricultural Policy, in turn, have presented measures to decouple the reliance on imported fertilizers, of which 31 per cent of nitrogen came out of Russia, and offered financial aid to stabilize the food system (Andreica et al., 2023) [1]. These strategic frameworks aim at reducing the effects of inflation on food accessibility, so that the elevated prices do not reduce to chronic food insecurity of vulnerable European populations.

In this context, the purpose of this research is to assess the perception of food security by Bulgarian consumers during the initial period of adopting the Euro as a national currency in Bulgaria. A study case was made on a panel of consumers from the South-East part of the country.

MATERIALS AND METHODS

The current paper uses mixed methods to test the hypothesis of linking currency integration and consumer food security in Bulgaria. The real-time perceptions of price volatility and expenditure changes were measured by the quantitative data which was collected in the form of the structured questionnaires carried out among the representative group of local households in the Southeast region of the country. The time constraints connected with the studied topic – consumer price change perceptions created a limitation for higher survey participation. The survey was completed through the last week of January and first week of February 2026 – from 26.01.2026 to 08.02.2026. Any extension of the survey period would have led to collection of data that might distort the results, that are meant to provide a snapshot of consumer perception for a specific period – the beginning of the full integration of the common currency – euro in Bulgaria in January of 2026. The survey was developed digitally with participants mainly form the southeast region of the country. The electronic questionnaire was disseminated through multiple channels, including social media, in person - through QR codes among part time students form Trakia University, and other means of digital distribution. Data was collected from 156 participants that indicated a wide variety in age groups, household sizes, food budgets and other characteristics of respondents. The small number of participants

and the selected survey method – digital distribution to willing participants weakens the representativeness of the results, but still some conclusions can be drawn. In the future a larger scale survey is planned to verify and add to the results achieved by the current study.

The data reconciliation or triangulation methodological approach of using a pairing of statistical data to survey findings is aimed at confirming the subjective consumer perceptions with a pair of objective macroeconomic variables. This is necessary in the process of discovering whether the issue of public concerns (like food security in currency transitions) are endorsed by empirical economic patterns.

The major purpose of selected research methods is to apply official statistical measures as a reference point or benchmark to compare findings of surveys (Marchetti et al., 2015) [10]. In the literature on the Bulgarian food market, the researchers provide comparisons of particular data on consumer perception surveys with the official indices, including the Total Producer Price Index of Food and Harmonised Consumer Price Index of Food (Borisov, 2022) [2].

To compare the two sets of data, it is necessary to use certain mathematical tools to determine whether the observed relationships are significant. Using Pearson coefficient to measure the strength and direction of relationship between subjective survey-based perceptions of price volatility and other relevant consumer characteristics.

It is a technique that is frequently associated with time comparison, i.e., the contemporary survey outcomes are compared to past statistical numbers, with the aim to detect the behavioural change or the lack of such (Kramolis, 2015) [9].

The key aspect of this methodology is to find out where subjective perception is out of line with objective data. Compared to the statistics, which may indicate the presence of stability, a survey may indicate a high level of perceived insecurity based on such factors as price fluctuations or low income (Trasca et al., 2025) [15]. Their comparison helps the researchers to learn about the physical and psychological issues related to food access that can remain unnoticed with the help of official price indices (Matejkova et al., 2024) [11].

RESULTS AND DISCUSSIONS

Consumer perception of food security is tightly connected to their perception of food prices and budgetary constraints. Low-income earners are more likely to be impacted by any inflationary process and at higher risk concerning food security. This connection requires a study of consumer perception of food price fluctuations and their related reactionary strategies.

Consumer prices for most food groups on the Bulgarian market are on an incline through 2025, and consumer did already feel the inflationary pressure on their budgets, based on data from Eurostat database [6]. Some food groups are more affected, such as bread and cereals, meat and meat products, dairy and dairy products. These key products formulate a large portion of the food consumption basket for low-income households, and thus they are more impacted by these changes.

Table 1. Harmonised index of consumer prices in Bulgaria, in %, 2015 used as base

	Jun-25	**Aug-25**	**Oct-25**	**Dec-25**
Bread and cereals	143.82	144.64	144.58	144.78
Meat	145.44	146.93	148.1	148.35
Milk, cheese and eggs	148.96	149.95	150.13	149.53
Oils and fats	169.45	168.33	165.52	160.92
Fruit	157.14	151.6	150.85	148.95
Vegetables	152.33	150.97	149.53	153.07
Coffee, tea and cocoa	149.66	153.97	154.3	153.91
Food	148.31	148.45	148.5	148.62

Source: EUROSTAT Database [6].

The harmonised index of consumer prices for food products throughout the second half of 2025, available in the Eurostat database is presented in Table 1. This period marked the beginning of the transition for local currency of Bulgarian LEV (BGN) to the common European currency of EURO (EUR). During the latter half of 2025 all prices in physical

stores and online ware shown in both currencies (with BGN prices on top and EUR prices in the bottom) so consumers can adjust their expectation and can build up familiarity and confidence.

While starting from the beginning of February 2026 only EUR is accepted in all forms of payment in the country both prices will continue to be displayed (currently with EUR prices on top and BGN prices in the bottom) in both currencies.

During the last two quarters of 2025 consumer prices for food, averaged among different products, have barely changed, marking an increase of 0.31%, using the 2015 prices as a base. The highest increase in consumer prices was recorded for Coffee, tea and cocoa – 4.25%, followed by meat – 2.91%. During the same period there are also products, that have decreased in price, such as Oils and fats – 8.53% and Fruits by 8.19%. Overall, the available statistical data shows that consumers should not feel any inflationary pressure on their food budgets for the latter half of 2025, as the prices on average have not increased meaningfully.

Statistical data for consumer price changes in the beginning of 2026 is only available through the studies and monitoring conducted by the National statistical institute of the Republic of Bulgaria, at the time of conducting of this study.

The data presented in Table 2 shows the change in average prices for major consumer expenditure groups on a yearly basis.

The consumer prices for food have increased form February 2025 to February 2026 by 3.8%, with 0.8% of that increase have been recorded through 2025 (February to December).

Including both data resources, a conclusion can be drawn, that the average increase in consumer prices for food products in the first two months of 2026 is not higher than 3%. This increase of 1.5% per month is far more pronounced than any increase in 2025 and can be felt by some consumers and decrease their consumer confidence, as well as raise the question of their food security if the trend continues. This inflationary process can be expected during periods of transition and is monitored closely by government and non-government institutions.

Table 2. Annual consumer price change for consumer goods and services (from February 2025 to February 2026)

Consumer goods and services	**Annual change in consumer prices (in % from February 2025 to February 2026)**
Average	**2.9**
Food products and soft drinks	3.8
Clothing & Footwear	-1.4
Housing, water, electricity, gas and other fuels	2.6
Household furnishings, goods and services for the usual maintenance of the home	4.3
Healthcare	1.7
Transport	0.7
Information and communication	1.6
Entertainment, sports and culture	1.4
Personal care, social protection and miscellaneous goods and services	0.3
TOTAL:	
Food	3.8
Non-food	1.8

Source: National Statistical Institute of Bulgaria Database [12].

Media, being traditional or digital, have also focused on monitoring consumer prices and have focused consumer's attention on any price deviation during the studied period. This uninterrupted flow of information on price changes has led to a low consumer confidence, and price increase expectation. Some retailers have relayed on these expectations and in term increased their prices and in doing so have fed the process loop. Some price increases can be justified by the seasonal characteristics of some food groups that are largely imported – fruits, vegetables, some meats and especially fish. The uncertain geopolitical and macroeconomic environment in the first two months of 2026 have also added to this process with some suppliers increasing prices to recoup their increased expenses for safety stock and insurances. The survey was conducted at during the 3rd and 4th week of February 2026, and consumers had access to a large amount of available information. The first set of questions ware focused on their perception of price increases,

if they think there are any at all. In Figure 1 the average results for all surveyed consumers are presented as perceived percentage price changes – positive or negative.

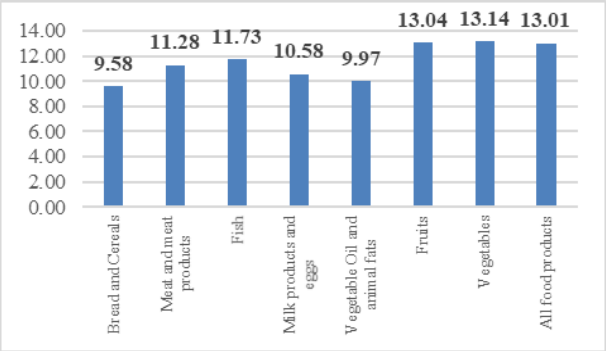

Fig. 1. Average price increase for different food groups from September 2025 to February 2026 according to surveyed consumers, in percentages
Source: Calculated results based on the survey data.

Surveyed consumers have stated that price for food products have increased by 13.01% between September 2025 and February 2026, while the actual change was under 3%. Participants have felt the increase as over four times stronger than the actual data shows. This can be accredited to the significant media focus on all singular cases of price increase, thus creating a certainty in consumers there is such an increase. The highest average numbers are recorded for fruits and vegetables, due to the imported character of these goods, and their higher-than-average prices, as compared to the summer months when local fruits and vegetables are available on the market. The lowest numbers are related to bread and cereals and are justified by the large ratio of these products in Bulgarian food consumption and tradition, and thus their higher frequency of purchase and closer price monitoring, both institutional and individual. Overall, almost all food groups have a higher than 10% evident price increase according to surveyed consumers.

The perceived price increase might lead to restriction on the food budgets of some consumers, and especially those with lower incomes and no access to supplementary services or own food production. These vulnerable groups will face food security issues if the consumer prices have increased by 13% during the studied period. The question of food security was raised in the survey by requiring consumers to provide information on their choice of reducing the purchase and consumption of any or all food groups, due the perceived price changes. The results are presented in Figure 2 as an average for all respondents. The sum of all responses is higher than 100%, since consumers that state they will lower the purchase and consumption of food can select multiple food groups.

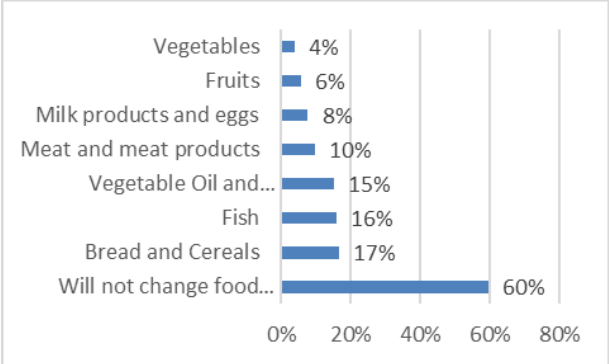

Fig. 2. Consumer attitudes towards food consumption reduction, due to price increase for different food groups from September 2025 to February 2026 according to surveyed consumers, in percentages
Source: Calculated results based on the survey data.

The collected survey data shows that 60% of all surveyed consumers will not change anything in their purchasing patterns. This result illustrates that although consumers feel food prices are increased as evident by surveyed data, that did not lead to a significant enough increase in their food budget, and thus they have not felt economic pressure to change their consumption.

Another explanation is associated with the very low price elasticity of food products, that do not decrease in sales with raising of the prices. In order for that explanation to be true consumers would state that they will lower consumption of more expensive products, such as meat, fresh fruits and vegetables, while increasing the consumption of basic foods like bread and cereals. The survey results do not support that hypothesis and on the contrary shows that consumers state that if anything, they will lower the consumption of bread to a higher degree than the far more expensive fresh vegetables. This result demonstrates the first hypothesis, that

consumers perceive the prices as increased, but do not feel the budgetary constraints due to the reality of far lower, although not insignificant, consumer food price increase. This process of false price perception was expected by experts in academia and in government institutions and has led to the development of multiple information sources, as well as a special Internet portal (https://foodprice.bg/) [17] that clearly shows all consumers data on the price dynamics of multiple food products in all regions of the country. The collected surveyed data shows that consumers have to a large degree not approached such information sources and relay on popular media, that due to its incidental case presentation character, can mislead their perceptions.

Price perception can also change with the increase of volumes purchased and consumed. In order to study this process Pearson's correlation is calculated between the size of the household and the consumer price perceptions, with the expectation of larger households purchasing and consuming larger amounts of food products. The correlation data is presented in Table 3.

The highest positive correlation is evident for smallest households with largest food budgets that have felt the price of bread and cereal, milk products and eggs, oils and fats, fruits and vegetables increase. It is expected of this group of consumers with high budgets to react more accurately for food groups with higher relative prices per calorie – fresh fruits and vegetables, meat and fish, while being uninterested with lower priced foods as bread and cereals.

Table 3. Pearson's correlation calculated for monthly food budgets and consumer perception of price increases

Size of house hold	Bread and Cereals	Meat and meat products	Fish	Milk products and eggs	Vegetable Oil and animal fats	Fruits	Vegetables	All food products
1	0.8449	0.0646	0.1316	0.4362	0.3716	0.5000	0.5657	-0.0866
2	0.0784	0.0646	0.1316	0.4362	0.3716	0.5000	0.5657	-0.0866
3	0.2417	0.2426	0.0748	-0.0361	0.1775	0.0938	-0.0370	0.0284
4	0.2713	0.1047	0.3684	0.2666	0.2663	0.3914	0.2374	0.2673
5+	-0.1905	-0.4481	-0.3951	-0.2572	-0.3814	-0.1270	0.1010	-0.5734

Source: Own calculations based on survey data.

The results from the correlation calculations proves that these consumers perceived the price of food products that are a very small part of their basket as rapidly increasing based on media information, rather than personal experience. The correlation is reversed for the largest households that have felt that bread and cereals are not as expensive the largest their food budgets are. The households with five or more than five members that have a low food budget perceive an increase of price of bread to a smaller degree, because they purchase more of these products and are more familiar and aware of the actual prices. The same results are evident for almost all the consumers in the largest households, as the significant reversed correlations shows that the lower their food budget is the more likely it is for respondents to say that prices have not increase as much, compared to the average perception. This is especially true when surveyed about their perception for all food in general, where the highest reversed correlation is marked with a clear link between the budget and perception. These results show that the group of consumers in large households with high food budgets and incomes do not track actual food prices and formulate opinions based on media information, while budgetarily restrained consumers that must be constantly aware of food prices are formulating their opinions on actual market prices.

There is also a significant correlation between the food budget of four-member households and perception of price increase, excluding only the meat and meat products group. This again demonstrates that the less restraint by their budget a household is for their food intake, the higher their perception of raising prices are. This is also evident in the smaller households of just two members for milk

products and eggs, oils and fats, fruits and vegetables. These smaller households with large food budgets have proven to be very responsive to price increase for the food groups expected to formulate a larger portion of their basket.

CONCLUSIONS

The transition of the Bulgarian economy to the Euro that leads to that currency being the only legal tender as of February 1, 2026, has been described as an approach to consumer transparency and price stability. One of the pillars of this shift included the obligatory two-price reading in both Bulgarian Lev (BGN) and Euro (EUR) value, which is being implemented since August 2025 and will continue to exist until August 2026. By making the labels easy to read, understand, with similar font size in both currencies, the government hoped to have reduced the psychological effects of the move and have a level on which to base fair market conduct.

The analysis of the available statistical data demonstrates that although there was a concern of a large-scale inflationary spike, the real impact on food prices was very tame. During the 3rd and 4th quarters of 2025, the harmonized index of food prices increased at a slight 0.31. This stability indicates that the numerous government responses, such as the introduction of monitoring portals, and the need to make major retailers place daily price lists on them, worked to prevent price increases. During the transition period some of the basic commodities such as coffee and tea had shown some form of increases in prices of over 4 percent, this was compensated by huge increase in the prices of oils and fats and also of seasonal fruits by a significant margin.

By February 2026, the greater financial environment has recorded the rate of inflation at 2.9% on a yearly basis, a figure that is consistent with the one-off slight rises that have generally been experienced in the other Eurozone accession nations. Although some of the industries such as food and soft drink marginally outpaced the overall average by a 3.8 percentage point, other industries such as clothing and footwear recorded a price decrease.

Consumers according to the survey show that three out of every five consumers have not altered their food purchasing habits although they are perceiving food prices as increasing. This would indicate that the majority of consumers lack sufficient economic motivations to change their consumption or the food products are inelastic and thus the price increase will not impact their food purchase quantities. The respondents claimed they would rather decrease consumption of the simple staple foods such as bread than more expensive foods such as fresh vegetables, something that does not correspond with the expectation that they would switch to consuming cheaper foods that they refer to as basic foods to save money.

The analysed survey data shows a significant number of consumers to have a false price perception.

They think that the prices have been increased substantially but their food budgets are not constrained since the actual price increases are not as severe as it is being perceived.

This disparity can be explained by the fact that consumers tend to rely on media, as a source of food price fluctuation information, frequently which are interested in incidental cases, as opposed to government databases (such as foodprice.bg) that monitor the real dynamics of prices in various regions.

The correlation data of the household size, food budgets and the price perception indicate that, small households with big budgets have the highest tendency to experience the rapid change in prices of different food groups. Ironically, such consumers tend to respond to the prices of products comprising a very low percentage of their basket.

This means that they are strongly affected by the external information in media as opposed to their first hand purchasing experience on the relative price per calorie of the food.

On the other hand, big households with small food budgets exhibit an opposite relationship; they feel the price increment to a less extent. These consumers are limited in their budgets, and this fact makes them constantly aware of real market prices.

This experience with food expenditure causes them to develop opinion that is more grounded in the fact of the market as compared to households with a higher income level, that are to a larger degree guided by general impressions.

Food security was not raised as a critical issue for any of the surveyed groups and we can conclude that it is not an evident risk for surveyed consumers at this time.

Further research is required in order to study this process in the future, especially if the upward trend of actual food prices continues through 2026.

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SUSTAINABLE DEVELOPMENT OF BULGARIAN AGRICULTURE AND ITS ABILITY TO MEET THE SUSTAINABLE DEVELOPMENT GOALS

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Abstract

After the accession to the European Union, Bulgaria's agricultural sector was modelled by the Common agricultural policy. This led to settling of a monocultural model for an ever-increasing number of producers. The high level of specialization and concertation of production and the lack of diversity are detrimental to the sustainability of the sector. The main goal of this study is to measure the current level of achievement of sustainable development goals by Bulgarian agriculture, based on selected indicators, aligned with the "Bulgaria 2030" strategy, as well as access its ability to meet these goals by 2030. To achieve this goal the following tasks are completed: through literature review to select the key SDGs that Bulgarian agriculture can impact; to analyse the achieved levels for these SDGs in Bulgaria and to assess the ability to meet the 2030 targets. As a result of this research, we can conclude that the real factor income in Bulgarian agriculture has been declining since 2022, jeopardizing the achievement of the 2030, as well as lagging behind the European requirements to reduce ammonia emissions by 3% per year, with the target values being reached only in 2019. The share of organic production areas is doubling to 3.95% in 2024 compared to 2021 and giving a real chance to reach the target of 7% by 2028. The results are positive for the content of nitrates in groundwater, where the reported 28.18 mg/l is far below the permitted limit of 50 mg/l.

Key words**:** *agriculture, sustainability, SDGs, Bulgaria, trends*

INTRODUCTION

Modern agriculture faces a complex set of environmental, economic and social challenges that threaten its long-term sustainability. Climate changes, soil degradation and water scarcity limit the production potential of agriculture (Krasteva & Angelov, 2025) [4]. At the same time, unstable markets, rising production costs and dependence on subsidies create economic uncertainty for farmers. Social challenges, such as the ageing population in rural areas and the shortage of skilled labour, further complicate the development of the sector (Harizanova-Bartos & Kadadzhova, 2024) [3].
The main goal of the study is to measure the current level of performance of some of the key Sustainable Development Goals (SDGs) by Bulgarian agriculture and to assess its ability to achieve them by 2030. The assessment is based on a literature review in order to select the key SDGs on which Bulgarian agriculture can have an impact, by analysing the levels achieved for these SDGs in Bulgaria and assessing the possibility of achieving the goals by 2030.
In the face of significant challenges, it is increasingly necessary for countries to take coordinated and purposeful actions to support the sustainable development of agriculture. National policies should be coordinated with international commitments and good practices in sustainable management of resources. In this context numerous action has already been taken with an outlook of EU an UN goals. These initiatives create a framework for cooperation and sharing of responsibilities among countries. Through joint efforts, global and regional problems in agriculture can be solved more effectively.
For these efforts to be effective, there must be clearly formulated goals (SDGs) and corresponding indicators to assess progress. Such goals must be measurable, comparable and applicable in different national and

regional contexts. Universal indicators enable tracking trends and objective assessment of the results achieved. In this way, a basis for transparency, accountability and effective planning of sustainable development policies is created. The great importance of the Agenda for sustainable development 2030, developed by the United Nations was met by a large-scale adaptation. This overarching agenda includes many very specific coals, formulated in 17 categories, aimed at eradicating poverty, fighting inequality and injustice and protecting the planet by 2030 (Sirbu, 2025) [10]. Sustainable Development Goals represent an integrated framework for humanitarian, economic and environmental development that links human well-being with sustainable management of natural resources.

After the initial formulation of these significant goals, the framework has evolved in the context of international sustainable development practices, focusing on different regions and sectors. R. Barbu and D. Dumitras, highlight that food system is expected to contribute to SDGs established by the international community in 2015, and to do so, they must operate within planetary boundaries. The same authors point out that food system have the potential to significantly contribute to 14 out of the 17 SDGs (Barbu, Dumitras, 2025) [1]. This integration shows how the global framework of SDGs is evolving from theory to practice.

Within the European community and specifically the European Union (EU) the SDGs are integrated into numerous strategic documents and policies that aim to promote sustainable rural development and agriculture. M. Stan and M. Ciobotea conduct research on sustainable rural development as a key factor for implementing the SDGs. They remark that sustainable rural development encompasses a holistic approach, aiming to improve living conditions in rural areas while preserving the environment (Stan and Ciobotea, 2024) [11]. Within the EU, these goals are linked to policies such as the Union's Common Agricultural Policy (CAP) and other initiatives that promote balanced development between economic efficiency, social justice and environmental protection.

MATERIALS AND METHODS

For the purposes of this study, data from centralized statistical sources were used – the Eurostat database (EU), National Statistical Institute of the Republic of Bulgaria and Agrostatistics database of the Ministry of Agriculture and Food (Bulgaria). This research is focused on specific EU SDG's part of group 2 - Zero Hunger. The selection of specific indicators is based on the significance of the problems assessed by them for the sustainable development of Bulgarian agriculture.

Four indicators were selected for the analysis - real factor income in agriculture per annual work unit (AWU); ammonia emissions from agriculture; share of areas occupied by organic production (in percent) and nitrate content in groundwater. For the purpose of the study, the selected indicators are nationally significant and are embedded in the detailed strategy of the National Development Program "Bulgaria 2030". Average values for the entire EU were calculated for the purpose of conducting a comparative analysis. A graphical visualization of time series is used in order to conduct an analysis and track the trends and dynamics of the observed indicators.

The presented indicators are sufficient to illustrate the progress in implementing the sustainable development goals in agriculture. They have been selected to cover all three aspects of the concept of sustainability - economic, social and environmental. Agricultural real factor income per Annual Work Unit (AWU) determines the motivation of farmers to continue their agricultural activities, to maintain their economic stability in external crises and to increase their market power. Also, high and stable incomes are a factor in maintaining a good quality of life and long-term employment, as well as a guarantee of the social sustainability of rural areas. The indicator Share of areas used for organic production also has social, economic and environmental aspects. Organic production creates the opportunity to access specialized markets, it has a higher market value, as well as quality and in term can lead

to increases in the quality of life of consumers. The remaining two indicators are markers of the environmental sustainability of the agricultural sector, as they reflect the degree of pollution and the impact of agricultural activity on the environment.

RESULTS AND DISCUSSIONS

In recent years, agriculture in Bulgaria has retained an important role in the economy and social structure of the country, but its relative share in the total economic product remains low. According to NSI data, the added value of "agriculture, forestry and fisheries" accounts for about 1.96 % of Bulgaria's gross domestic product (GDP) in 2025, while industry and services have a significantly larger contribution to GDP. The sector continues to be a significant source of food and raw materials, but its contribution to the economy is limited and significantly below the EU average, reflecting the structural challenges and dynamics of the national economy (NSI statistical data) [7].

A significant part of the problems of Bulgarian agriculture result from human and institutional factors, including the unstable regulatory framework, frequent legislative changes, structural polarization of farms and unfavourable demographic trends. Previous research has concluded that the agricultural sector in Bulgaria is burdened by a constat fluctuation and changes in legislation. This in turn leads to market uncertainty and also has the effect of further concentration of production. Currently a small number of farms concentrate a significant portion of the usable agricultural land in many regions of the country. (Mantarova, Yovchevska, 2025) [5]. All these processes have led to low labour requirements in these regions and thus a largescale outward migration form rural areas (Shopova, 2023) [9]. Taking all these factors under consideration there are also global climatic changes that affect Bulgarian agriculture. The increase in average yearly temperatures and the increased frequency of extreme weather events are becoming a source of high economic and environmental risk for the sector.

This new and evolving environment requires adaptation of current production methods as well as adapting new models (Naydenov, et al., 2025) [6]. In this regard, Shopova (2023) points the environmental challenges as a significant factor requiring the introduction of environmentally friendly technologies and targeted training. Insufficient readiness to implement such measures increases the vulnerability of agricultural farms and limits their opportunities for long-term adaptation [9].

Previous research has concluded that the agricultural sectors in Eastern Europe has yet to reach the sustainability focus of Western European producers (Popescu, 2025) [8].

The National Development Program “Bulgaria 2030” focuses on sustainable agriculture as one of the key priorities for the country. By achieving these goals, the country will be able to better preserve its limited natural resources and secure its food production in the future.

Bulgaria has committed in its implementation of the Common agricultural policy for the period 2023-2027 to focus on improving its key sustainable development indicators, as proven by the Strategic Plan for the Development of Agriculture and Rural Areas 2023–2027. This is further by the introduction of the “Bulgaria 2030” strategic document, outlining the key goals the country will focus on achieving by the end of the decade.

The CAP Strategic Plan includes measures to support small and medium-sized farms, stimulating innovation and sustainable land management. It also includes important elements related to adaptation to climate change, which directly contributes to the implementation of SDGs such as “Industry, Innovation and Infrastructure” and “Responsible Consumption and Production”. National documents, such as the Strategic Plan for the Development of Agriculture and Rural Areas 2023–2027, also set specific objectives for mitigating climate effects, managing water and soil resources, reducing dependence on chemical products and improving biodiversity, which are in harmony with both European and global sustainable development frameworks.

An important indicator for assessing sustainable development in agriculture is the real factor income in agriculture per annual work unit (AWU). The modelling of its dynamics is carried out within CAP on EU level, and at the local level through the National Program for the Development of Rural Regions in Bulgaria, for the current planning period of 2023-2027. The defined goal, set by the local strategic documents is general - to increase the income of those employed in the agricultural sector. Although no specific rate of increase is set, the overarching goal is for agricultural producers' income to follow the general trend of increase of average salaries in Bulgaria. Data on the dynamics of the AWU for Bulgaria and the average values for the EU are presented in Table 1.

Table 1. Dynamics of key indicators for sustainable agricultural development (SDG–Goal 2)

		2017	2018	2019	2020	2021	2022	2023	2024	2025
Real factor income in agriculture per annual work unit (AWU)	Bulgaria	134.51	137.29	147.99	156.50	196.15	204.18	144.75	138.08	126.93
	EU average	116.73	113.34	118.10	122.63	128.71	145.88	136.25	136.31	148.80
Ammonia emissions from agriculture (kg/ha)	Bulgaria	57,340	57,120	59,410	57,493	57,699	58,576	57,492		
	total for the EU	3,522,120	3,465,380	3,372,740	3,322,180	3,247,720	3,046,630	3,060,550		

Source: Own calculations based on Eurostat database [2].

Ammonia emissions from agricultural activities involving nitrogen compounds are another important indicator of sustainability. They indicate the degree of pollution of the water and soil environment, as well as the efficiency of the use of nitrogen fertilizers. Controlling ammonia emissions is defined as a sustainable development objective in the EU Directive 2016/2284 on national emission ceilings. Table B of Annex II of the Directive sets out the obligations of Member States to reduce ammonia emissions by 2030. When measuring the level of achievement of this goal 2005 levels are taken as a baseline. Bulgaria's target in that regard is to reduce nitrogen emissions by 3% on a yearly basis from 2020 to 2029. Local legislative and strategic documents reflect this goal as evident in the National Air Pollution Control Program 2020-2030, which explicitly states that "the target is to reduce ammonia emissions from fertilizer use by 25% by 2026-28", and that the target is currently being achieved.

The share of areas occupied by organic production also plays a key role in the implementation of common efforts to achieve sustainable development of agriculture. The EU strategy "From Farm to Fork" formulates the goal to increase the share of agricultural land managed organically to at least 25% of the total agricultural area in the EU by 2030. Member States are encouraged to develop national action plans that include activities to increase organic areas. This strategic commitment is set out in the National Action Plan for the Development of Organic Production by 2030 in the Republic of Bulgaria as a leading mechanism for strengthening the sustainability and further development of the sector. The second part of the Plan explicitly states as an objective the increase in the number of areas certified for organic production (Table 2). In this context, the nitrate content in groundwater is the next sustainability indicator that is in the focus of our attention. EU Directive 91/676/ EEC on Nitrates (Nitrates Directive) sets the maximum permissible nitrate content of 50 mf of NO_3 per litter as a standard that is applied to protect human health and the environment.

Table 2. Dynamics of results achieved according to key indicators for sustainable development of agriculture (SDG–Goal 2)

		2017	2018	2019	2020	2021	2022	2023	2024	2025
Real factor income in agriculture per unit of annual work unit (%)	Bulgaria	100%	102%	110%	116%	146%	152%	108%	103%	94%
	average for EU	100%	97%	101%	105%	110%	125%	117%	117%	127%
Ammonia emissions from agriculture (%)	Bulgaria		-0.38%	4.01%	-3.23%	0.36%	1.52%	-1.85%		
	total for EU		-1.61%	-2.67%	-1.50%	-2.24%	-6.19%	0.46%		
Share of areas used for organic production (%)	Bulgaria	2.72	2.56	2.34	2.30	1.71	2.20	2.95	3.95	
	average for EU	7.47	7.99	8.47	9.10	10.1	10.3	10.6	10.7	
Nitrate content in groundwater (mg/l)	Bulgaria	27.10	27.50	27.82	28.08	28.35	28.70	29.18		
	average for EU	18.19	17.42	16.66	16.10	15.99	15.90	15.89		

Source: Own calculations based on Eurostat data [2].

In the Republic of Bulgaria, this goal is implemented in Regulation No. 2 (2007) regarding water protection (with special focus on underground water sources) form nitrate pollution from agriculture in accordance with European requirements (Figure 1).

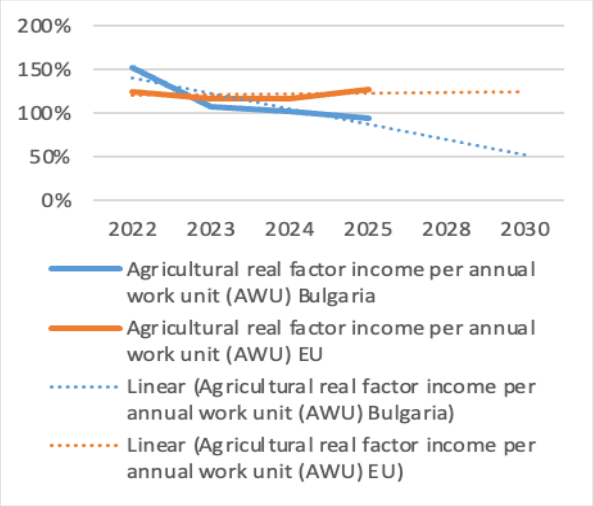

Fig. 1. Annual data and trends for agricultural real factor income per annual work unit (AWU) in Bulgaria and EU (%)
Source: Own calculations based on Eurostat data [2].

Real factor income in agriculture has been developing dynamically over the period under review. The goal of permanently increasing the values, using 2017 as the base year, has been achieved in all years except 2025. The trend of gradual decline is worrying, especially when compared to the average values for the Union. In Bulgaria, we report a trend of income growth after 2017 and a decline after 2022. The dynamics of the prices of basic production factors, as well as the slow adaptation of national policies to the changing environment, have led to a loss of the inertia accumulated by the middle of the period. If the degree of uncertainty of the external environment and the monocultural model of agricultural production in the country remain, Bulgaria will not be able to achieve the set goals – to increase the real factor income in agriculture by one working annual unit by 2030 compared to 2017 (Figure 1).

This monoculture model of agricultural production is the natural outcome of the specialization and concertation of production in the sector. This process was in large part supported by the Common agricultural policy of the European union, evident by the large-scale adaptation of the model in the Union. The breakdown of it will require concentrated effort towards the diversification of farms, with a specific focus on crop rotation and single production cycle diversification, not just between cycles. In order to achieve such results an extensive support for knowledge sharing and provision networks needs to be promoted on local level, where such exist (as is the case in Bulgaria with its Agriculture extension services bureau). These networks will have to provide diversification and crop rotation advice as well as monitor local producers to break down the monoculture model. A largescale change of agricultural policy in the Union is already on the way but has to focus more on this important issue and

specifically target for support diversified farms in order to share the risks involved with such lack of specialization and help recover the increased costs of production.

A similar negative trend is also observed in the dynamics of ammonia emissions from agriculture in Bulgaria (Figure 2).

During the studied period, these emissions must be reduced by 3% annually by 2029 in order to achieve the EU targets.

Based on the information presented in Table 2, we report that only in 2019 Bulgarian agriculture managed to achieve this target.

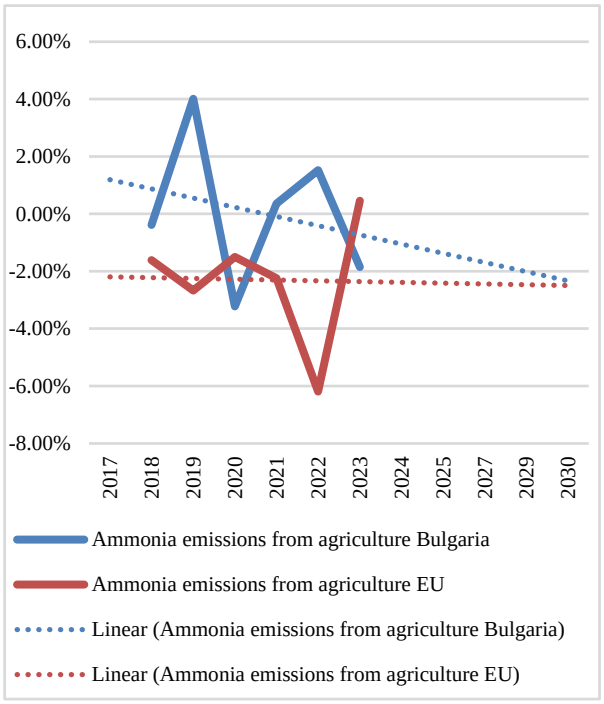

Fig. 2. Annual data and trends for ammonia emissions from agriculture in Bulgaria and EU (in percent compared to the previous year)

Source: Own calculations based on Eurostat data [2].

Even more - in three years of the period, an increase in ammonia emissions from the sector was reported.

If these negative trends persist and if there are no specific policies to counteract, Bulgaria will not be able to achieve the targets set for 2029 (Figure 2).

Ammonia emissions from agriculture in Bulgaria are mainly due to the use of mineral fertilizers, due to the constantly decreasing role and scale of the livestock sector.

The only possibility to achieve the targets is related to a permanent increase of the prices of mineral fertilizers on international markets, which will lead to more efficient use by farmers. The trends in the EU do not differ from those analysed in Bulgaria and achieving this specific SDG will be possible only through the development and implementation of entirely new policies focused on a fundamental transformation of the Union's livestock sector.

Ammonia emissions are mainly the result of agricultural activity. According to data from the National Report on the State and Protection of the Environment, prepared annually by the Executive Agency for the Environment, 94 percent of ammonia emissions are due to agriculture. Another major source is domestic combustion – 3 percent. The main reason for Bulgaria's failure to meet its commitments regarding the reduction of ammonium emissions is the increase in the amounts of inorganic fertilizers used in agriculture. The lack of more detailed data does not allow for a more accurate calculation of NH3 emissions from the "Agriculture" sector.

Organic production is characterized by sustainable production practices and the expansion of their share is stimulated by the CAP of EU. Bulgaria aims to increase the share of organic production to 7% by 2030. Throughout the entire studied period, a significantly lower share of organic production is reported - only 1.71% of the country's arable land is registered in this system in 2021. The trend is positive after 2021, as the share doubles by 2024 and reaches 3.95%. If this trend of at least doubling the areas in the control system by 2028 continues, Bulgaria can reach the desired values of this indicator (Figure 3).

This process should be encouraged by the National Rural Development Program, providing the necessary framework to support the registration, development and certification of these agricultural systems. The certification process is still burdened with difficulties and very high transaction costs. Overall, the desired values were achieved in the European Union throughout the studied period, which suggests the adequacy of the EU policies and the desire of European consumers to consume products from organic farming.

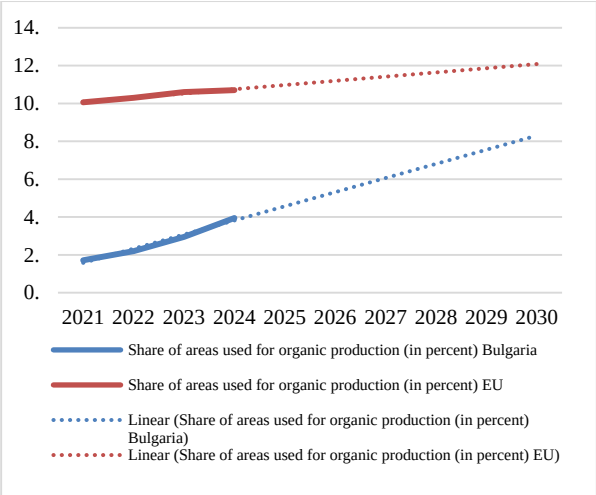

Fig. 3. Annual data and trends for share of areas used for organic production in Bulgaria and EU (%)
Source: Own calculations based on Eurostat data [2].

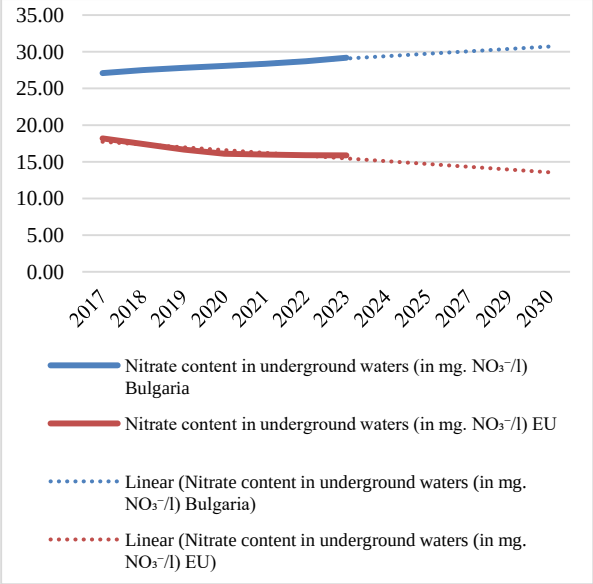

Fig. 4. Annual data and trends for nitrate content in underground waters in Bulgaria and the EU (in mg. NO_3^- /l)
Source: Own calculations based on Eurostat data [2].

Bulgaria has a very positive track record in meeting the targets for nitrate content in groundwater, with the maximum value set in EU Directive 91/676/ EEC for nitrates being 50 mg.NO_3^- /l. During the entire reviewed period, no average levels higher than 28.18 mg./l were recorded in Bulgaria, which is only slightly more than half of the permitted values.

If current trends continue, Bulgaria will achieve the goal of not reporting average values for nitrate content in groundwater above 50 mg. NO_3/l by 2030. It should be noted that during the entire studied period, the values are increasing, but this increase is only 2 mg./l in six years, which currently does not pose a threat to the achievement of this particular sustainable development goal. The average values in the EU are significantly lower than those recorded in Bulgaria and are decreasing throughout the reviewed period (Figure 4).

It is necessary to adapt the national institutional framework to the European one in order to ensure the preservation of the purity of groundwater in the future.

Bulgarian food producers, much like their European counterparts are beginning to feel the effects of climate change, mostly evident by disruption of rainfall patterns, longer summer droughts and spring temperature fluctuations leading to shock frosts. Bulgarian farmers are adapting to these risks by focusing on crop varieties that are resistant or can withstand better such conditions. Producers are also looking for more complex technical solutions that can improve their sustainability, when available. Sprig frosts and long summer droughts have become very common in many regions of the country, but a wholesale solution is not available within the means of local farmers and local governmental bodies.

CONCLUSIONS

Bulgarian agriculture has been developing dynamically during the period under review. Under the influence of the EU Common Agricultural Policy, Bulgarian agricultural production is actively involved in providing the European population with food products. In this regard the future availability of food and its quality will hinge on the sustainable development of the agricultural sector in all member states, including Bulgaria. The country and its leadership assumes its responsibility in this process in the form of specific commitments to achieving the European sustainable development goals.

These commitments have not lead to real results when considering some of the key goals analysed in this research. Real factor income in Bulgarian agriculture has been declining since 2022, jeopardizing the

achievement of the 2030 targets. At the same time, the country is lagging behind the European requirements to reduce ammonia emissions by 3% per year, with the target values being reached only in 2019. The main reason for these negative environmental trends is the massive use of mineral fertilizers as a result of a shrinking livestock sector. To overcome these challenges, a fundamental transformation of national policies and more effective management of production factors are needed.

The share of organic production areas shows encouraging dynamics, doubling to 3.95% in 2024 compared to 2021 and giving a real chance to reach the target of 7% by 2028. The results are positive for the content of nitrates in groundwater, where the reported 28.18 mg/l is far below the permitted limit of 50 mg/l. Despite the slight increase in these levels over the last six years, Bulgaria remains stable and meets the requirements of the European Directive 91/676/ EEC. The future success of the sector depends on reducing transaction costs for certification and promoting sustainable agricultural systems more actively.

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GAPS IN QUALITY OF TOURISM IN BULGARIAN RURAL AREAS

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Abstract

Rural areas make up a large part of Bulgaria's' landmass and play an important role for its economy. The development of these areas is dependent on their ability to sustain a competitive economic environment for the local population. Tourism services create an opportunity for additional employment and income for rural communities. The quality of these services is essential for their attractiveness among urban consumers. The goal of this study is to analyze consumers perceived quality of tourism services in Bulgarian rural areas. In order to achieve this goal, the following tasks are completed: to survey tourism service consumers in the Southeast region of Bulgaria aimed at their level of satisfaction; to implement the GAPS statistical method, based on the SERVQUAL methodology to analyze the consumer satisfaction with tourism services in rural areas in order to present strategies for future improvement.

Key words**:** *rural tourism, SERVQUAL, GAPS Model, consumer satisfaction, Southeast Region, Bulgaria*

INTRODUCTION

Rural areas in Europe and Bulgaria specifically have undergone a dynamic transformation in recent decades.

From traditional suppliers of agricultural produce, they are evolving into multifunctional spaces offering ecosystem services, cultural identity, and recreational opportunities.

In the context of the Common Agricultural Policy (CAP) of the European Union and national priorities for regional development, the diversification of the rural economy is imperative for retaining the population and raising the standard of living (Lulcheva & Arseniou, 2018) [7].

Tourism has established itself as one of the most effective instruments for this diversification (Stanoeva, L. 2025) [15].

It creates opportunities for additional employment, stimulates local entrepreneurship, and supports the preservation of cultural-historical heritage (Lakov, P. 2012) [4]. However, the success of a tourist destination is directly dependent on the quality of services – a complex concept that includes not only the material base but also the human factor, the authenticity of the experience, and the degree of visitor satisfaction.

In Bulgaria, rural areas occupy a significant part of the territory, but their economic development is uneven. The South-East Planning Region, covering the districts of Burgas, Sliven, Yambol, and Stara Zagora, presents a unique case for study. It combines a highly developed Black Sea coast with lagging internal rural territories in Strandzha, Sakar, and the Balkan Mountains. This duality creates both opportunities for the overflow of tourist flows and risks of deepening regional disparities.

The theoretical basis of this research is the Gaps Model of Service Quality, developed by Parasuraman, Zeithaml, and Berry (1985) [11], which defines quality as a function of the difference (Gap 5) between consumer expectations and their perceptions of performance. In the context of rural tourism, this model acquires specific dimensions, as tourists often value "soft" factors such as hospitality and contact with nature more than luxury amenities (Lulcheva, 2021; Prabeharan et al., 2008; Puri & Singh, 2018; Shi & Shang, 2020) [6, 12, 13, 14]. While the existing literature extensively outlines the theoretical framework of rural tourism quality, comparative applications of the SERVQUAL

and RURALQUAL models reveal significant regional differences across countries. For instance, studies that apply these methodologies in highly developed European rural destinations often show that tourists prioritize the 'Tangibles' and 'Assurance' dimensions, expecting highly standardized infrastructure and services. Conversely, in emerging or transitioning rural destinations in Eastern Europe, such as Croatia (Marković & Kljaić Šebrek, 2020) [8], tourists place greater emphasis on "Empathy" and "Responsiveness". In such contexts, visitors actively seek authentic local interactions and traditional gastronomy to compensate for potential infrastructural deficits. This comparative dynamic makes the Southeast Bulgarian market a critical case study for understanding how emerging rural destinations balance infrastructural gaps with authentic hospitality.

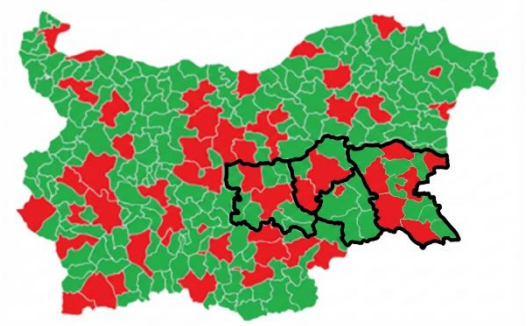
MATERIALS AND METHODS

The present study applies a mixed-method approach, integrating the analysis of secondary statistical data and the design of a primary empirical study through a questionnaire method. The territorial scope of the study is the South-East Planning Region of the Republic of Bulgaria. The region is selected due to its strategic location and contrast in tourism development. While the Burgas district concentrates over 70% of the accommodation capacity, the internal rural areas (Yambol, Sliven) remain peripheral despite their rich anthropogenic and natural potential (Thracian heritage, wine regions). Burgas and Stara Zagora provinces have the highest share of urban land due to their large industrial and maritime centers, while Yambol is the most rural province, with 4 out of 5 municipalities classified as rural.

In Bulgaria, the classification of territories as "rural" holds not only geographical but also profound financial and administrative significance, as it determines eligibility for support under the European

Agricultural Funds. The definition has evolved, but in the current programming period, it is strictly established within the strategic documents.

In accordance with the Strategic Plan for Agriculture and Rural Development of the Republic of Bulgaria for the period 2023-2027, the national definition of "rural areas" is established at the municipal level.



Map 1. Classification of Bulgarian municipalities by type: rural (green) and urban (red).
Source: Strategic Plan for the Development of Agriculture and Rural Areas 2023-2027 [16].

According to this document, rural areas are defined as:

"Municipalities in which there is no settlement with a population exceeding 15,000 people" (EU CAP Network, 2024) [1].

Based on this methodology, rural areas occupy approximately 86.4% of the total territory of the Southeast region. Out of a total of 33 municipalities in the region (on a territory of ~19,799 sq. km), 28 are classified as rural and only 5 as urban (Burgas, Sliven, Yambol, Stara Zagora and Kazanlak) (Map 1, Table 1).

Table 1. Administrative-Territorial and Demographic Characteristics of the South-Eastern Region

Metric	Southeastern Region Value
Total Area	~19,799 km^2
Total Number of Municipalities	33
Rural Municipalities	28
Urban Municipalities	5 (Burgas, Sliven, Yambol, Stara Zagora, Kazanlak)
Share of Rural Territory	~86.4%
Share of Rural Population	~42%

Source: Strategic Plan for the Development of Agriculture and Rural Areas 2023-2027 [16].

Data Collection and Instruments

Data Collection and Instruments for the purposes of the study, a structured questionnaire was developed based on the modified SERVQUAL scale, adapted for the

needs of rural tourism (RURALQUAL) (Marković & Kljaić Šebrek, 2020) [8]. The questionnaire is designed to measure Gap 5 (The Customer Gap) and consists of five sections:

(1)Consumer Profile: Establishes the frequency of travel and preferred destinations, testing the hypothesis of "weekend tourism" (Kilimperov, 2016) [2].

(2)Objective Evaluation: Measures satisfaction with specific elements (Accommodation, Food, Entertainment) on a 5-point scale.

(3)GAPS Analysis: The core of the instrument where respondents evaluate both their Expectations and Real Perceptions across five dimensions: Tangibles, Reliability, Responsiveness, Assurance, and Empathy.

(4)Qualitative Component: Open questions for detailing specific discrepancies.

(5)Demographics: Income, age, and household size.

The methodology includes descriptive analysis of secondary data from the National Statistical Institute (NSI) regarding the activity of accommodation establishments for 2023-2024.

Based on the structured questioner a survey among 379 tourist service consumers form the Southeast region of Bulgaria was deployed. The results from this survey were analysed and consumers were grouped based on common factors regarding to their service use frequency, size of their households, their household income and their price of services responsiveness. The data averages for these groups was used in the analysis based on the SERVQUAL model.

The SERVQUAL model was adopted for the needs of the study with an aggregate perceived quality indicator based on grouped data from the survey.

Aggregate perceived quality has the formula:

$$Qtotal = \sum_{i=1}^{5} (Ai - Ei) \text{……..(1)}$$

where:

A_i – achieved quality, the consumer's rating of the actual service performance for group *i*.

E_i – expected quality, the consumer's pre-service expectation or desired standard for group *i*.

The formula is designed so that the polarity of the result (positive or negative) immediately identifies the service status:

(a)Positive result when i>0 – performance exceeds expectations, leading to customer delight

(b)Zero result when i=0 – performance matched expectations, leading to service confirmation

(c)Negative result when i<0 – performance fell below expectations, indicating a service quality gap

The collected data was checked for errors and discrepancies during the collection process.

RESULTS AND DISCUSSIONS

Analysis of Secondary Data and Regional Disparities

The analysis of data from the National Statistical Institute (NSI) for 2023 [9] reveals drastic differences in tourism capacity within the South-East region.

Table 2 presents the key indicators for accommodation establishments. It is evident that the coastal district of Burgas dominates significantly, while the rural districts of Sliven and Yambol have limited capacity, primarily in the category of "guest houses" and "family hotels" (1-2 stars).

This structural imbalance confirms the thesis that tourism in the interior is still underdeveloped in the rural areas. As noted by Kilimperov (2017) [3], the lack of official statistics specifically for "rural tourism" hinders precise planning, but the data on low occupancy in Sliven and Yambol suggests a need for product diversification.

Based on the literature review, several key trends are emerging that define the "Gaps" in quality. Research by Lulcheva (2021) [6] on family hotels indicates that while hygiene and basic furniture are often rated highly, the surrounding environment (environmental protection, yard maintenance) receives lower scores. In the South-East region, the poor road infrastructure to remote villages in Strandzha and Sakar is expected to create a negative gap in the "Tangibles" dimension.

Table 2. Main indicators for the activity of accommodation establishments in South-East Region (2023)

Indicator	Burgas District	Stara Zagora District	Sliven District	Yambol District
Accommodation establishments (No.)	~252	~64	46	~25
Nights spent	142,272 (out of the season)	59,520	9,269	~5,000
Revenues from nights (BGN)	High (peak of the season)	Sustainable	Low	Low
Dominant Tourism Type	Bulgarian citizens and foreigners; Mass/Sea	Mostly Bulgarian citizens Cultural/Business	Mostly Bulgarian citizens; Rural/Mountain	Mostly Bulgarian citizens; Rural/Transit

Source: Aggregated data from NSI (2023) [10].

Modern tourists seek an "experience", not just a bed. Kilimperov (2016) [2] identifies a growing trend for weekend tourism driven by the desire to "escape everyday life". However, many rural guest houses offer only accommodation without organizing additional activities (hiking, craft demonstrations). This discrepancy between the desire for active recreation and the passive offering creates a gap in "Responsiveness" and "Empathy" (Sugiarto & Octaviana, 2021) [17].

Lulcheva (2020) [5] highlights that 94% of tourists appreciate traditional dishes. The South-East region, being a leader in wine production (Thracian Lowland), has the potential to close gaps in other areas through high-quality food and wine experiences. It is expected that the "Food" element will show a positive gap (expectations exceeded) in the upcoming survey.

Survey Results and GAPS Analysis

The implementation of the SERVQUAL analytic modules was adapted for the needs of this study.

Within this model a survey of 379 consumers from the Southeast region of Bulgaria has been done.

The group of participants have shown differentiating characteristics along the lines of: size of households, households income, tourism preferences and frequency of use, motivation factors for participation in tourism activities, age, gender etc.

All age groups that regularly participate in tourism activities are equally represented in the studied group with 28% aged between 18 and 30, 35.1% in the group aged from 31 to 40 and 31.4% aged from 41 to 55.

The largest part of participants are members of households with 4 members – 32.7%, followed by the small household with only two members – 29% and those with three – 26.4%.

Over half of the surveyed have disclosed that their households have shown higher the average income – 71.8%, with 44.4% outpacing the average by no less than 50%. This allows for the data collected for these groups to be relevant as they have sufficient disposable income for leisure and tourism activities.

The surveyed were grouped by one key indicator – the frequency of use of tourism services in 2025.

The group that showed the highest frequency of use of more than 7 services through the year represented 9 % of the surveyed.

The largest groups of people have only used tourism services one to two times last year – 33.8%, followed by the group that have used them three to four times on 2025 – 32.7%. Only 12.7 of the surveyed have stated that they have not used any rural tourism services during 2025.

All participants in the survey reside in the Southeast region of the country, where rural areas account for approximately 86.4% of the total territory, with just a few urban centers (Ministry of Agriculture and Food, 2022) [9].

This in term requires more actions stimulating tourism services in these areas, as they can provide a large variety – seaside tourism, cultural tourism, ecotourism, rural tourism, wine tourism, etc.

The analysis of gaps in quality of services has proven to be a valuable instrument for the sector, as it allows for problems within the service elements to be pinpointed. In Table 3 the average gaps in quality are presented grouped by the frequency of use of tourism services.

Table 3. Average GAPS in quality of tourism services, based on author survey

	Household income				Consumer price perception		
	Under the regional average	Regional average	Over the region average (up to 1.5x)	Highly above the regional average (above 1.5x)	Prices of tourism services are adequate	Prices are approachable, but slightly inflated	Prices are unnecessarily high
Group 1 - does not use tourism services	2.00	1.56	0.80	0.71	1.00	1.04	1.33
Group 2 - uses tourism services up to 2 times per year	1.71	-0.03	0.70	0.55	0.43	0.96	1.40
Group 3 - uses tourism services from 3 to 4 times per year	0.91	1.08	0.74	0.91	0.63	1.01	0.50
Group 4 - uses tourism services from 5 to 6 times per year	-0.60	1.56	0.25	1.58	0.80	0.92	0.75
Group 5 - uses tourism services more often than 7 times per year	0.20	0.29	1.00	0.00	-0.25	1.05	-1.33

Source: Own calculation based on the survey data.

The customer satisfaction with tourism services was highest for the Group 1, and especially those members that have earnings lower the regional average. As per their own statement they do not use tourism services at all, or if they do it is a rare occasion, and thus their opinion is highly stewed towards satisfaction – any service is good service when we use them on a rare occasion. At the other end of the spectrum the highest level of dissatisfaction in tourism services was recorded in Group 5, as their price perception is heightened due to the high frequency of use and any price increases adds up and leads to frustration. Notably for the same group, when the price of a service is perceived as approachable, they tend to show the highest satisfaction level when considering the rate for services as a key component. The highest level of price satisfaction is evident with Group 1, where we encounter low price elasticity and customers ware more satisfied when services overcharge them. This anomaly can only be explained by the lack of experience in the field of members of Group 1 and their higher perception of quality outliers and succumbing more easily to promotion material and commercials. Group 2 have shown similar tendencies with a slightly higher satisfaction with overpriced (in their own opinion) tourism services.

A highly visible trend is evident form the collected survey data regarding the relationship between service price and customer satisfaction. Consumers are not most satisfied when they access a service price as adequate, marked by the commonly used term “good deal”, but when they feel that there are overpaying for a service with an inflated price. This phenomenon is getting more pronounced with the increasing of the frequency of use of services. This results may suggest that tourism consumers in the southeast region of the country expect inflated prices and welcome them as the prerequisite for an adequately priced services are the expectation of lower quality, that does not change after the provided experience. This has often described by consumers as the service being “good enough for the money” and thus perceiving it in negative light as one of lower quality.

The correlation analysis of the surveyed groups reveals significant dependencies between the frequency of utilizing rural tourism services and three key variables: consumer price perception, household income level, and household size (Table 4). The most pronounced and statistically significant relationship is observed in the consumer price perception.

The data demonstrates a strengthening negative correlation as the frequency of service use increases, starting from a negligible 0.0267 for Group 1 (non-users or rare users) and peaking at -0.3895 for the most active tourists in Group 5 (using services more than 7 times a year) and the price

perception of consumers. This trend illustrates a strong price-quality connection within the region's rural tourism sector.

Table 4. Pearson correlation between aggregate perceived quality and key survey group indicators

	Income level of the household	Size of household	Consumer price perception
Group 1 - does not use tourism services	0.0831	-0.0406	0.0267
Group 2 - uses tourism services up to 2 times per year	-0.0561	-0.1474	-0.2181
Group 3 - uses tourism services from 3 to 4 times per year	-0.1569	-0.0103	-0.2759
Group 4 - uses tourism services from 5 to 6 times per year	0.3197	0.1882	-0.0705
Group 5 - uses tourism services more often than 7 times per year	0.0315	0.0805	-0.3895

Source: Own calculation based on survey data.

Discussion: Connecting Quality Gaps with Consumer Behaviour

Inexperienced tourists exhibit low price elasticity and often remain satisfied even when overcharged, primarily due to a lack of comparative experience and a higher susceptibility to promotional materials. Conversely, regular consumers develop heightened price sensitivity, where any unnotified price increase leads to frustration.

The lack of correlation between price perception and consumer satisfaction is evident in Group 1, as only very infrequent users do not necessarily seek the cheapest options; rather, they often associate “adequately” priced services with lower expected quality. They tend to welcome slightly inflated prices as a prerequisite and guarantee for higher service standards.

This phenomenon perfectly illustrates Gap 5 (the Customer Gap) of the SERVQUAL model, showing that price acts as a powerful tool for managing expectations: higher prices generate higher expectations, the fulfilment of which leads to genuine customer satisfaction.

Regarding the income level of the household, the correlations are predominantly weak across most groups, with one notable exception. Group 4, comprising individuals who use tourism services 5 to 6 times a year, exhibits the strongest positive correlation in the entire study at 0.3197. This indicates that for this specific cohort of moderately active tourists, the level of disposable income is a critical determinant of their tourism behaviour and overall satisfaction. Sustaining such a frequent travel rhythm requires careful financial planning, making their choices highly income-dependent. In contrast, for the most frequent travellers in Group 5, income plays a negligible role (0.0315), suggesting that frequent travel has become a stabilized routine lifestyle for them, shifting their focus entirely toward the price-to-quality ratio rather than budget constraints.

Finally, the size of the household demonstrates the weakest correlational links among all examined factors. The coefficients are ranging from negative values like -0.1474 (Group 2) to negligible positives for most groups. The most pronounced dependency is again seen in Group 4 (0.1882), likely because frequent trips for larger families necessitate stricter budgeting, tying this variable closely to their income considerations. However, we can draw another conclusion based on the correlation, as larger households are more likely to consider a service experience as positive. This may be a result of larger tourist groups being able to find some positive elements of the service and in combination there is a positive synergetic effect, leading to positive correlation between the size of the household and tourism service satisfaction levels, as one member likes the food, another the accommodations, etc.

Overall, the data implies that whether consumers travel alone, as couples, or with children, the sheer size of the household does meaningfully alter their fundamental expectations regarding the quality and pricing of rural tourism services in the Southeast region.

Our empirical findings regarding the Customer Gap (Gap 5) reveal a unique paradox in the Southeast Bulgarian region that contrasts with traditional SERVQUAL applications in other countries. As evidenced by Table 3, Group 1 (inexperienced tourists) reported highest satisfaction levels even when facing inflated prices, associating higher costs directly with higher expected quality. This

differs significantly from findings in more mature Western markets, where frequent users dictate standard pricing and maintain stable satisfaction. In Bulgaria, as shown by the strong negative correlation (-0.3895) for Group 5 in Table 4, highly experienced tourists become increasingly critical and price-sensitive.

This trend can be directly linked to the specific dimensions of the rural tourism product in the region. As previously highlighted by Lulcheva (2021) [6] regarding family hotels, while basic hygiene is met, broader environmental and infrastructural factors often lag. Our data confirms this: frequent tourists (Group 5) likely experience the negative gap in "Tangibles" due to the poor road infrastructure to remote villages in Strandzha and Sakar, which diminishes their satisfaction despite lower prices. Furthermore, modern tourists increasingly demand active recreation (Kilimperov, 2016) [3]. The frustration observed in frequent users (Group 5) indicates a severe gap in 'Responsiveness' and 'Empathy' (Sugiarto & Octaviana, 2021) [17], as many local guest houses provide passive accommodation rather than integrated cultural or wine-tasting experiences, which are crucial for offsetting infrastructural weaknesses in transitioning economies.

CONCLUSIONS

The analysis of rural tourism in the South-East Planning Region of Bulgaria demonstrates that the area possesses significant, yet unrealized, potential. With rural areas accounting for approximately 86,4% of the region's territory, these municipalities offer rich anthropogenic and natural resources that remain underutilized due to deep structural imbalances. A stark contrast persists between the highly developed coastal areas (Burgas district) and the lagging, peripheral rural interior (such as Yambol and Sliven). Addressing this disparity requires a strategic shift from intuitive to data-driven management, utilizing tools like the GAPS model to systematically align services with consumer expectations.

The empirical survey of 379 consumers reveals a pronounced Price-Quality correlation concerning Gap 5 (The Customer Gap). The data indicates a strong negative correlation between the frequency of tourism service usage and consumer price perception. Generally, tourists that rarely use these services welcome slightly inflated prices as a prerequisite and guarantee of higher service standards, achieving maximum satisfaction when these elevated expectations are met. Highly experienced, frequent tourists seek the lowest prices, as they prove to be very mindful of their travel budgets although they tend to associate "adequately" priced services with inferior quality, often describing them as merely "good enough for the money". Consequently, pricing acts as a crucial psychological anchor in managing consumer expectations in rural tourism for all studied groups.

Furthermore, the analysis shows that demographic factors influence tourism behaviour in highly specific ways. Household income plays a pivotal, strong correlational role primarily for moderately active tourists (traveling 5-6 times a year), for whom budget considerations directly dictate their ability to maintain their travel frequency. In contrast, for the most active tourists, travel has become a stabilized lifestyle relatively unaffected by income fluctuations, while household size shows almost no significant statistical impact on consumer expectations and satisfaction across any of the surveyed groups.

To achieve sustainable development and successfully close the existing service quality gaps, rural tourism providers must diversify their offerings. Modern tourists increasingly seek holistic, active experiences rather than passive accommodation. Upgrading "tangible" elements, such as surrounding rural infrastructure, and enhancing "responsiveness" through integrated regional products – such as combining coastal and mountain tourism, or leveraging the region's strong wine production capabilities – will be vital. By diversifying their services tourism providers can ensure that the synergetic effects we noticed for larger groups of 5+ members will lead to an overall increase in

customer satisfaction with a high degree of probability. Finally, targeted training for local administrators and the establishment of demonstration centers are necessary steps to close the knowledge gap among rural site managers, thereby elevating the overall professional standards and competitiveness of the destination.

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NATURAL AND CLIMATIC CHALLENGES TO THE MAIN FIELD CROPS – FOLLOWING THE EXAMPLE OF THE REGIONS OF RUSE, PLEVEN AND VELIKO TARNOVO, BULGARIA

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Abstract

Grain production is a strategic and structurally important sector in the economy of the Republic of Bulgaria, which in recent years has been under strong pressure from adverse climate change. The current study is focused on the analysis of climatic factors and their impact on the development of the sector. Within the framework of the study, the results of an empirical study of grain production in Ruse, Pleven and Veliko Tarnovo regions are presented. The state and structural characteristics of the sector for the period 2021-2024 are analyzed, identifying the main trends in its development, as well as the key problems and the factors that determine them. Based on the analysis, summarized conclusions are formulated and guidelines are proposed for increasing competitiveness and achieving sustainable development of grain production.

Key words**:** *grain production, climate change, adaptation of grain producers, measures*

INTRODUCTION

Grain production has established itself as a strategic and structurally determining sector in the economy of the Republic of Bulgaria, characterized by a significant contribution to the agricultural gross domestic product, employment and export potential of the country.

But in recent years, the sector is under increasing pressure from a combination of climate, market and political factors at global level. Climate change is emerging as a key determinant of yield variability and product quality, while increased volatility in international markets and changes in agricultural policies are further complicating economic conditions. In this regard, increasing the competitiveness of grain farms should be considered as a priority goal, the achievement of which requires the integration of innovative technologies, optimization of resource efficiency and the implementation of sustainable management practices. (Peneva, 2021) [6]. These have a direct impact on production results, resource security and economic efficiency of farms. (Ghilencea et al., 2025) [4].

Achieving sustainable development in the agricultural sector, viewed through the prism of both quantitative and qualitative parameters of production, presupposes the application of a systematic, innovative and complex analytical approach to modern trends and dynamic changes in the environment. In this context, the need for timely identification, assessment and management of emerging risks and constraints that affect the efficiency and stability of production processes is of particular importance (Varamezov, 2025) [11].

Of paramount importance for the long-term development of the grain production sector is the formation of a favorable environment that stimulates its efficiency, sustainability and economic viability. The realization of **stable economic benefits** implies, on the one hand, the achievement **of constant and reliable yields**, and on the other hand, the provision of profitable realization of the produced products.

Due to these circumstances, this study aims to analyze the influence of the main climatic factors on the development of grain production, with an emphasis on assessing

their impact on the production and structural parameters of the sector. In an empirical aspect, the processes and trends in grain production in the districts of Ruse, Pleven and Veliko Tarnovo have been studied, which have established themselves as one of the leading regions for grain production in the country.

The scope of the study includes the cereals of wheat, barley and maize, as well as oilseed sunflower, as they constitute essential elements of crop production both in these regions and on a national scale, and are grown under similar agrotechnical practices.

The analysis covers the period 2021-2024, looking at the state, dynamics and structural features of the sector. The main trends in its development are identified, as well as the existing problems arising from climatic risks and resource constraints. A systematization of the factors determining the observed changes has been carried out in order to better interpret the interrelations between the climatic environment and economic performance.

All three areas studied by us border each other, they are located in the central part of northern Bulgaria, as their northern border is the Danube River and it amounts to about 200 km. , in total for the three districts. To the south of them is the Balkan Mountains, to the east they border with the districts of Razgrad and Silistra, to the west with the district of Vratsa. The total area of the three districts amounts to 12,118.7 km² or about 11% of the country's territory.

The studied areas are characterized by a favorable geographical position and a significant variety of relief, including mountainous, hilly and flat terrains. This landscape heterogeneity, combined with suitable agro-climatic and soil conditions, creates prerequisites for a high degree of development of agricultural production. The climate of the studied territory is significantly influenced by the proximity of the Danube River, which determines specific temperature characteristics. The winter season is characterized by relatively low temperatures, with the average January temperature ranging between –2°C and –3°C. Summers are warm, with an average July temperature of about 26°C. In recent years, there has been a tendency towards more frequent droughts, especially in the months of July and August. The summer period is also characterized by the appearance of intense thunderstorms and hailstorms, which have a significant impact on agricultural production.

Agricultural activity is particularly intensive in the plains, where significant tracts of arable land are concentrated, intended mainly for the cultivation of grain and oilseeds of strategic importance for the agricultural sector of Bulgaria. The share of agricultural territories in the districts under consideration reached approximately 80%, which significantly exceeds the national average (57.4%). The analyzed districts rank among the leaders on a national scale in the production of cereals and oilseeds, with the largest relative share being wheat, corn, sunflower and barley. These crops annually occupy a predominant part of arable land, which determines the region's pronounced specialization in grain production. The climatic characteristics of the three regions are determined by their belonging to the zone of temperate continental climate. This climatic type, combined with the wide distribution of fertile alluvial-meadow and chernozem soils, creates favorable natural prerequisites for intensive development of agriculture. Crop production has established itself as one of the most sustainably developing sectors in the economic structure of the districts.

The district of Veliko Tarnovo is the largest and has an area of 4662 sq.km, very little by little is the district of Pleven with 4653 sq. km. km. and the smallest is Ruse with 2803 sq. m. km., in. Veliko Tarnovo region has 10 municipalities, with 167 lands, 2,937,294 Dec. agricultural area and 204,033 population. Structurally, agricultural land is allocated to 2,190,119 Dec. fields, 127,903 Dec. perennial crops, including vineyards and 395,729 dec. pastures, meadows and meadows. Administratively and territorially, Pleven District is divided into 11 municipalities, with 123 lands. The largest amount of agricultural land is in the region of Pleven 3,989,095 Dec. of which 3,076,240 Dec. fields, 110,826 Dec. perennials, 441,437 Dec pastures, meadows

and meadows. Ruse region consists of 8 municipalities with 83 lands, agricultural land amounted to 2,018,455 Dec., 1,530,013 Dec. fields, 24,380 Dec. perennials.

The territory of the studied area is differentiated into three main morphostructural zones: plain, semi-mountainous and mountainous, the latter occupying a relatively small spatial share. The relief diversity causes significant differences in the genesis, morphology and composition of the soil cover. The soil layer is characterized by a high degree of heterogeneity, manifested both at the level of administrative units (municipalities) and within the individual lands. Spatial variability of soil characteristics includes differences in mechanical composition, humus content, water regime and agrochemical indicators. The lowland areas are dominated by soils with high natural fertility and favorable agrophysical and agrochemical properties, which creates prerequisites for intensive development of crop production. In contrast, in semi-mountainous and mountainous areas, different types of forest soils predominate, characterized by lower values of basic agrochemical indicators and more limited production potential for agricultural use.

The research thesis is that in recent years, a very important sector for the country, such as grain production, has been experiencing extremely negative trends caused by climate change, both structurally in terms of crop rotation and yield, especially in spring crops.

To achieve this goal, the following research tasks have been formulated:

•monitoring and analysis of the state of grain production;

•identification of the main trends in the development of the sector;

•analysis of climate change and its impact on crop yields and structure;

•development of recommendations to limit and overcome the negative consequences of climate change.

The implementation of these tasks will contribute to the formulation of guidelines for sustainable and competitive grain production, adapted to dynamically changing climatic conditions.

MATERIALS AND METHODS

Both primary and secondary sources of information were used in the framework of this study. The primary sources include official documents, reports, as well as statistical and analytical materials of the Ministry of Agriculture and Food (MAF) and the Regional Directorates of Agriculture. Secondary sources include scientific publications, as well as empirical data collected through interviews with farmers, grain buyers and chairmen of agricultural cooperatives. The interviews were conducted both in person and by phone.

In the analysis of the collected information, traditional methods of scientific research were used. Among them are general scientific methods – historical and logical approaches, as well as logical-theoretical methods, including analysis, synthesis, comparison, induction and deduction.

Based on the results obtained, summarized conclusions have been formulated regarding the sustainability and adaptive capacity of grain production, as well as guidelines have been proposed to increase its competitiveness and ensure long-term sustainable development in the context of climate uncertainty.

RESULTS AND DISCUSSIONS

Structural and quantitative indicators of the main arable crops in the areas studied by us for the period 2021-2024

The analysis of agricultural production in the regions under consideration is focused on the leading crops that determine the structure of crop production. It has been found that in order to ensure agronomically justified and ecologically balanced crop rotation, a ratio between spring and autumn crops is maintained, close to parity (approximately 50:50). The group of autumn crops includes wheat and barley, while corn and sunflower are classified as spring crops. The maintenance of such a structure of the sown areas creates prerequisites for optimizing agrotechnical measures and limiting the risk of degradation of soil resources.

These practices constitute an essential element of the implementation of the principles of sustainable management of agricultural resources and are in line with modern requirements for environmentally friendly agriculture.

Table 1. Areas sown in decares and relative share of the main crops as a percentage of the total sown area, by year for the period 2021-2024

Culture	**2021**	**%**	**2022**	**%**	**2023**	**%**	**2024**	**%**
Wheat	2,192,834	38%	2,243,183	39%	2,211,556	39%	2,344,835	40%
Barley	215,555	4%	214,927	4%	244,285	4%	408,121	7%
Sunflower	1,459,886	25%	1,530,134	27%	1,484,340	26%	1,663,872	28%
Corn	1,889,243	33%	1,727,790	30%	1,675,327	30%	1,451,453	25%
Total area	5,757,518	100%	5,716,034	100%	5,615,508	100%	5,868,281	100%

Source: "AGRICULTURE" – V., 2024) (Veliko Tarnovo, 2025) (Ruse, 2025) (Pleven, 2025) [1, 12, 9, 7].

Barley areas remained almost unchanged relative share of 4% in the period 2021-2023, but in 2024 a significant increase to 408,121 decares (7%) was recorded, representing a significant structural change. (Ruse O. d., 2023).

Sunflower has a fluctuating but generally upward trend. After an increase of 25% in 2021 to 27% in 2022, a slight decrease follows in 2023 (26%), and in 2024 the area reaches 1,663,872 decares (28%), which is the highest value for the period considered.

Unlike other crops, corn has a steady downward trend. Its share decreased from 33% in 2021 to 25% in 2024, with the sown areas reduced from 1,889,243 decares to 1,451,453 decares. This indicates a significant restructuring in favour of other crops.

The total sown area remained relatively stable in the period 2021-2023, with a minimal decrease, followed by an increase in 2024, when it reached 5,868,281 decares.

The analysis of the average yields of the main arable crops in the district for the period 2021-2024 shows a clear distinction between autumn crops (wheat and barley) and spring crops (maize and sunflower) in terms of sustainability and amplitude of variation in productivity (Fig. 1).

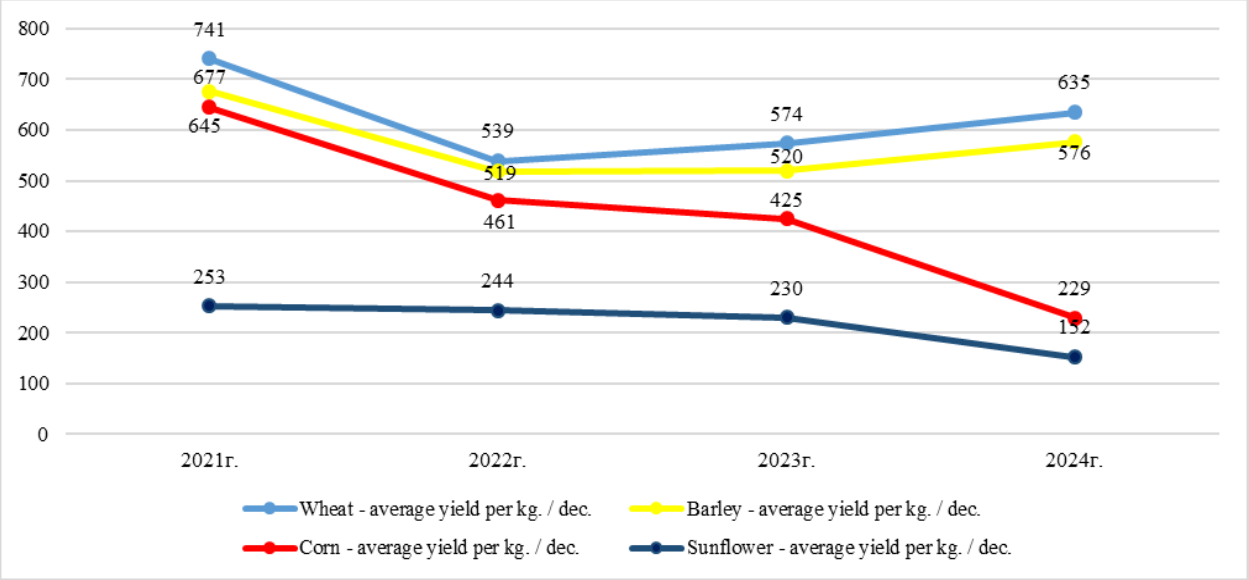

Fig. 1. Analysis of the dynamics in the yields of the main arable crops for the period 2021-2024
Source: "AGRICULTURE" – V., 2024) (Veliko Tarnovo, 2025) (Ruse, 2025) (Pleven, 2025) [1, 12, 9, 7].

For wheat, the following values of the average yield are observed: 741 kg/ha in 2021, decrease to 539 kg/ha in 2022, partial recovery to 574 kg/ha in 2023 and reaching 635 kg/ha in 2024. Despite the distinct decline in 2022, the crop has demonstrated

relative stability and recovery capacity, with the 2024 final value remaining around 14% lower than the 2021 baseline.

Similar dynamics is reported for barley – 677 kg/ha in 2021, 519 kg/ha in 2022, 520 kg/ha in 2023 and 576 kg/ha in 2024.

The trend is significantly less favorable for spring crops. Corn has seen a consistent and significant decline in yields, from 645 kg/ha in 2021 to 461 kg/ha in 2022, 425 kg/ha in 2023 and only 229 kg/ha in 2024. This high amplitude of variation indicates a strong sensitivity of the crop to adverse climatic conditions, especially to drought.

Sunflower also reports a downward trend: 253 kg/ha in 2021, 244 kg/ha in 2022, 230 kg/ha in 2023 and 152 kg/ha in 2024. Although the reduction is significant, the crop exhibits a more moderate amplitude compared to corn (Fig. 1).

The biological characteristics of the sunflower – a shorter growing season and earlier entry into the reproductive phase – allow it to use spring rainfall more efficiently, which partly explains its relatively better adaptability to dry conditions.

The comparison between the four crops clearly shows that autumn crops retain a higher degree of stability and less variability of yields in conditions of climatic instability. On the contrary, spring crops, and especially corn, show a strong dependence on the rainfall regime during the growing season, which leads to a sharp decrease in productivity during drought.

The economic analysis further aggravates the situation with spring crops. With an average yield of 152 kg/ha of sunflower in 2024 and an average purchase price of 800 BGN/t, the income amounts to approximately 121-122 BGN/ha, which casts doubt on the profitability of production. The picture is even more unfavorable for corn – with a yield of 229 kg/ha and an average price of 374 BGN/t, the income is approximately 85-86 BGN/ha, a value that is economically extremely insufficient at modern production costs. (Yordanova, 2025) [13].

In summary, the analyzed data for the period 2021-2024 show a clear downward trend in the yields of spring crops, especially corn, which increases production risk and reduces economic efficiency. This explains the observed reorientation of farmers towards more sustainable autumn crops and the reduction of areas occupied by spring crops.

The analysis of the state and dynamics of the main agricultural crops in the crop sector of the areas under consideration outlines the presence of significant structural and production problems, primarily related to the cultivation of **spring crops** and the implementation of **effective crop rotation**. The identified unfavorable trends testify to a disturbed agrotechnical balance, which creates prerequisites for a decrease in productivity and sustainability agricultural systems in the medium and long term. Particularly worrying are the indications of a potential decline in the production of strategic crops such as corn and sunflower, which are key to both domestic consumption and the functioning of the processing industry. A decrease in yields from these crops could lead to a shortage of raw materials for enterprises in the agri-food and oil processing sectors, which in turn creates a risk of limited supply of final products and an increase in price pressure on the market. In this context, the problem acquires not only regional but also national economic importance.

In addition, reduced yields and instability in the production of major cereals and oilseeds may have a negative impact on the country's food security. The decline in domestic production capacity increases dependence on imports and increases the vulnerability of the agricultural sector to external market and climate shocks.

Empirical observations and farmers' opinions further underline the seriousness of the situation. According to them, if unfavorable conditions persist for another one to two business years, there is a real risk of mass bankruptcies and withdrawal of farms from grain production. Such a development could escalate into a systemic crisis affecting the entire agricultural sector, with long-term socio-economic consequences for rural areas and the national economy as a whole.

In summary, the analyzed data outlines the need for targeted policies and interventions

aimed at stabilizing production, optimizing crop rotation and increasing the sustainability of crop production in the region.

Main reasons for negative trends in crop production

As the root cause of negative trends in agricultural production, modern climate change stands out, the manifestations of which have intensified over the past decade. Their impact is characterized by both a gradual increase in average annual temperatures and an increase in the frequency and intensity of extreme weather events. Which, in turn, have an impact on the productivity of agroecosystems.

Soil fertility is determined by the content and balance of macro- and microelements, as well as by the amount of organic matter, in particular organic carbon, which is essential for the structure, water retention capacity and biological activity of the soil. However, the presence of these elements is not a sufficient condition for the realization of soil fertility. Their availability for plants is directly dependent on soil moisture, which provides an environment for biochemical processes and for the absorption of nutrients by the root system. In this context, the water regime of the soil is an integral component of the production potential.

In recent years, climate change has been deepening, manifested through more frequent and more intense extreme events – prolonged droughts, heat waves and uneven rainfall distribution. These factors have a significant impact on the development and fertility of crops, especially spring crops, whose growing season coincides with the warmest months of the year (Atanasova, 2021) [2].

The data of the National Institute of Meteorology and Hydrology show a steady trend towards an increase in the average annual temperature in the country. In 2021, it was 1.3 °C above the climatic norm, in 2022 – by 0.8 °C, and in 2023 – 1.6 °C above normal. At the same time, 2024 has been set as the hottest year since the start of instrumental observations, according to the State of the Climate in Europe report. As a result, there is an increasing trend in the number of so-called. "hot days" (with a maximum temperature above 32 °C), which creates additional stress for plants, especially in critical phases of development (Gospodinov, 2025) [5].

Hot periods are defined as extended intervals with maximum air temperatures ≥ 32, 34, 36, 38 and 40 °C, with a minimum duration of 2,3,4,5 and 6 consecutive days respectively. (Fig. 2).

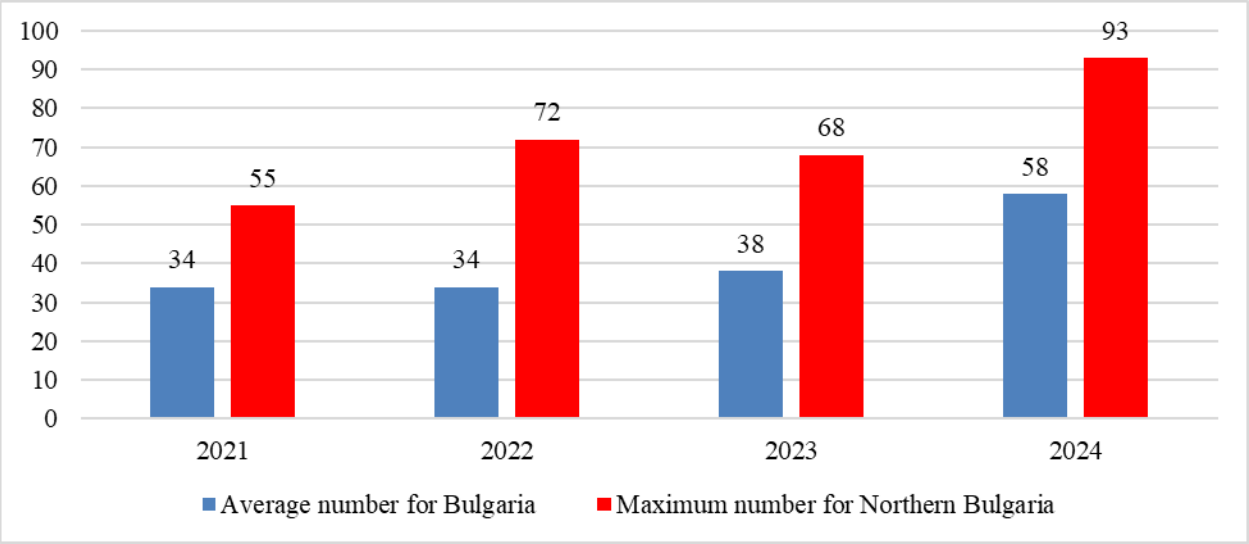

Fig. 2. Number of consecutive hot days for the period 2021/2024
Source: Gospodinov, 2025.

By combining two main parameters – intensity and duration of temperature anomalies – this indicator provides a comprehensive assessment of the degree of heat stress on agroecosystems. Such an approach allows not only the quantitative

measurement of extreme temperature manifestations, but also a more precise tracking of their impact on the physiological processes of cultivated plants and on the productivity of agricultural systems.

According to the data presented in Fig. 2, in the period 2021-2024, there is a clear trend towards a high frequency of consecutive hot days on a national scale. In 2021, the average number of hot days for the country amounted to 34, with maximum values reaching 55 days in Northern Bulgaria. In 2022, the average value remains 34 days, but a significant increase in the maximum is registered - up to 72 days in North-eastern Bulgaria. In 2023, the average number of hot days increased to 38, and the maximum value reached 68 days in the central parts of Northern Bulgaria (Gospodinov, 2025) [5].

The number of hot days (with a maximum temperature above 32 °C) shows a steady upward trend of around 0.4 days/year. for areas with an altitude of up to 1,000 m. In 2024, the average number of hot days in Northern Bulgaria is 58, and the maximum of 93 days was reached in the city of Sofia. Ruse: These data testify to the stable retention of high temperature values and spatial concentration of extreme events in the northern regions of the country.

In parallel with the temperature anomalies, changes in the rainfall regime are also detected. Although the total annual amount of precipitation during the years under review varies approximately within ±30% of the climatic norm for the country, their distribution is highly uneven both by month and by territory. According to initial data, the surface water runoff formed on the territory of Bulgaria in 2024 is about 9,000 million cubic meters. m³. Compared to the average annual outflow volumes for the periods 1961–1990, 1971–2000, 1981–2010 and 1991–2020, it is less by about 51%, 44%, 42% and 47%, respectively (Gospodinov, 2025) [5].

In addition to the smaller precipitation over the years, there is also a tendency to increase the intensity and unpredictability of rainfall events, including short-term torrential rains leading to floods, as well as prolonged dry periods. This unevenness in the distribution of precipitation limits the effective accumulation of moisture in the soil profile.

As a result, a deficit of soil moisture is formed in the root layer (up to 1 m deep), which is a significant limiting factor for the development of late agricultural crops. The shortage of available water disrupts traditional agrotechnical cycles and increases the risk of yield reduction. The increase in temperatures further contributes to the prolongation of drought periods and an increase in the frequency of heat waves, which has a negative impact on the processes of pollination, fertilization and yield formation in most varieties and hybrids of spring crops.

The combined effect of high temperatures and water deficiency leads to shortening of the interphase periods in plant ontogeny, accelerated phenological phases and premature end of vegetation. This is manifested in premature drying of plants, incomplete pouring of grain or the formation of productive organs, and, ultimately, in lower and unstable yields. The observed trends highlight the need to adapt agrotechnical practices and breeding approaches to increasing climatic variability.

Recommendations and measures to reduce the negative consequences of climate change.

Over the past four years, accelerating climate change has established itself as a significant factor having a multifaceted impact on global grain production. The increasing frequency and intensity of extreme weather events – prolonged droughts, intense rainfall, heat waves and late spring frosts – lead to significant fluctuations and, in many cases, to a permanent decrease in average yields of major cereals.

Climate instability affects not only production volumes, but also price dynamics in international markets. Reduced or unpredictable yields create conditions for increased volatility, including speculative fluctuations in cereal prices. This volatility is carried over the value chain – from producers and traders to processors and final consumers – driving up food costs and deepening the risk to food security, especially in countries with high dependence on imports. In this context, the need for a strategic and coordinated

response is becoming increasingly urgent. As stressed, adaptation to climate change requires a complex and integrated approach that combines agrotechnical, economic, institutional and technological measures (Stoyanova, 2022) [10].

A shared and clearly articulated vision between all stakeholders is a key factor for the effective implementation of policies and measures aimed at adaptation to climate change. The existence of a common strategic framework creates prerequisites for building trust, improving coordination and promoting cooperation between the participants in the process (Dale, 2020) [3].

Within the framework of the study, measures have been identified in three main areas that can support the adaptation capacity of farmers to changing climatic conditions.

First direction: Improvement of production practices in the cultivation of cereals and oilseeds.

The proposed measures include:

- rehabilitation of the existing and construction of new hydro-melioration infrastructure;
- optimization of the deadlines for carrying out agrotechnical measures (sowing, planting, treatment);
- introduction of more thermophilic and stress-resistant varieties and hybrids;
- application of practices to improve and restore soil structure, increase the content of organic matter and increase the infiltration capacity of the soil. These interventions are aimed at reducing the vulnerability of production systems and increasing their resilience to climate extremes.

Second strand: Development of research, innovation and training.

This group includes:

- development of new crop varieties with improved adaptability;
- introduction of innovative technologies and practices to limit the risk of climate impacts;
- conducting research to identify and characterise climate risks, assess the degree of vulnerability and analyse the potential opportunities arising from current and projected climate change;
- organizing trainings and increasing the capacity of farmers. This strand aims to create a science-based basis for decision-making and strengthen the adaptive potential of the sector.

Third strand: Legal and institutional changes.

The necessary measures include:

- updating the legal framework in order to integrate policies to mitigate the impact of climate change and implement adaptation solutions;
- development of mechanisms for insuring crops against climate-related losses;
- providing targeted support and compensation mechanisms for crops affected by climate anomalies. These actions are aimed at creating an enabling institutional environment supporting the sustainable development of agriculture.

In terms of financial aspects, the costs of implementing the majority of the proposed measures can be defined as low to medium. An exception is made for investments related to the design, construction and modernization of irrigation systems and related infrastructure, which require significant financial resources. However, there are opportunities to support them through instruments such as the Rural Development Programme, which creates prerequisites for the implementation of strategically important infrastructure projects.

CONCLUSIONS

The increasing intensity and frequency of climate change in recent years has had a significant impact on grain production, in terms of a decrease in average yields, an increase in price volatility and an increase in risks to food security. Growing climate uncertainty puts the sector in front of the need for systematic and coordinated action aimed at strengthening its resilience, flexibility and adaptive capacity.

In this context, the implementation of targeted adaptation measures is a strategic priority. Increasing the ability of farmers to respond adequately to dynamic climatic conditions requires an integrated approach encompassing

technological, organizational and institutional solutions.

Although the present study is based on empirical data from a specific region, the analysed indicators characterising the status, structure and main challenges of grain production largely reflect trends valid at national level as well. This allows the conclusions and recommendations to be considered as relevant in a broader context and applicable in the formation and improvement of the national agricultural policy aimed at sustainable development of the grain production sector.

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THE BULGARIAN COOPERATIVE MODEL: ECONOMIC, SOCIAL AND GOVERNANCE DIMENSIONS

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Abstract

This report examines the economic, social and managerial dimensions of the current cooperative model in Bulgaria. The cooperative is a traditional and widespread legal and organizational form in various sectors of the national economy. The role of operating cooperatives for employment and regional development in the country is analyzed, and the features of cooperative management based on cooperative principles are examined - voluntariness in establishment, equality of members, democracy in making management decisions, etc. The aim of the study is to analyze the Bulgarian cooperative model as a specific legal and organizational form, combining economic activity with social responsibility, which functions on the principle of democratic governance in the conditions of contemporary challenges. The report analyzes the current state and dynamics of the cooperative sector in Bulgaria in accordance with established European cooperative practices. The results obtained reflect the contemporary challenges facing the development of Bulgarian cooperatives. In conclusion, guidelines are given for the sustainable development of the Bulgarian cooperative model as a basis for the economic, social and territorial development of the country.

Key words**:** *cooperatives, cooperative model, sustainable development, social economy, governance, Bulgaria*

INTRODUCTION

A cooperative is a voluntarily established association of individuals whose purpose is to carry out economic activity that protects the economic and social interests of its members. According to classical definitions in cooperative theory [2, 20], cooperatives are based on the principles of voluntariness, democratic governance and equal participation of members in economic activity. According to (Birchall and Ketilson, 2009) [3] and (Birchall J. , 2011) [2] cooperatives function both as economic operators and as social institutions that protect the interests of their members and local communities.

In Bulgaria, cooperatives play a particularly important role in small towns and villages, where they are often the main employer and provider of important social services. They contribute substantially to regional economic stability and to limiting socio-economic imbalances. The combination of economic efficiency and social mission creates a synergistic effect that helps improve the well-being of local communities and society as a whole.

In modern conditions, the cooperative sector faces a number of systemic challenges that call into question its long-term sustainability. According to Chaddad & Cook (2004), Theuvsen & Ebneth (2005), Valentinov (2007), the processes of demographic decline in rural areas, limited access to investment resources, as well as the increasing competition in the market environment stand out [4, 17, 18]. These factors determine the need for a targeted state policy and the creation of an adequate regulatory framework through which the cooperative model can be integrated into the national economic priorities.

Under the current socio-economic conditions, the development and support of the cooperative model can be seen as a strategic investment with a long-term effect on the economic growth and social stability of each country. As (Novkovic, 2008) [12] highlights, the sustainability of cooperatives is closely linked to the institutional environment and to the political will to maintain this

specific organizational model. Without an objective assessment of the real state of cooperatives, there is a risk that political decisions will remain formal and will not contribute to increasing their sustainability.

Therefore, an in-depth analysis of the economic scale and financial situation of cooperatives is essential to assess their sustainability and long-term development potential. The financial independence and economic magnitude of the cooperative are key determinants of its ability to realize both its economic goals and its social mission.

The aim of the research is to analyze the Bulgarian cooperative model as a specific organizational form, combining economic activity with social responsibility and functioning on the principle of democratic governance in the conditions of modern challenges.

To achieve the set goal, the following tasks are solved:

(i) To develop a methodological framework for the study based on criteria that would group cooperatives by size of economic activity.

(ii) Operating cooperatives in Bulgaria should be grouped by basic economic indicators.

(iii) To characterize the structure, dynamics and features of the development of cooperatives in Bulgaria.

(iv) To outline the social and managerial aspects of Bulgarian cooperatives in the face of contemporary challenges.

The object of the study are the registered and operating cooperatives in Bulgaria, which carry out economic activity in accordance with the Cooperatives Act and the Accountancy Act.

The subject of the study is the classification of these cooperatives by economic size, according to the established criteria for distinguishing enterprises into micro, small, medium and large.

The information for the analysis is based on empirical data obtained from the Ciela Norma information system in 2023. The time scope of the survey covers the period 2005-2023 in terms of the indicator "employed personnel" in the cooperatives and the period 2005-2021, concerning the financial indicators "annual turnover" and "book value of assets". The time interval allows to trace the structural changes in the cooperative sector in Bulgaria and to identify trends in its development.

Methodological approach to categorization of cooperatives

The classification of enterprises according to their economic size is a widely used analytical tool in economic research and in business practice. Such typology allows for the systematization of economic entities into relatively homogeneous groups and creates prerequisites for a more in-depth analysis of their economic significance, structure and contribution to the national economy. According to the established practice of the EU and international statistical organisations, the differentiation of enterprises by size is key to the design and implementation of policies to promote entrepreneurship, competitiveness and sustainable economic development [5, 13].

Within the EU, the generally accepted methodology for classifying enterprises is regulated in Recommendation 2003/361/EC of the European Commission. It groups non-financial enterprises by size into micro, small and medium-sized. Leading criteria for determining size are: (1) number of employees in the enterprise; (2) annual turnover and (3) book value of assets. This methodological framework is widely applied both in statistical surveys and in European and national enterprise support programs [5, 7, 8].

In Bulgarian legislation, these criteria are implemented through the provisions of the Small and Medium-sized Enterprises Act (SME) [15], which defines the conditions for categorization of economic entities according to their economic size. The classification of enterprises by size is also important in the analysis of the cooperative sector, as it allows to assess its structure, economic concentration and degree of participation in economic activity.

One of the main and mandatory indicators in this categorisation is *the average annual number of employees*, which serves as a key indicator of the scale of the economic activity of the enterprise, respectively of the cooperative. In combination, the first with the

other two financial indicators – *annual turnover and carrying amount of assets* – makes it possible to determine more objectively the economic size of the analyzed economic entities. Cooperatives are traditionally considered as a specific organizational form of economic activity, which combines economic with social goals. For this reason, the analysis of their structure by economic size provides valuable information on the degree of economic concentration in the sector, as well as on the potential of cooperatives to actively participate in regional economic development. Such a categorization also reveals the role of cooperatives in the formation of employment, the generation of economic value and the development of local economies in the country.

In this context, the application of the established criteria for the size of enterprises under the SME Act – micro-, small, medium and large – to cooperative structures allows to formulate reasonable conclusions about their role in the national economy (Table 1).

Table 1. SME Act Criteria in Bulgaria, applied to the Classification of Cooperatives by economic size

Cooperation category	Average number of staff	Annual turnover (thousans of euros)	Value of assets (thousans of euros)
Micro-enterprises	Less then 10	up to 2,000	up to 2,000
Small enterprises	10–50	2,000–10,000	2,000–10,000
Medium-sized enterprises	50–250	10,000–50,000	10,000–43,000
Large enterprises	over 250	over 50,000	over 43,000

Source: Low on Small and Medium-Sized Enterprises, 1999, State Gazette No 84 of 24 September 1999 (last amended and supplemented SG No 43 of 27 May 2025) [11] [17], SME Act and own summary [15].

RESULTS AND DISCUSSIONS

Economic dimensions of Bulgarian cooperatives

This study examines the economic dimensions of Bulgarian cooperatives through an analysis of basic quantitative indicators, namely: number of employed persons, annual turnover and value of assets (Table 1).

Analysis by indicator number of employees:

The analysis of the data on the average number of staff during the 19-year period under review shows that on average annually about 61.1% of active cooperatives have employees. In 38.9% of the cooperatives in the country, no data on employed personnel were reported. This means that they carry out their activities with minimal staff or through personal participation of the cooperative members without an employment contract. This confirms the results established by the study by Atanasova-Kalaydzhieva (2025) [1], according to which the dominant part of cooperatives in Bulgaria are microenterprises with limited human resources, which limits their potential for investment and innovation.

The distribution of the 2,818 active cooperatives according to the criterion of average annual number of staff reveals a significant predominance of the smallest structures. About three-quarters of them fall into the category of micro-enterprises with up to 10 employees, which in relative terms represents 74.5% (2,100 units). This sustained dominance of micro-cooperatives throughout the period is an indicator of a specific employment model in which economic sustainability often depends on the individual contribution of individual members and on the flexibility of the organisational structure, which is also noted as a characteristic feature of the socio-economic nature of the cooperative sector.

After micro-cooperatives, the largest group of cooperatives with employees between 10 and 50 people turned out to be the largest. These are small-sized cooperative structures that operate and sell products on local markets. They perform locally oriented socioeconomic functions, which is why they employ a limited number of people. On an average annual basis, these small cooperatives are 645, which forms a relative share of 22.9%. Only 71 cooperatives (2.5%) fall into the category of medium-sized enterprises with employees of 50 – 250 people. It is found that large cooperative structures with more than 250

employees are on average only 2 per year for the period or their relative share is extremely low and is 0.1%.

The main conclusion from the analysis of the average annual number of employees in cooperatives in Bulgaria is that their activities are highly concentrated in the micro-entrepreneurial segment. Less than 3% of all existing cooperatives have the capacity to operate as medium or large enterprises, reflecting a pronounced fragmentation and limiting their economic weight, competitiveness and opportunities to achieve economies of scale in the long term.

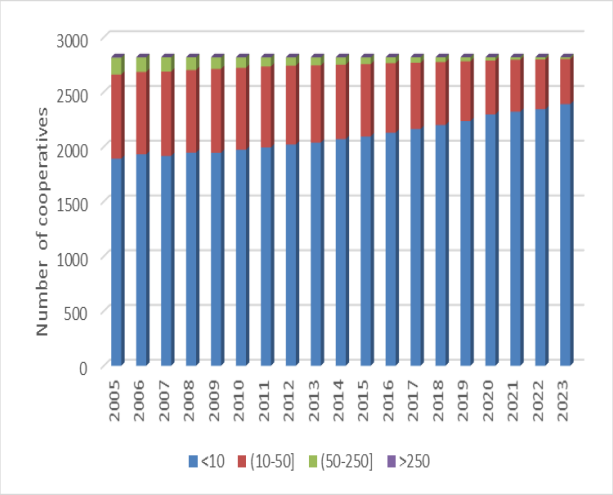

Fig.1. Distribution of cooperatives in Bulgaria according to the average annual staff for the period 2005-2023

Source: The Ciela Norma [16].

This characteristic distribution of cooperative organizations is a direct result of the profound transformation that the sector has undergone over the past two decades [21]. To establish the main trends in its development, it is necessary to track the changes in the selected indicators over time. The dynamic analysis of the number of operating cooperatives in terms of employees shows an outlined restructuring in the period 2005-2023, with a pronounced increase in the share of microenterprises. Micro-cooperatives are the only category that shows an increase – from 1,891 cooperatives in 2005 to 2,389 in 2023. This is an increase of 498 cooperatives for the period or a growth of 26.3%. This growth is observed in parallel with a decrease in the number of cooperatives in the other categories. The most significant decline was in the group of small cooperatives (10–50 employees) – from 769 units in 2005 to 412 in 2023, which represents a decrease of 46.4%. Similarly, the average cooperatives with 50–250 employees decreased from 153 to only 16 employees, i.e. there was a decrease of 89.5%. The category of large cooperatives (with more than 250 employees) was low in number at the beginning of the observed period, and the subsequent decrease of 75% confirms the almost complete disappearance of these structures from the cooperative sector. Overall, the data on the criterion "average number of staff" outline a steady trend towards strong polarization in favor of micro-cooperatives with up to 10 employees. This change in the cooperative sector in Bulgaria over the years is a sign of structural problems related to the liquidation of larger cooperatives, mergers, transitions to other legal and organizational forms, lack of capital for technological renewal, inability to adapt to the market, etc.

The reduction of staff cannot be seen only as a temporary adaptation, but rather as a long-term strategy to preserve the cooperative model in the face of ongoing economic pressures. This negative dynamics of labor resources is associated with a contraction in the value indicators of economic activity of cooperatives. The significant fragmentation, with the predominance of micro-cooperatives over other groups, is an indicator of structural challenges described by other authors. In a study by (Sarov, 2025) [14], it is emphasized that Bulgarian cooperatives, under the influence of market conditions and the institutional requirements of the Common Agricultural Policy, demonstrate limited capacity for growth and adaptation.

In order to find an explanation of the existing trend, an assessment of cooperative structures according to the second and third classification criteria follows, namely their compliance with one of the financial requirements for annual turnover or value of assets, which is key to determining their market sustainability and growth potential.

Analysis by annual turnover indicator

The analysis of Bulgarian cooperatives according to the criterion "annual turnover"

for the period 2005-2021 shows a strong concentration in the micro-cooperatives segment, which highlights the limited economic scale of the sector. A predominant part of the cooperative organizations – over 2,766 units or 98.2% of the observed ones generate an annual turnover of up to EUR 2 million. euros. This confirms that a significant part of the cooperatives in Bulgaria operate with minimal operational capacity and low intensity of commercial activity, while their financial structure remains homogeneous in terms of unsustainability.

Even cooperatives with larger staff often fail to generate higher revenues, indicating low labor productivity and highlighting problems in the efficient use of human capital. A small part of the cooperatives – only 49 units or 1.7% – exceed the threshold of 2 million euros per year turnover, remaining in the category of small enterprises with a turnover of up to 10 million euro and medium-sized enterprises with a turnover of up to 50 million euro are extremely small – only 3 units, which is only 0.1% of the total. A similar trend for limited financial scale has been observed in other European studies, which show that agricultural cooperatives in particular often operate with minimal resources and limited market potential [6, 10].

In a dynamic aspect, there is a weak trend towards an increase in turnover in some of the cooperatives – in 2021. There is a decrease of 3.4% in micro-cooperatives with a turnover of up to EUR 2 million, compensated by the increase in the number of cooperatives in the next category of 2-10 million euros. This indicates some progress in the market positions of certain cooperatives and creates prerequisites for the transition to larger groups of cooperatives. However, most of them remain permanently positioned as micro-cooperatives, confirming the persistent structural disproportion and limited potential for economic autonomy.

Persistently low turnover poses challenges to the competitiveness and long-term viability of cooperatives. Limited financial capacity reduces their ability to make a meaningful contribution to GDP and job creation, while limiting their potential to achieve economies of scale. Despite economic constraints, cooperatives continue to play an important socio-economic role, providing employment, supporting local communities and supporting social cohesion.

Asset value analysis

The analysis continues with a grouping of cooperatives according to the balance sheet value of assets. This establishes the degree of collateralization of cooperatives with fixed assets and their relationship with the number of employed personnel and the annual turnover. The analysis for the period 2005-2021 shows that the dominance of microstructures is also durable in terms of assets, reflecting their limited property scale. Similar studies on the capital structure and limited scale of cooperative organizations are confirmed by international studies that focus on financial fragmentation and challenges to the growth of cooperatives in the context of competitive markets [9, 18, 19]

Of the 2,818 monitored cooperatives for the study period, an average of 2,736 units (97.1%) have assets of up to 2 million euros, which classifies them as micro-entrepreneurial entities. Cooperatives with assets between EUR 2 million and 10 million are only 77 units (2.7%), and medium-sized cooperatives have assets of EUR 10 million to 43 million and are even less – 4 units or 0.1%. The presence of only one cooperative with assets of more than EUR 43 million throughout the period, proves the almost complete absence of large cooperative structures at the national level. The conclusion is that cooperatives function mainly as micro-enterprises not only in terms of the number of staff, but also in terms of financial indicators. Similar conclusions are found in the studies of (Iliopoulos, 2012) [10] on agricultural cooperatives in neighbouring Greece, i.e. there are similar characteristics for cooperatives in the two countries.

The dynamic analysis shows a slight but positive trend towards an increase in the capital base: the relative share of the smallest cooperatives decreased by 5.3%, while the share of entities with assets between 2 million and 10 million euros is increasing. This suggests that some cooperatives manage to

accumulate minimal capital and move up to the next category, demonstrating initial processes of vertical mobility and potential for structural transformation.

The group of small cooperatives increased significantly during the period under review, and by the end of 2021 their number was 5.6 times higher than at the beginning. The most dynamic growth was observed between 2008 and 2012, followed by a period of some slowdown. The latest data from 2021 show a recovery and acceleration of the positive trend, which indicates that cooperatives are gradually strengthening their capital potential and preparing the basis for future structural diversification.

Social Dimensions of Bulgarian Cooperatives

The Bulgarian cooperative model is distinguished by a pronounced *social mission and solidarity,* which underlies the functioning of these organisations. Cooperatives do not focus solely on profit, but provide employment and social protection for their members, while ensuring the development of local communities. This social aspect is manifested through various forms of support, including employment provision, participation in educational and professional initiatives, as well as through collective decisions for a fair distribution of resources. In this way, cooperatives function as a mechanism for social stability and a tool to reduce social inequalities.

The impact on local development is another key aspect of the cooperative model in Bulgaria. Especially in peripheral and underdeveloped regions, cooperatives provide access to resources, services and markets that would otherwise be inaccessible to smallholder farmers. They boost the local economy by purchasing goods and services from local suppliers, creating jobs, and supporting social programs. In this sense, cooperatives play the role of a "local engine" for economic and social development, combining economic goals with public benefit.

Membership and participation of cooperative members constitute an essential dimension of the social fabric. In Bulgarian cooperatives, the personal contribution of the members not only ensures the day-to-day functioning of the organization, but also forms social commitment and a sense of community. This is in line with the results of research by (Valentinov, 2007) and (Iliopoulos, 2012) [18, 10], which point out that the active participation of members strengthens collective identity and helps to overcome the limitations of small scale. Through voluntary work, participation in governance and joint decision-making, cooperatives develop social networks and mutual aid practices that strengthen them.

The socio-economic nature of cooperatives is capable of balancing economic efficiency with the social mission. Micro-cooperatives and small cooperatives often operate with limited financial resources, but manage to keep members employed and provide services that have a significant social impact. This nature is not only a matter of economic resilience, but also of the ability to adapt to specific market niches and social needs.

The main conclusion about the social dimensions of Bulgarian cooperatives is that these organizations are not just economic entities, but key carriers of social stability, local development and collective engagement. This symbiosis between social mission and economic activity distinguishes the cooperative model and makes it an indispensable element of the Bulgarian socio-economic structure.

Managerial dimensions of Bulgarian cooperatives

The Bulgarian cooperative model is also characterized by a unique combination of social mission and democratic governance, which distinguishes cooperatives from other economic entities (Table 2). The social and managerial dimensions of these organizations are mutually reinforcing. The management of Bulgarian cooperatives is determined by their small scale and flexibility. In micro-cooperatives, in contrast to medium and larger cooperatives, there is a simplified organizational model, adapted to local conditions. Their limited capital resources and low turnover hinder the implementation of

innovations and modern management practices.

The lack of financial resources, especially for small cooperatives, limits their access to technology, expert management and hinders their participation in national and European markets.

Table 2. Economic, Social and Managerial Characteristics of Bulgarian Cooperatives for the period 2005-2021

Cooperation category	Average number of staff	Annual turnover (€)	Book value of assets (€)	Share of total number (%)	Main economic, social and governance features
Micro-enterprises	up to 10	up to 2 million	up to 2 million	97–98 %	Limited economic scale, high social role, member involvement, adaptability to local niches
Small enterprises	10–50	2–10 million	2–10 million	1.5–2.7 %	Moderate economic activity, potential for clustering and vertical mobility
Medium-sized enterprises	50–250	10–50 million	10–43 million	0.1 %	Limited in number, they require targeted investments and management for economic and technological transformation
Large enterprises	over 250	over 50 million	over 43 million	<0.1 %	They are almost absent at the national level; lack of scale for market influence, high dependence on the social mission and membership work

Source: Own Research 2025.

Therefore, for them, from the point of view of resource optimization, it is necessary to achieve horizontal and vertical unification through clustering on a geographical or sectoral basis. Some of the larger cooperatives are able to gradually implement new technologies and management practices, strengthening their capital base and achieving vertical mobility. This allows them to increase their market share and move to higher categories of enterprises, despite structural constraints. To achieve long-term sustainability of the cooperative sector, it is necessary to combine the social mission with modern management practices and strategic investments, supported by a targeted state and institutional policy.

The analysis and data presented in Table 1 characterize the relationships between the economic, social and governance parameters of cooperative models in Bulgaria. The results obtained allow for the formulation of guidelines for their future development.

Some Bulgarian cooperatives development guidelines

The distribution of cooperatives and the dynamics of their economic size allow the following guidelines for their future development to be formulated:

- ***Institutional strengthening and consolidation:***

Cooperatives should seek opportunities for horizontal and vertical aggregation, including through clustering on a territorial or sectoral basis, in order to overcome the limitations of the microstructural model. Consolidation would allow for economies of scale, optimisation of logistics costs, lower delivery prices through collective bargaining, as well as joint access to specialized equipment and innovation.

- ***Targeted investment support:***

State and European policies should stimulate investment activity and the implementation of innovative management and production models in those cooperatives that reach a critical threshold for moving to a higher category. Targeted support can accelerate vertical mobility, turning micro-cooperatives into sustainable small and medium-sized enterprises.

- ***Increasing economic power and market power:***

The lack of large cooperative structures limits the ability of cooperatives to participate equally in large-scale trade operations and sustainable market channels. The establishment of national and regional cooperative clusters and platforms for joint realisation could strengthen their market presence and increase competitiveness.

- ***Attracting highly qualified specialists:***

Limited economic scale hinders access to expertise, which slows down the implementation of modern business models and technological innovations. The solution includes the creation of centers for shared expert services to provide small cooperatives with access to professional management and technological solutions through optimization and cost allocation.

- ***Increasing competitiveness and sustainability*:**:

For long-term sustainability, cooperatives need to develop partnerships with scientific and academic institutions, which would support knowledge transfer, the implementation of innovative management models and modern organizational practices. This strengthens the economic and social role of cooperatives, but the effectiveness depends on the institutional will to overcome the structural fragmentation and technological backwardness of small cooperative forms.

These priorities outline the strategic directions for the development of Bulgarian cooperatives in the conditions of the single European market, while emphasizing the need for a targeted institutional and investment policy to overcome the limitations of the microstructural model.

CONCLUSIONS

The analysis clearly shows that cooperatives in Bulgaria are characterized by high structural fragmentation and a predominant share of micro-enterprises with limited investment potential and minimal capital base. The majority of organizations fall into the category of micro-entities – with a staff of up to 10 people – while at the same time not exceeding the financial threshold of EUR 2 million for annual turnover and book value of assets.

Small cooperatives, with a staff of between 10 and 50 people, although significant in number, also demonstrate weak economic dynamics, limited turnover and modest capital capacity. Medium and large cooperatives remain barely perceptible in the aggregate, which is explained by their limited competitiveness and lack of resources for technological renewal.

Despite indications of gradual capital consolidation, cooperative structures have largely lost their role as major employers and significant economic actors at national level. They operate primarily as small, local economic units and not as large enterprises with the potential for a significant macroeconomic effect. Limited staff, low turnover and modest capital base call into question the market profitability and competitive sustainability of these organizations.

The viability of cooperatives in Bulgaria is due not to traditional market efficiency, but to the specific nature of the cooperative model, in which the social mission and personal labor contribution go beyond purely economic indicators. By ensuring economic sustainability and social solidarity, cooperatives provide security to their members and maintain their labor potential.

Last but not least, cooperatives play a key role in supporting local communities, providing access to resources, services and markets in peripheral and underdeveloped areas where the interest of traditional commercial enterprises is limited. It is these functions that define cooperatives as subjects of socially oriented entrepreneurship, whose sustainable development requires targeted state policy and institutional support.

A thorough knowledge of the economic profile of cooperatives should provoke adequate state interventions aimed at strengthening their economic power. Strategic investments and targeted policies are critical to ensuring the long-term viability of this specific socio-economic model in Bulgaria. In this context, state support is not just an alternative, but a condition for the survival of cooperatives. Urgent political will is needed to preserve, promote and develop the economic potential of cooperatives as an irreplaceable pillar of the social economy in the country.

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GROSS DOMESTIC PRODUCT GROWTH VERSUS FOOD INSECURITY IN AFRICA - INSIGHTS FROM NIGERIA AND DR CONGO

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Abstract

Food insecurity remains one of the most persistent challenges in Sub-Saharan Africa, despite the commitments made globally through the 2030 Agenda for Sustainable Development, in particular through SDG 2 - Zero Hunger. In this context, the study analyses the relationship between economic growth dynamics and the maintenance of high levels of food insecurity in Nigeria and the Democratic Republic of the Congo, two countries rich in natural resources but characterized by significant structural vulnerabilities in terms of access to food. The analysis integrates longitudinal data on GDP per capita for the period 1990–2024 with the Global Hunger Index (GHI) and its components for the reference years 2000, 2008, 2016, and 2025. Using a comparative-descriptive approach, economic developments and the four dimensions of food insecurity are examined in parallel: population undernutrition, child wasting, child stunting, and child mortality. The results highlight the existence of a partial decoupling between economic growth and hunger reduction. Although both countries have made significant economic progress since 2000, improvements in food security have been limited, uneven, and, in some cases, reversible. The findings highlight a partial decoupling between economic growth and hunger reduction and underline the need for stronger institutions and more resilient food systems to advance progress toward SDG 2: Zero Hunger.

Key words**:** *food insecurity, Global Hunger Index (GHI), Nigeria, DR Congo, SDG 2: Zero Hunger*

INTRODUCTION

Achieving Sustainable Development Goal 2 (SDG 2 – Zero Hunger) remains one of the most difficult global challenges, even though many developing regions have recorded significant economic growth in the last three decades (United Nations, 2015; FAO et al., 2023) [15, 2].

In this context, Sub-Saharan Africa continues to stand out for its high levels of food insecurity, and the most recent data suggest not only a slowdown in progress, but even a regression in some countries after 2016 (FAO, 2023; FAO, IFAD, UNICEF, WFP, WHO, 2023; World Food Programme, 2023) [2, 3, 21]. According to the Global Hunger Index 2025, the global hunger reduction trajectory has slowed significantly, and some countries have seen increases in undernutrition and other forms of child malnutrition (Global Hunger Index, 2025; Headey and Fan, 2010; HLPE, 2020) [4, 5, 6]. This context raises a fundamental question: to what extent is economic growth translating into measurable improvements in food security?

Gross Domestic Product per capita (GDP/capita) is frequently used as a synthetic indicator of average income level and standard of living (World Bank, 2024; Our World in Data, 2025; Ritchie, 2023) [19, 10, 12]. It represents the total value of final goods and services produced in an economy, per capita, expressed in constant international

dollars to adjust for the effects of inflation and differences in purchasing power between countries. By its nature, GDP per capita allows for the comparison of economic performance over time and space and is considered a relevant tool for the analysis of economic developments and living standards (Maxwell and Wiebe, 1999; Our World in Data, 2025) [9, 10]. Although, at a theoretical level, economic growth is associated with improving the standard of living of the population, the concrete way in which it influences access to food, income distribution or the organization of food systems remains difficult to capture and deeply unequal (Pinstrup-Andersen, 2009; Smith & Haddad, 2015) [11, 13]. The specialized literature constantly emphasizes the fact that economic development does not automatically translate into increased food security, and the manifestations of this relationship vary considerably depending on the national and regional context.

Structural factors such as armed conflicts, institutional fragility, the exposure of agricultural systems to climate shocks or unequal income distribution can decisively influence the extent to which the benefits of economic growth are felt at the population level. In this framework, the comparative analysis of Nigeria and the Democratic Republic of the Congo allows an empirical investigation of the relationship between economic dynamics and the evolution of food security in a context marked by persistent structural vulnerabilities.

At the same time, the Global Hunger Index (GHI) offers a multidimensional assessment of the phenomenon, based on four standardized indicators: population malnutrition, child wasting, child stunting and infant mortality. These indicators capture both caloric insufficiency and acute and chronic forms of malnutrition and their consequences on child survival (Global Hunger Index, 2025; Maxwell, 1996) [4, 8].

GHI is a composite indicator designed to measure the severity of hunger at national, regional, and global levels. It combines four dimensions of food deprivation: the prevalence of undernourishment in the population, child wasting, child stunting, and under-five mortality. The index is presented on a scale from 0 to 100, where higher values indicate more severe levels of hunger. GHI scores are calculated using multi-year averages of the underlying indicators to ensure comparability across countries and over time (Global Hunger Index, 2025) [4].

Nigeria and DR Congo are relevant case studies for investigating the relationship between economic growth and food insecurity. Both countries are rich in natural resources and have experienced periods of economic growth since 2000. Nigeria is one of the largest economies in Africa, while DR Congo has significant agricultural and mineral potential. However, both countries are classified, according to GHI 2025, in the "serious" or "alarming" categories in terms of hunger levels (Global Hunger Index, 2025) [4]. This apparent contradiction between macroeconomic performance and the persistence of food insecurity justifies the proposed comparative analysis.

While the relationship between economic growth and food security has been widely discussed in the literature, comparatively fewer studies examine the long-term dynamics between macroeconomic performance and multidimensional hunger indicators using standardized international metrics such as the GHI. Although the literature shows that economic growth does not automatically lead to improved food security, the concrete manifestation of this relationship differs considerably across countries and regions. In Sub-Saharan Africa, there is still a relatively limited number of comparative analyses that simultaneously examine the dynamics of economic growth and the evolution of multidimensional hunger indicators over the long term.

The central objective of this study is to examine the dynamics GDP per capita and the evolution of hunger indicators in Nigeria and DR Congo over the period 2000–2025. Without assuming a direct causal relationship, the analysis seeks to identify the extent to which increases in average economic output per person have been accompanied by sustainable reductions in multidimensional

food insecurity. By combining longitudinal data on GDP per capita (Our World in Data, 2025) [10] with the standardized scores of the GHI and their components (Global Hunger Index, 2025) [4], the study investigates the existence of patterns of convergence, divergence or decoupling between economic growth and food security.

Understanding this relationship is essential for assessing progress towards SDG 2 and for underpinning policies capable of addressing the complexity of the relationship between macroeconomic performance and nutritional outcomes.

MATERIALS AND METHODS

Data sources

The analysis uses two main sources of secondary data.

Food insecurity indicators were taken from GHI 2025 (Global Hunger Index, 2025) [4]. The Global Hunger Index (GHI) values are calculated based on a standardized methodology, which integrates four essential indicators: the prevalence of undernutrition among the population (expressed as a percentage), child wasting, child stunting, and under-five mortality. This methodological approach allows for international comparisons for the reference years 2000, 2008, 2016, and 2025, with each score calculated based on corresponding multi-year average intervals (Global Hunger Index, 2025) [4]. To avoid methodological bias, the analysis uses only these four standardized time points.

Data on economic performance were taken through the Our World in Data platform, from the World Bank database, (Our World in Data, 2025) [10]. The indicator used is GDP per capita, expressed in constant international dollars, adjusted for inflation and differences in purchasing power between countries. GDP per capita represents the total value of final goods and services produced in an economy in a year, reported to the population, being a synthetic indicator of average economic output per person.

Period analysed

For economic dynamics, the period analyzed is 1990–2024, representing the complete range available in the World Bank database for the two countries studied.

For the analysis of food insecurity, GHI scores for the reference years 2000, 2008, 2016, and 2025 were used, according to the official GHI methodology. These time points allow for the assessment of long-term evolution and the identification of possible structural breaks, especially in the post-2016 period.

Indicators

The analysis is based on the following indicators:

1. GDP per capita, expressed in constant international dollars.

2. Total GHI score, expressed on a numerical scale where higher values indicate a more severe level of hunger.

3. Population malnutrition (% of population).

4. Wasting in children under 5 (%).

5. Growth retardation in children under 5 (%).

6. Mortality of children under 5 (%).

GHI indicators allow for a multidimensional assessment of food insecurity, while GDP per capita provides a synthetic measure of average economic performance.

Analytical approach

The methodology used is descriptive-comparative and longitudinal.

The analysis included:

- comparing the evolution of GHI scores between 2000 and 2025;
- analysis of absolute and percentage changes for the intervals 2000–2016, 2016–2025 and 2000–2025;
- separate assessment of the evolution of each GHI component;
- analysis of GDP per capita dynamics in the period 1990–2024;
- calculating the percentage changes in GDP for the periods 2000–2016, 2016–2024, and 2000–2024.

To highlight the relationship between economic dynamics and the evolution of food insecurity, a comparative analysis of temporal trajectories was used, without assuming the existence of a direct causal relationship. The approach allows the identification of patterns of convergence, divergence or decoupling between economic growth and the level of

hunger. All percentage calculations were performed using the formula (Lovric, 2025) [7]:

$$\%\Delta = \frac{Value_{final} - Value_{initial}}{Value_{initial}} \times 100 \quad \ldots\ldots\ldots\ldots \quad (1).$$

The data has been processed and organized into tables and graphical representations to facilitate comparative analysis between DR Congo and Nigeria.

To facilitate the comparison of the evolution of economic and food insecurity indicators, GDP per capita and GHI score were also expressed in index form, using the year 2000 as the base year (2000 = 100). The values for subsequent years were calculated according to the formula (Lovric, 2025) [7]:

$$Index_t = \frac{Value_t}{Value_{2000}} \times 100 \quad \ldots\ldots\ldots \quad (2).$$

This transformation allows for comparison of the relative pace of change between indicators that are expressed in different units.

RESULTS AND DISCUSSIONS

Evolution of GDP per capita (1990–2024)

The dynamics of GDP per capita in Nigeria and DR Congo over the period 1990–2024 highlight distinct economic trajectories in terms of both the level and pace of growth (Table 1).

Table 1. GDP per capita in DR Congo and Nigeria (constant international dollars)

Country / Year	DR Congo	Nigeria	Country / Year	DR Congo	Nigeria
1990	2,403.97	5,423.81	2008	1,136.95	7,215.77
1991	2,129.45	5,301.36	2009	1,108.58	7,581.41
1992	1,842.55	5,403.15	2010	1,158.01	7,962.64
1993	1,538.40	5,154.76	2011	1,205.74	8,153.53
1994	1,410.06	4,929.27	2012	1,267.24	8,265.91
1995	1,362.19	4,797.51	2013	1,342.74	8,581.21
1996	1,322.58	4,869.82	2014	1,392.76	8,884.77
1997	1,228.39	4,884.05	2015	1,433.22	8,892.06
1998	1,176.05	4,880.88	2016	1,388.80	8,534.69
1999	1,088.65	4,781.67	2017	1,395.72	8,396.78
2000	981.42	4,889.00	2018	1,431.73	8,362.62
2001	930.86	5,039.55	2019	1,394.76	8,361.79
2002	929.45	5,654.90	2020	1,361.03	7,664.21
2003	953.04	5,905.32	2021	1,402.39	7,588.48
2004	987.75	6,275.30	2022	1,484.34	7,752.26
2005	1,016.63	6,496.93	2023	1,559.34	7,843.83
2006	1,036.13	6,702.95	2024	1,602.08	7,994.22
2007	1,091.00	6,949.43	2025	1,585.96*	8,105.93*

* Estimated values based on World Bank projections
Source: World Bank, 2025 [20].

In the case of Nigeria, GDP per capita was 5,423.81 constant international dollars in 1990, decreased to 4,889.00 in 2000 and subsequently increased steadily to a maximum of 8,892.06 in 2015. In 2016, the indicator recorded a value of 8,534.69, and in 2024 it reached 7,994.22. Thus, for the period 2000–2016, GDP per capita in Nigeria increased by 74.56%, while for the period 2016–2024 there was a decrease of 6.33%. Overall, for the period 2000–2024, the cumulative increase was 63.54%.

In DR Congo, GDP per capita was 2,403.97 in 1990, but declined sharply to 981.42 in 2000, reflecting the economic and political instability of the period. Since the 2000s, there has been a gradual increase, with GDP per capita reaching 1,433.22 in 2015, 1,388.80 in 2016, and 1,602.08 in 2024. For the period 2000–2016, the increase was 41.49%, and for 2016–2024, it was 15.36%. Overall, between 2000 and 2024, GDP per capita increased by 63.23%.

Comparatively, although the absolute level of GDP per capita in Nigeria remains significantly higher than in DR Congo, the long-term percentage dynamics (2000–2024) are relatively close in the two countries (63.54% in Nigeria versus 63.23% in DR Congo). The structural difference, however, lies in the base level: in 2024, Nigeria's GDP per capita (7,994.22) is approximately 4.99

times higher than that of DR Congo (1,602.08). The long-term evolution also highlights a change of pace after 2016. While DR Congo continued a moderate growth trend, Nigeria experienced a phase of stagnation and downward adjustment, without returning to the peak of 2015 (Figure 1).

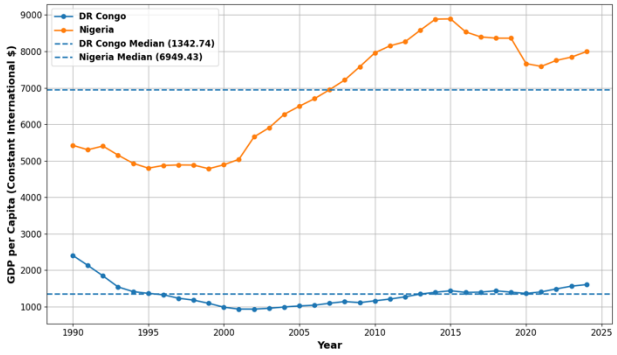

Fig. 1. Dynamics of GDP per capita in DR Congo and Nigeria (1990-2025) (constant international dollars)
Source: [20].

In addition, the analysis of the distribution of GDP per capita values for the period 1990–2024 highlights relevant differences between the two economies. In DR Congo, the median GDP per capita was 1,342.74 constant international dollars, a value close to the average of the period (1,328.40), which suggests a relatively balanced distribution of values around the central tendency. In Nigeria, the median was 6,949.43 constant international dollars, slightly above the average (6,753.60), indicating a distribution influenced by the lower levels recorded in the 1990s. The difference between the mean and the median thus reflects the particularities of the economic trajectories of the two states.

Evolution of the GHI (2000–2025)

Evolution of the total GHI score

The analysis of the evolution of GHI score for the reference years 2000, 2008, 2016 and 2025 highlights distinct, but at certain stages converging, dynamics for Nigeria and DR Congo (Table 2). In DR Congo, the GHI score was 46.10 in 2000, decreasing to 39.50 in 2008 and 36.40 in 2016. In 2025, the score increased slightly to 37.50. Thus, for the period 2000–2016, the absolute reduction was 9.70 points, corresponding to a percentage decrease of 21.05%. For the period 2016–2025, there was an absolute increase of 1.10 points, equivalent to an increase of 3.02%. Overall, between 2000 and 2025, the total reduction was 8.60 points, or 18.65%.

Table 2. GHI Scores in DR Congo and Nigeria (2000-2025)

Country \ Year	2000	2008	2016	2025
DR Congo	46.1	39.5	36.4	37.5
Nigeria	38.2	32.3	29.9	32.8

Source: [4].

In Nigeria, the GHI score was 38.20 in 2000, decreased to 32.30 in 2008 and 29.90 in 2016, and increased to 32.80 in 2025. Over the period 2000–2016, the absolute reduction was 8.30 points, corresponding to a percentage decrease of 21.73%. Over the period 2016–2025, the increase was 2.90 points, equivalent to 9.70%. Over the entire period 2000–2025, the cumulative reduction was 5.40 points, or 14.14%. Comparatively, both countries made significant progress in reducing the severity of hunger by 2016, followed by a partial reversal of the trend between 2016 and 2025. However, the intensity of the post-2016 regression is more pronounced in Nigeria (9.70%) than in DR Congo (3.02%).

Analysis of the distribution of GHI score for the period 2000–2025 highlights further differences between the two countries. In DR Congo, the median GHI score was 38.50, close to the period average (39.88), suggesting a relatively balanced distribution of values around the central tendency. In Nigeria, the median was 32.55, very close to the period average (33.30), indicating a comparably stable distribution across the four time points analyzed (Figure 2).

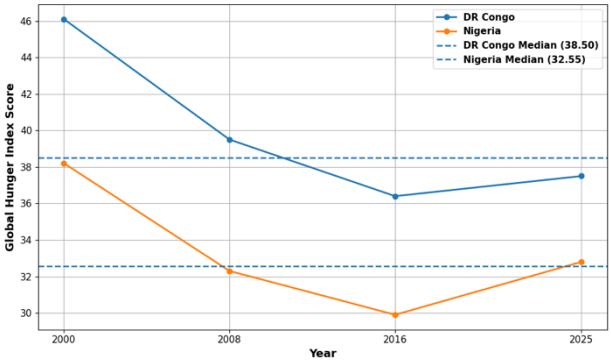

Fig. 2. Evolution of the GHI Score in Nigeria and DR Congo (2000–2025)
Source: [4].

The developments presented in Figure 2 show that although the absolute level of food insecurity remains higher in DR Congo, both countries show a similar temporal structure: improvement until 2016 and deterioration thereafter.

Analysis of the GHI components

To understand the dynamics of the total GHI score, it is necessary to analyze the evolution of the four components that underlie its calculation: population undernutrition, child wasting, child stunting, and under-five child mortality.

Table 3. GHI components in DR Congo and Nigeria

	Country	DR Congo	Nigeria
Undernourishment (% of population)	2000–2002	26.8	8.7
	2007–2009	27.7	9.6
	2015–2017	32.3	10.8
	2022–2024	38.5	19.9
Child wasting (% of children under five years old)	1998–2002	15.9	13.0
	2006–2010	10.4	9.8
	2014–2018	7.3	9.1
	2020–2024	7.2	11.6
Child stunting (% of children under five years old)	2000	46.0	41.8
	2008	44.5	39.3
	2016	42.5	35.4
	2024	44.1	33.8
Child mortality (% of children under five years old)	2000	15.9	18.2
	2008	12.2	14.1
	2016	9.2	12.5
	2023	7.3	10.5

Source: [4].

Population undernutrition (% of population)

In DR Congo, the prevalence of undernutrition increased from 26.80% in 2000 ('00–'02) to 27.70% in 2008 ('07–'09), then to 32.30% in 2016 ('15–'17) and to 38.50% in 2025 ('22–'24). This evolution corresponds to an increase of 43.66% between 2000 and 2025, suggesting a significant deterioration in the population's access to sufficient food. In the case of Nigeria, the level of undernutrition followed an upward trend, from 8.70% in 2000 to 9.60% in 2008, 10.80% in 2016 and 19.90% in 2025. Overall, the cumulative increase for the period analyzed reaches 128.74%, indicating a rapid increase in food vulnerability in recent years.

Child Wasting

In DR Congo, the child wasting rate has been steadily decreasing, from 15.90% in 1998–2002 to 10.40% in 2006–2010, continuing with 7.30% in 2014–2018 and 7.20% in 2020–2024. Overall, the reduction between 2000 and 2025 is 54.72%, indicating a significant improvement in acute malnutrition. In Nigeria, the evolution of the indicator has been less stable: it initially decreased from 13.00% to 9.80%, then to 9.10%, but increased again to 11.60% in 2020–2024. Although, compared to 2000, the level in 2025 is 10.77% lower, recent trends suggest a reversal of previous progress.

Child Stunting

In DR Congo, the prevalence of stunting in children recorded values of 46.00% in 2000, 44.50% in 2008, 42.50% in 2016, and 44.10% in 2024. Even though a slight decrease can be observed between 2000–2016, the level remains high in 2024, the total reduction compared to the reference year being only 4.13%. In Nigeria, the evolution of the indicator is more favourable, with a decrease from 41.80% in 2000 to 39.30% in 2008, 35.40% in 2016, and 33.80% in 2024.

Child mortality

In DR Congo, infant mortality decreased from 15.90% in 2000 to 12.20% in 2008, 9.20% in 2016, and 7.30% in 2023. The total reduction is 54.09%, indicating notable progress in public health. In Nigeria, the indicator evolved from 18.20% in 2000 to 14.10% in 2008, 12.50% in 2016 and 10.50% in 2023. The cumulative decrease between 2000 and 2023 is 42.31%. The analysis of the components highlights different dynamics of the indicators that make up the total GHI score. In both countries, child mortality has recorded significant long-term reductions, and in DR Congo a consistent decrease in wasting is observed. In contrast, the prevalence of undernutrition in the population has increased considerably over the period analyzed, especially after 2016. This divergent evolution of the components contributes to the understanding of changes in the total GHI score and prepares the framework for the analysis of the relationship between economic dynamics and food insecurity.

GDP vs. GHI – The Paradox

Comparing the evolution of gross domestic product per capita with the dynamics of GHI scores highlights the existence of an apparent paradox between economic growth and the evolution of food insecurity in the two countries analyzed. In Nigeria, GDP per

capita increased from 4,889.00 in 2000 to 7,994.22 in 2024, corresponding to a total increase of 63.54%. Similarly, in DR Congo, GDP per capita increased from 981.42 in 2000 to 1,602.08 in 2024, representing an increase of 63.23%. From a macroeconomic perspective, these developments indicate a significant increase in average economic output per person in both countries over the long term (Figure 3).

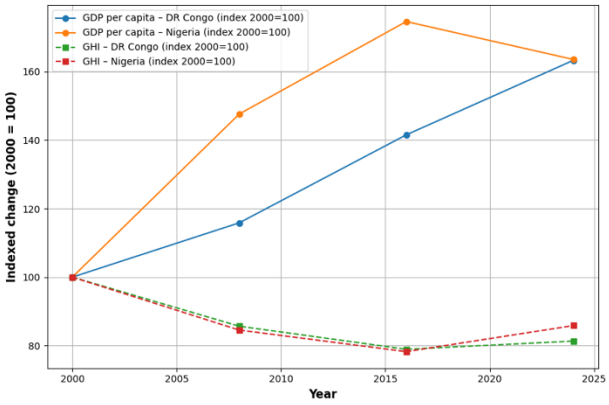

Fig. 3. Indexed evolution of GDP per capita and GHI in Nigeria and DR Congo (base year 2000 = 100). Values for subsequent years are expressed relative to the 2000 level.
Source: [4].

However, the dynamics of hunger indicators do not reflect a proportional reduction in food insecurity. In Nigeria, GHI score decreased from 38.20 in 2000 to 29.90 in 2016, suggesting an improvement in the nutritional situation in the early part of the period under review. Later, in 2025, the score increased again to 32.80, indicating a partial deterioration of previous progress. In DR Congo, the GHI score decreased from 46.10 in 2000 to 36.40 in 2016, but then increased to 37.50 in 2025. This divergent evolution suggests that the dynamics of economic growth are not automatically reflected in proportional improvements in food security. The Global Hunger Index 2025 report highlights that in both countries armed conflicts and political instability continue to affect food security by disrupting agricultural production, destroying rural infrastructure and limiting the population's access to food resources (World Food Programme, 2023; FAO, 2023) [21, 2].
Internal displacement caused by conflict and insecurity also contributes to increased food vulnerabilities. Displaced populations often lose their livelihoods and access to agricultural land, which increases dependence on food aid and reduces the ability of households to ensure their long-term food security (Swinnen and Squicciarini, 2012; World Food Programme, 2023) [14, 21].
Another important factor is climate shocks (United Nations Development Programme. 2022; Zhou et al., 2018) [16, 22]. Precipitation variability, drought episodes, and extreme weather events affect agricultural productivity and food availability. In economies where agriculture plays a major role in employment and food production, these shocks can amplify food insecurity even in the context of aggregate economic growth.
In addition, institutional fragility and limited capacity to implement public policies can reduce the efficiency of the mechanisms through which economic growth is transformed into improvements in the well-being of the population (von Braun & Torero, 2009) [17]. Unequal income distribution, limited access to rural infrastructure and food price volatility can prevent the benefits of economic growth from being transmitted to vulnerable households. Therefore, the comparative analysis of Nigeria and DR Congo suggests that the relationship between economic growth and food security is mediated by a complex set of structural factors. These structural constraints limit the translation of economic growth into consistent improvements in food security, even in the context of positive macroeconomic developments.

CONCLUSIONS

The results of the presented comparative analysis carried out in this study highlight the complex nature of the relationship between economic growth and food security in two of the most important economies in Sub-Saharan Africa, Nigeria and DR Congo.
Although both countries have recorded significant increases in gross domestic product per capita during the period under review, the evolution of GHI shows that these

economic advances have not been accompanied by proportional improvements in food security.

In Nigeria, GDP per capita increased considerably between 2000 and 2024, reflecting significant long-term economic expansion. However, the evolution of the GHI score indicates a fluctuating dynamics of hunger indicators, with a deterioration of the situation after 2016. In the DR Congo, although the absolute level of GDP per capita remains significantly lower than in Nigeria, the economic growth trend observed in recent decades has not been sufficient to generate a consistent reduction in food insecurity. In both cases, the results suggest the existence of a partial decoupling between macroeconomic dynamics and the evolution of multidimensional hunger indicators.

A detailed analysis of the components of GHI shows that developments are not uniform across the different dimensions of food insecurity. While indicators such as child mortality have shown significant improvements over the long term, other indicators, in particular the prevalence of undernutrition among the population, have evolved in a less favourable direction in recent years. This heterogeneity confirms the deeply multidimensional nature of food insecurity and underlines the need for integrated public policies capable of simultaneously addressing multiple dimensions of the phenomenon (Maxwell, 1996; Béné et al., 2020) [8, 1].

The results presented in the Global Hunger Index 2025 highlight that food insecurity in many regions of Sub-Saharan Africa is influenced by a complex set of structural factors, including armed conflict, political instability, internal population displacement, the vulnerability of agricultural systems to climate shocks, and food price volatility. In such contexts, aggregate economic growth does not automatically translate into improved access to food for the population, as the benefits of growth may be unevenly distributed or limited by institutional fragility and structural constraints of food systems.

These results take on particular importance in the context of the United Nations' Agenda 2030 for Sustainable Development, especially in relation to SDG 2 – Zero Hunger, which aims to end hunger, ensure food security and improve nutritional status by 2030. (United Nations, 2015; Welthungerhilfe, Concern Worldwide, & Institute for International Law of Peace and Armed Conflict, 2024) [15, 18].

The limited progress observed in some of the components of the GHI indicates that achieving this goal requires more than economic expansion. Sustainable reduction of food insecurity depends on strengthening institutions, developing resilient food systems, and implementing policies that reduce structural vulnerabilities that limit people's access to adequate food resources.

Therefore, the comparative analysis of Nigeria and DR Congo suggests that the relationship between economic growth and food security is mediated by structural and institutional factors that may limit the transformation of economic growth into real improvements in the well-being of the population. In this regard, the study results emphasize the need for integrated approaches to development policies that combine economic growth strategies with measures dedicated to strengthening food systems and reducing social and economic vulnerabilities.

Although the analysis provides relevant insight into the relationship between economic growth and food insecurity in Nigeria and DR Congo, the study also has some methodological limitations that need to be considered. First, the analysis relies on a limited number of reference points for GHI scores, which limits the possibility of using more sophisticated statistical methods to model the relationship between economic and food security indicators. Second, the analysis relies on aggregate macroeconomic indicators, such as GDP per capita, which do not directly capture income distribution or socio-economic inequalities at the country level. Future research could expand the analytical framework by integrating additional indicators, such as poverty levels, income distribution, access to agricultural infrastructure, or climate variables, to better understand the mechanisms through which economic growth influences food security.

Similarly, more extensive comparative analyses, conducted at a regional scale or across a larger sample of countries, could facilitate the identification of broader structural patterns in the relationship between economic development and food insecurity dynamics in Sub-Saharan Africa.

In this perspective, the results of the study indicate that progress towards achieving Sustainable Development Goal 2 – Zero Hunger, within the 2030 Agenda, cannot be explained exclusively by the dynamics of economic growth, but depends essentially on the capacity of societies to transform this growth into more equitable, resilient and accessible food systems for the entire population.

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DETERMINING INTERACTIONS BETWEEN LIVESTOCK SYSTEMS AND GREENHOUSE GAS EMISSIONS: THE CASE OF ROMANIA (2008–2024)

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Abstract

Understanding the relationship between livestock structure, forage areas and greenhouse gas (GHG) emissions is essential for designing effective interventions to reduce emissions in agriculture. We analysed an annual series (2008–2024) including cattle, pig, goat, sheep herds, green forage areas and emission inventories (CO_2, CH_4, N_2O, HFC). The aim of this study is to analyse the relationship between livestock farming, areas dedicated to fodder crops and greenhouse gas emissions in Romania, based on data provided by the National Institute of Statistics, using Pearson correlation analysis and principal component analysis to investigate the links between greenhouse gas emissions, livestock numbers and areas cultivated with fodder plants during the period 2008–2024.The results show a significant reduction in pig (-47.24%) and cattle (-23.87%), while goats increased by 58.75% and sheep by 8.07%. The areas intended for green fodder remained relatively stable, suggesting an adaptation of the crop structure to changes in animal husbandry. In terms of emissions, CH_4 decreased by 25.44%, reflecting the decrease in ruminant livestock, but CO_2 increased by 81.46% and N_2O by 3.77%, an increase associated with the intensification of mechanization and agricultural practices with high energy consumption. The analysis highlights the interdependence between livestock production, plant resources and environmental impact, underlining the need for integrated policies to reduce emissions and optimize agricultural systems.

Key words**:** *GHG emissions, livestock, feed, statistical analysis, trends 2008–2024, Romania*

INTRODUCTION

Agriculture is among the main economic activities responsible for generating greenhouse gas emissions, especially methane (CH_4) and nitrous oxide (N_2O), occupying the second position after the energy sector (Holden et al., 2014; Kabange, et al., 2023; Dumitras et al, 2025) [6, 9, 4]. At the same time, this field has a dual function, being recognized both as a source of emissions and as a potential mechanism for capturing and storing these gases (Rawnsley et al., 2018) [19]. Although the role of agriculture in total global emissions has been analysed in depth in the specialized literature, its implications for the sustainability and resilience of agri-food systems have been treated marginally for a long time, until the aggravation of the climate crisis forced a reconsideration of this perspective (Del Prado et al., 2013; Micu et al, 2022) [2, 13]. The main manifestations of climate change are reflected in a pronounced and persistent trend of global temperature increase, accompanied by a higher frequency of abiotic and biotic stress episodes (Jose at al., 2016) [8]. These climatic disruptions contribute to exacerbating economic difficulties, intensify social disparities and the vulnerabilities of exposed communities, and lead to a significant worsening of food insecurity (Rusali, 2018; Andrea, 2024) [20, 1].

Greenhouse gases (GHGs) have multiple origins, deriving from both biological and natural processes generated by the activity of specific microorganisms in the soil or by spontaneous chemical reactions and from anthropogenic activities. Human emissions are dominated by the energy sector, which accounts for approximately 73.2% of the total, followed by industry (5.2%) and waste management (3.2%). The difference is attributed to the agricultural sector, which

includes crop production, soil dynamics used for agriculture and animal husbandry, as well as activities related to the use and management of land and forests (Kamyab, et al., 2024) [10].

Within the agricultural sector, methane (CH_4) from ruminant enteric fermentation and emissions from animal manure management practices are two of the main sources of greenhouse gases. Enteric fermentation, a physiological process inherent to the digestion of ruminant species, produces significant quantities of CH_4, a gas with a global warming potential much higher than that of carbon dioxide (CO_2), especially in the short term (You et al., 2022; Hu et al., 2023) [24, 7]. Similarly, activities related to the handling, storage and application of manure on agricultural land generate considerable emissions of both CH_4 and nitrous oxide (N_2O) (Gaudaré, et al., 2021) [5].

The majority of N_2O emissions from agriculture are due to land interventions, in particular the application of synthetic nitrogen fertilizers and the inadequate management of nutrient flows (Omirou, et al., 2022) [17].

N_2O is recognized as a very potent greenhouse gas with long atmospheric persistence and significant climate consequences. Energy consumption in the agricultural sector is a major contributor to carbon dioxide (CO_2) emissions. Modern agriculture increasingly relies on energy-intensive technologies, such as mechanized machinery, advanced irrigation systems, and the logistics infrastructure needed to transport raw materials and finished products. These equipment are predominantly powered by fossil fuels, contributing significantly to the sector's energy needs (Mehryar et al., 2021) [12]. As a result, the combustion of fossil fuels in agricultural activities — from the operation of tractors and combines to the internal and external transport of products — generates significant volumes of CO_2, amplifying the carbon footprint of modern agriculture (Moldan et al., 2012) [14].

In addition, carbon dioxide associated with agricultural activities comes mainly from land-use changes such as deforestation to expand cultivated areas and from the energy consumption associated with mechanized agricultural operations, including tillage, irrigation, and the transport of raw materials and agricultural products (Nugrahaeningtyas et al, 2024) [16].

Animal manure management practices in agricultural systems are a major source of methane (CH_4) emissions. Due to their high organic matter content, manure creates favourable conditions for the formation of CH_4 when stored or treated in anaerobic environments (Tedeschi et al., 2024)[21]. Microbiological processes that occur in the absence of oxygen cause the anaerobic degradation of organic components, which leads to the generation of significant amounts of methane (Petri et al., 2021) [18].

Many factors determine the level of greenhouse gas emissions generated in cattle production, including the composition of the feed ration, feeding methods, genetic characteristics of the animals and management strategies adopted at the farm level (Xie et al., 2023) [23]. Methane (CH_4) production in ruminants is strongly dependent on the nature and nutritional quality of the feed ingested, as the dietary profile influences the fermentative processes in the rumen (Zanon, et al., 2025) [25]. Equally, animal management systems — including manure handling, optimizing welfare conditions and the organization of housing spaces — represent additional elements with significant potential to reduce emission flows (Lileikis et al., 2023) [11].

These interventions can contribute substantially to reducing CH_4 emitted by ruminants by shaping physiological processes and limiting conditions that increase the generation of greenhouse gases. Gaining a deeper understanding of the complex mechanisms that govern emissions from livestock is an essential prerequisite for formulating rigorous strategies that can optimize the efficiency of livestock production and, simultaneously, reduce its carbon footprint (Warsame et al., 2023) [22].

By differentiating emission sources between ruminant and non-ruminant species and integrating the variables that influence these emissions, it becomes possible to implement more sustainable and resilient livestock

production systems with a reduced climate impact (Doyle, et al., 2019) [3].

This paper aims to study in depth the interdependence relationship between the livestock sector and greenhouse gas emissions in Romania, over the period 2008–2024. The analysis is based on official datasets made available by the National Institute of Statistics [15], which provide consistent information on the size of livestock herds, the structure of livestock production and the evolution of emissions associated with agricultural processes. By simultaneously examining the dynamics of livestock activities and their contribution to the generation of methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions, the research aims to highlight the mechanisms through which transformations in the livestock sector influence the climate footprint of national agriculture.

Within this analytical framework, the study is not limited to identifying quantitative trends, but aims to observe the structural and functional processes that shape the relationship between the development of livestock farming and the phenomenon of climate change. In this way, the research provides a comprehensive understanding of how developments in the livestock sector contribute to the dynamics of GHG emissions, facilitating the formulation of strategic directions aimed at reducing the climate impact and promoting sustainability in agriculture.

MATERIALS AND METHODS

The annual collection of data on livestock herds is an essential element for monitoring developments and analysing the structure of the livestock sector in Romania.

The National Institute of Statistics (INS) is responsible for producing these official data, which are used both in national assessments and in reports submitted to European institutions.

The collection process is carried out in accordance with international statistical standards and is harmonized with the Eurostat methodology and the reporting requirements established by the European Commission, thus ensuring the comparability and credibility of the data.

To obtain the necessary information, the INS carries out annual statistical surveys addressed to all categories of agricultural holdings, using standardized questionnaires, digital reporting tools and direct field collection by specially trained enumerators. These surveys systematically monitor the number of animals by species and category, the distribution of livestock, changes compared to the previous year and a series of relevant indicators regarding production capacity.

In the case of small-scale farms, data are obtained by applying stratified sampling methods, which allow for an adequate representation of the regional and structural diversity of farms. Based on this information, the INS uses weighting and extrapolation procedures to generate robust estimates at county and national level, ensuring the accuracy and stability of the statistical series over time.

Livestock numbers are one of the main variables used in national emission inventories, and the annual periodicity of data collection allows for an accurate assessment of the contribution of the livestock sector to methane (CH_4), nitrous oxide (N_2O), carbon dioxide (CO_2), as well as hydrofluorocarbons (HFCs) emitted indirectly through the use of refrigeration and cooling systems associated with animal production. The inclusion of HFC-related data is essential, as these compounds possess a high global warming potential and are increasingly relevant in modern livestock management systems that rely on technologically advanced cooling infrastructure. Thus, statistical information becomes indispensable for monitoring Romania's climate commitments and for developing effective strategies to reduce the overall carbon footprint of the agricultural sector.

To ensure quality, the INS applies rigorous verification and validation procedures, which include comparing current data with historical series, identifying and correcting any statistical anomalies, and performing additional checks when significant deviations

are detected. At the same time, data on livestock are correlated with other agricultural statistics, such as livestock production or land use, to strengthen the internal coherence of the information.

RESULTS AND DISCUSSIONS

The evolution of livestock populations in Romania between 2008 and 2024 indicates major structural changes in the livestock sector, with both economic and ecological implications. The data show a profound transformation in the distribution of livestock populations among the main species, a transition influenced by factors such as economic competitiveness, adaptability to pedoclimatic conditions, epidemiological pressures and agricultural policy orientations. In the case of cattle, the trend is one of constant decline throughout the period. The population decreases from approximately 2.68 million heads in 2008 to around 1.8 million in 2024, indicating a reduction of almost a third of the population. This decrease suggests persistent structural difficulties in the cattle sector, associated with high production costs, the volatility of the milk market and the increasing orientation towards intensive production systems, characterized by fewer, but larger and more technologically advanced farms. Ecologically, the decline of cattle has direct implications for methane emissions, as this species is the main source of enteric CH_4 in livestock farming.

Pig populations are also showing a sharp downward trend, from over 6.1 million in 2008 to around 3.2–3.3 million after 2020. The steep decline reflects the severe impact of African swine fever on commercial farms and households, as well as the pressure of imports on the competitiveness of the pig sector. This substantial decline partly explains the negative relationship observed between total CO_2 emissions and the number of pigs: while livestock populations are declining, CO_2 emissions continue to increase, indicating that these emissions are driven more by energy processes, transport and related activities of agriculture than by livestock farming itself.

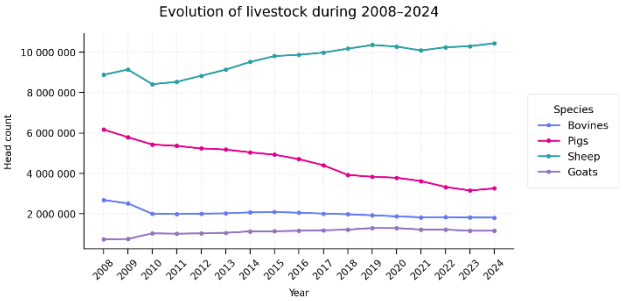

Fig. 1. The evolution of livestock during 2008-2024
Source: Own design based on the data from NIS, 2026 [15].

In contrast to the previously mentioned species, sheep are experiencing a predominantly upward trend. While in 2008 there were approximately 8.8 million heads, in 2024 the population will exceed 10.4 million, confirming a stable and sustained growth. This trend can be associated with the high resilience of sheep to variable climatic conditions, low maintenance costs, as well as the increased demand on external markets for meat, milk and derived products. The increase in livestock contributes to the level of CH_4 and N_2O emissions, but in a more moderate manner than in the case of cattle, due to the physiological characteristics and the extensive systems in which sheep are raised.

Goat herds follow a more moderate but constant upward trajectory, increasing from approximately 740,000 heads in 2008 to over 1.16 million in 2024. This evolution reflects the excellent adaptability of goats to diverse environmental conditions and the growing interest in dairy products obtained from goat milk. The goat sector thus remains one of the most dynamic segments of Romanian livestock.

(Fig. 1).

The analysis of the evolution of the areas cultivated with the main categories of forage plants in Romania during the period 2008–2024 highlights structural changes relevant for the dynamics of the livestock sector and for the functioning of agri-food systems. The dynamics of these crops are essential for understanding the availability of fodder resources, which influences both the productive performance of farms and the emission flows associated with soil and manure management. During the analysed period, the total area cultivated with green

fodder from arable land remains relatively stable, oscillating between approximately 828,000 and 907,000 hectares, with a slight upward trend around 2018, followed by a moderate recovery after 2020. This stability suggests a structural dependence of farms on these crops, which are mainly used in the feed of herbivorous livestock, especially ruminants. The moderate fluctuations probably reflect the adaptation of agricultural practices to annual climatic conditions, as well as to variations in feed demand depending on the dynamics of livestock populations.

In the case of alfalfa, the data indicate a progressive increase in areas between 2008 and 2018, followed by a maintenance at high values after this interval. Alfalfa, being one of the most important perennial legume plants used in fodder systems, contributes to improving soil fertility by biologically fixing nitrogen. The expansion of this crop can thus be associated both with the high need for crude protein in fodder and with the interest of farmers in more sustainable agronomic practices that reduce dependence on chemical fertilizers.

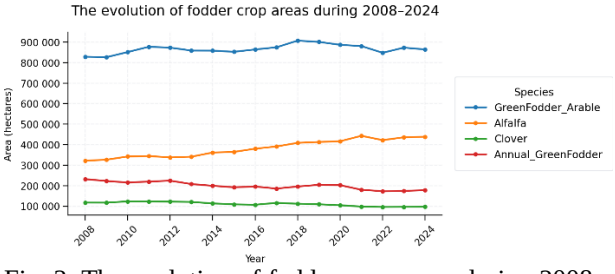

Fig. 2. The evolution of fodder crop areas during 2008-2024

Source: Own design based on the data from NIS, 2026 [15].

The areas cultivated with clover indicate a sinusoidal evolution, with periods of moderate growth followed by decreases, remaining in the range of 95,000–123,000 hectares. This variability may reflect the sensitivity of clover to interannual climatic conditions and to the type of farms that use it, being a preferred crop in small and medium-sized households, where soil rotation and labour availability play a decisive role.

Regarding annual green fodder, the evolution of the areas is similar, with a relatively high stability and a slight downward trend after 2020. The decrease after 2020 could indicate changes in the crop structure, determined either by adaptation to drought and water stress, or by the reduction of livestock in certain sectors, which implicitly decreases the demand for certain types of annual fodder (Fig. 2).

The analysis of the evolution of the main greenhouse gases (GHG) generated by the Romanian agricultural sector between 2008 and 2024 highlights distinct trends for each pollutant, reflecting structural changes in agriculture, livestock numbers, soil management practices and the energy intensity of production. The data show divergent evolutions between CO_2, CH_4, N_2O and HFCs, suggesting that these pollutants are influenced by different mechanisms of the agri-food system. Figure 3 presents the evolution of GHGs during 2008-2024, where CO_2 is on the right axis and CH_4, N_2O and HFC are on the left axis.

Of all the gases analysed, CO_2 shows the most pronounced upward trend, increasing from approximately 985,000 Mg in 2008 to over 1.8 million Mg after 2020, remaining at high levels until 2024.

This sustained growth is characteristic of an agricultural sector increasingly dependent on energy consumption for processes such as the mechanization of operations, the transport of raw materials and the use of equipment in storage and processing chains. Unlike CH_4 and N_2O, which are mainly influenced by the biological activity of animals and nutrient management, CO_2 rather reflects the intensification of fossil fuel consumption, thus reinforcing the idea that a significant part of the climate pressure associated with agriculture comes from indirect activities, but essential for the functioning of the sector. Methane (CH_4), on the other hand, shows a slightly decreasing trend in the long term. While in 2008 the values were around 438,000 Mg, after 2010 the levels stabilised at around 350,000–360,000 Mg annually, with minor fluctuations between years. This gradual reduction can be explained by the decrease in cattle and pig herds, confirmed by parallel analyses of animal herds, as well as

by better efficiencies in manure management. Given that ruminants are the main source of enteric methane, their numerical decline directly contributes to the moderation of CH_4 emissions. The very strong correlations previously calculated between CH_4 and cattle herds support this interpretation.

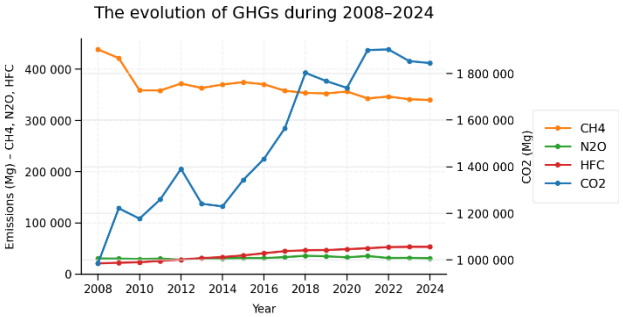

Fig. 3. The evolution of GHGs during 2008-2024
Source: Own design based on the data from NIS, 2026 [15].

Regarding nitrous oxide (N_2O), the evolution shows a moderate increase, from approximately 30,000 Mg to values between 31,000 and 35,000 Mg in subsequent years. This trend can be associated with the dynamics of forage areas, soil management and nitrogen fertilizer application. N_2O is closely linked to soil microbial processes, and its variations most likely reflect changes in agronomic practices, fertilization intensity and the evolution of forage areas. The moderate positive correlations ($r \approx 0.72$) between N_2O and total forage area, observed in previous statistical analyses, support the hypothesis that soil–nutrient factors are the main determinants of this pollutant.

Hydrofluorocarbon (HFC) emissions, although lower in absolute terms than other GHGs, are steadily and rapidly increasing, reflecting the accelerated adoption of refrigeration and cooling equipment in farms, slaughterhouses and food distribution chains. This increase, from approximately 20,000 Mg in 2008 to over 53,000 Mg in 2024, indicates the expansion of refrigeration infrastructure, an aspect associated with the modernization of the sector, but also with a high climate footprint due to the very high global warming potential of these compounds (Fig.3). The Pearson correlation analysis presented in Figure 4 on the relationships between greenhouse gas emissions (CO_2, CH_4, N_2O, HFC), livestock numbers and forage crop areas over the period 2008–2024 highlights a complex structure of interdependencies that reflect both biological and agronomic processes, as well as the socio-economic dynamics of the agro-zootechnical sector. The figure shows a set of well-defined positive and negative correlations, which allow understanding the dominant mechanisms associated with the generation of emissions and the use of agricultural resources.

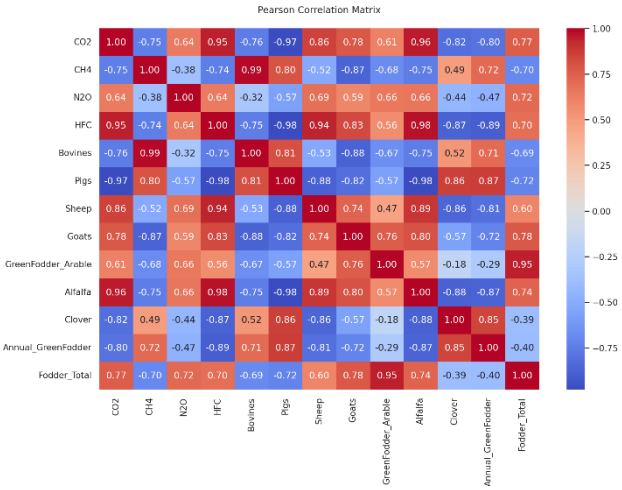

Fig. 4. The Pearson correlation matrix
Source: Own calculations.

A first notable result is the very high correlation between methane emissions (CH_4) and cattle numbers ($r \approx 0.99$), the strongest association in the entire data set. This almost perfectly linear relationship confirms that large ruminants are the main source of enteric methane, and variations in their numbers are directly transmitted to annual CH_4 levels. A similarly high correlation between CH_4 and sheep ($r \approx 0.98$) suggests a cumulative contribution from small ruminants, although the individual impact per animal remains lower than for cattle. This pattern confirms the literature that attributes over 90% of agricultural methane to ruminants and highlights the sensitivity of emissions to livestock population dynamics.

In contrast to methane, CO_2 shows a distinct evolution, being negatively correlated with cattle ($r = –0.76$) and pig ($r = –0.97$) herds. This inverse relationship indicates that the reduction in herds of these species,

documented in national data, is not reflected in a decrease in CO_2 emissions. On the contrary, CO_2 increases in parallel with the intensification of energy processes in agriculture — mechanization, transport, use of refrigeration systems — a fact supported by the extremely strong correlation between CO_2 and HFCs (r = 0.95). This association suggests that the modernization of the food sector and the increase in the use of refrigeration equipment have amplified the contribution of emissions with high global warming potential, which indicates profound changes in post-harvest infrastructure and cold chains. Nitrous oxide (N_2O) shows an intermediate profile, with moderate correlations with both animal species and forage areas. Positive values with sheep ($r \approx 0.64$) and pigs ($r \approx 0.57$) and negative values with goats ($r \approx -0.38$) suggest a certain indirect contribution of livestock to total N_2O emissions, but the highest correlation value is observed between N_2O and total forage area ($r \approx 0.72$). This association confirms the dominant role of soil microbial processes responsible for nitrification and denitrification, influenced by nutrient management and forage crop-specific practices. At the same time, moderate correlations with alfalfa and green forage suggest that perennial and annual forage systems contribute differentially to soil nitrogen fluxes, depending on fertilization intensity and biomass dynamics. The correlation matrix also highlights relevant relationships between animal species and forage crops. Sheep, for example, show strong positive correlations with alfalfa (0.74) and arable green fodder (0.74), indicating the traditional co-evolution of extensive-pastoral systems with the national forage structure. In contrast, goats, although increasing in numbers, show lower values in relation to forage crops, which suggests a lower dependence on intensively cultivated forages and confirms their adaptability to natural pastures or spontaneous vegetation. Pigs also show high correlations with forage areas, but these values are influenced by the general dynamics of agricultural areas, as their type of forage is predominantly based on cereals and concentrated fodder, not on perennial forage crops.

Analysing these relationships as a whole, the Figure 4 highlights three major climate mechanisms in the Romanian agricultural sector: (1) methane is almost entirely controlled by ruminants, especially cattle; (2) nitrous oxide is mainly determined by soil processes influenced by the area and type of forage crops; (3) carbon dioxide and HFCs are associated with energy intensification and modernization of agricultural infrastructure, not with livestock farming. This diversity of drivers shows that GHG emissions from agriculture do not respond uniformly to the same factors and that mitigation policies need to be tailored to each pollutant category: reducing CH_4 requires ruminant management, reducing N_2O requires soil and fertilization interventions, and reducing CO_2 and HFCs requires investments in energy efficiency and cleaner technologies.

Principal component analysis (PCA) was applied to a set of standardized variables (z scores) covering greenhouse gas emissions (CO_2, CH_4, N_2O, HFC), livestock (Bovines, Pigs, Sheep, Goats) and forage indicators (GreenFodder_Arable, Alfalfa, Clover, Annual_GreenFodder, Fodder_Total), for the years 2008–2024. Standardization and PCA calculation were performed with classical procedures (centered and scaled scores, decomposition on the covariance matrix of standardized data).

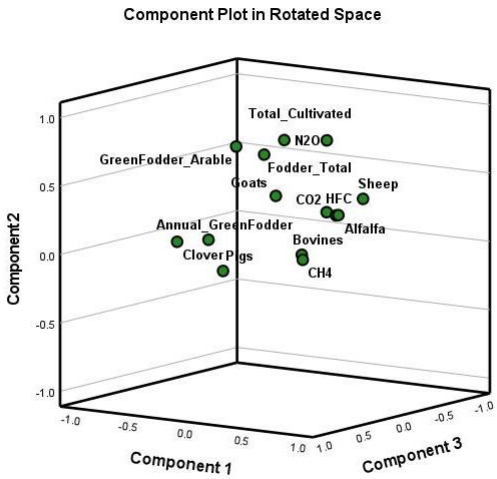

Fig. 5. The principal component analysis boxplot
Source: Own design.

The three-dimensional Figure 5 (scores + loading vectors) synthesizes the relationship between the three components: PC1 consistently separates the energy dimension (CO_2/HFC) from the zootechnical one, PC2 aggregates the feed/soil variables, and PC3 places N_2O and CH_4 in the proximity of ruminants, highlighting their biological character. The variant with only loading vectors (without scores) encapsulates the same message in a clean map of the dominant directions: the arrows for energy GHGs are distinct from the arrows for feed and ruminant variables, and N_2O/CH_4/Bovines jointly define the "biological" axis.

The figure "Component Plot in Rotated Space" highlights the organization of variables into three major agricultural subsystems, the structure of which results from the rotation of the principal components. The first grouping is represented by the agronomic subsystem, predominantly associated with Component 2, where variables describing forage crops and cultivated areas present high loadings and convergent orientations. This structuring reflects the fact that agronomic processes, such as crop productivity and land management, constitute a distinct explanatory factor in the multivariate architecture of the agricultural system.

The second group is the livestock–emissions subsystem, located mainly on the combined directions of Components 1 and 3. Variables such as CH_4, CO_2, HFC, as well as the number of Bovines and Sheep, along with the perennial crop Alfalfa, align in this area. Their configuration indicates a clear association between livestock production — especially ruminant production — and biological and energy flows of greenhouse gases, confirming the fundamental role of this subsystem in determining the agricultural climate footprint.

Between the two extremes lies the intermediate subsystem, formed by variables such as Goats, N_2O and Fodder_Total. This group occupies a central area in the rotated space, suggesting a role as connecting points between soil and forage crop dynamics, on the one hand, and livestock activity, on the other. Their intermediate location reflects the mixed nature of these processes: Goats is a flexible species in relation to plant resources, N_2O is produced by both biological and agronomic processes, and Fodder_Total synthesizes the interaction between feed availability and herd structure.

This triad – agronomic, zootechnical–emissions and intermediary – reveals a coherent architecture of the agro-ecological system, in which climatic, biological and agronomic processes are deeply interconnected, but at the same time structurally differentiated by their orientation in the space of the main components.

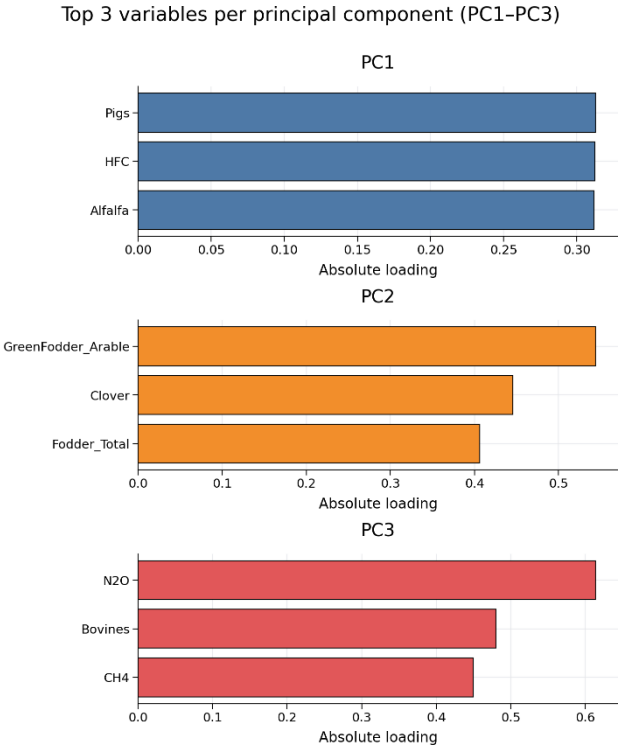

Fig. 6. Top 3 variables per principal component (PC1–PC3)
Source: Own design.

The Figure 6 highlights the latent structure of the analysed agroecosystem system, synthesized by the first three principal components resulting from the PCA analysis applied to the set of zootechnical, agronomic and emission variables. Each component retains a coherent subsystem from a functional and statistical point of view, indicating the existence of distinct but interdependent agricultural processes. The first principal component (PC1) captures a zootechnical–energetic subsystem, in which variables such

as Pigs, HFC and Alfalfa present the highest absolute loadings. Their configuration suggests that PC1 reflects a structural gradient associated with intensive zootechnical systems, characterized by high pig herds, significant energy consumption (marked by the presence of HFC as an indicator associated with refrigeration and air conditioning infrastructure) and the use of perennial crops such as alfalfa, which are essential in the rations of high-productivity farms. This component thus describes an integrated dimension of industrial animal production and its dependence on specific energy and feed resources. The second component (PC2) clearly highlights an agronomic subsystem, dominated by variables such as GreenFodder_Arable, Clover and Fodder_Total. These loadings reflect an essential factor of plant production, related to soil management, forage crop rotations, cropland structure and the availability of fodder for animal feed. PC2 can be interpreted as the agronomic dimension of the system, in which fodder production and soil quality are primary elements that indirectly influence livestock performance and the level of associated emissions. The third component (PC3) configures a bio-emissions subsystem, in which the variables N_2O, Bovines and CH_4 present the highest loadings. The simultaneous presence of biological emissions (CH_4 from enteric fermentation, respectively N_2O generated by soil microbiological processes) alongside cattle herds indicates an ecological mode in which greenhouse gas fluxes are closely correlated with ruminant metabolism and the soil nitrogen cycle. PC3 thus captures the core of biogeochemical processes in agriculture, combining the influence of ruminants with the dynamics of fertilized soil, which reinforces the integrated nature of CH_4 and N_2O emissions within the system. Overall, the figure reveals a tripartite architecture of the agricultural system: a livestock-energy subsystem, an agronomic subsystem based on forage production, and a bio-ecological emissions subsystem. The relationships identified show that these processes do not act in isolation, but are part of a complex system in which livestock structure, soil management, and energy consumption together shape environmental pressure and agricultural performance. This interpretation confirms the importance of integrated approaches in assessing agricultural sustainability, highlighting the need for differentiated policies to reduce CH_4, N_2O, and CO_2, specifically adapted to each identified subsystem.

CONCLUSIONS

Taken together, this study confirm that the structure of forage crops has remained largely stable in the long term, but with occasional adjustments related to climatic, technological and economic factors. This stability is essential for the functioning of livestock systems, as continuity in forage production is a critical element for maintaining farm performance, especially in regions dependent on their own feed production.

On the ecological dimension, the dynamics of forage crops have direct implications for greenhouse gas emissions, in particular nitrous oxide (N_2O). The expansion of legumes (alfalfa, clover) can contribute to reducing the use of synthetic fertilizers, thus reducing associated emissions. Conversely, the decrease in the area of these crops in certain years can lead to increased pressure on the soil, if they are replaced by crops that require intensive fertilization. The correlation identified between N_2O and total forage area observed in previous statistical analyses underlines the active role of soil management in shaping emission fluxes. In conclusion, the evolution of forage areas during the period 2008–2024 reflects a continuous adaptation of agricultural systems to climatic and economic challenges, while maintaining a stable functional structure, adequate to livestock needs. This balanced dynamic between stability and gradual adjustment is essential for the resilience of the agro-zootechnical sector and constitutes a fundamental element in the evaluation of national strategies regarding agricultural sustainability and GHG emissions reduction. The comparative analysis of the evolution of GHGs highlights the fact that their dynamics are not uniform,

but determined by different mechanisms. While CO_2 is increasing exponentially due to the energy intensification of agriculture, CH_4 is decreasing as a result of the reduction of ruminant livestock, and N_2O remains moderately dependent on agricultural soil management practices. HFCs show an accelerated growth, reflecting the modernization of agri-food chains and the technological advancement of post-harvest infrastructure. This diversity of trajectories indicates the need for differentiated emission reduction policies by category of pollutants, as they react differently to agricultural management measures. Overall, the data suggest that the period 2008–2024 was characterized by an energy intensification of the agricultural sector and a reduction in the biological components that generated methane, but also by a gradual increase in flows associated with soil fertilization. This complex evolution confirms that reducing the climate footprint of agriculture requires integrated interventions, targeting both energy efficiency and the management of livestock, soils and technologies in the food supply chain. The perspectives on changes in production practices, technological developments, the adaptation of livestock management strategies, as well as the impact of agricultural and environmental policies implemented in Romania during the analysed period are integrated.

ACKNOWLEDGEMENTS

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ASSESSMENT OF EFFECTS OF FUEL SUBSIDY REMOVAL ON TECHNICAL EFFICIENCY OF STAPLE CROP PRODUCTION IN GOMBE STATE, NIGERIA

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Abstract

This study assesses the influence of fuel subsidy removal on technical efficiency (TE) of Staple Crop Production in Gombe State. Multistage, purposive and simple random sampling techniques was used to select 360 farmers, data were collected with the aid of structured questionnaires. The results revealed that majority of the respondents were male (66.94%), adults with a mean age of 60 years, married (81.67%), household size of 10 persons and above (54.44%) and good literacy level of (89.73%). Source of financing is personal savings, the SF analysis showed that coefficients of farm size (0.2734) was significant at 1%, fertilizers and quantity of seeds were both significant but at 5%, while family size, hired labour and agrochemical were all significant at 10%. This suggests that a slight increase in fuel price significantly affect staple crop production, evident from their mean TE of 56%. Gamma was 0.85.Constraints such as, high cost of petrol, high cost of transportation, labour, fertilizer, quality seeds, were the highest. Government should refine crude oil locally, tax exemption on inputs, establish mega stores, revive extension services.

Key words: *effects, subsidy removal, technical efficiency, staple crop, production*

INTRODUCTION

On May 29, 2023, in Nigeria it was officially announced the removal of the decade-long subsidy on petroleum products. The reason was the budget deficit and the need to channel the funds towards public infrastructure and improving the lives of the Nigerian people. The fuel subsidy removal led to the inflation increase which has affected the population.

Removal of fuel subsidy, there was a very dramatic rise in prices of premium motor spirit (petrol) from less than ₦200 per litre to ₦550/litre, which in turn triggers an astronomical rise in the price of goods and services including those of agricultural inputs [3]. Furthermore, the prices of petrol kept increasing by the day to the extent that prices of food as well as prices of agricultural inputs such as quality seeds, fertilizers, pesticides, herbicides as well as cost of labour and transportation skyrocketed beyond the reach of an average farmer [1].

Total removal of the fuel subsidy ignited poverty and food insecurity in Nigeria [7]. It has to evolve strategies of how to mitigate the effects of fuel subsidy removal such as investing in agricultural investment and subsidize transportation to cushion the impact on food security. Furthermore, incorporating safety nets like providing free healthcare services for low-income earners and free or subsidized education is essential to bridge the wide income inequality in the country [6].

Staple crop is simply defined as food which dominates substantial portion of our and for provision our energy and nutrient needs. This suggest that when such crops are subjected to drought, poor-nutrient soils, pests and diseases, hunger and poverty are imminent at an alarming proportion. Staple crops are commodities traded all over the world. Therefore once they are threatened by difficult

growing conditions limit their output, consequently their effects are felt globally.

Recently, the government has been contemplating whether or not to remove fuel subsidies, a decision that has far-reaching implications for the poor citizens. Although removing fuel subsidy may be necessary to stabilize the economy, concerns about what impact will it have on the average citizens, agriculture, especially those already burdened by the challenges of daily living [8]. Traditionally, fuel subsidies were believed to have a dual impact in Nigeria. While it is meant to alleviate financial burden on the government and trigger economic growth, its removal has generated a domino effect on the cost of living. One of the most immediate and visible consequences is the surge in fuel prices, directly impacting transportation costs and subsequently affecting the prices of staple crops, goods and services [8]. Conversely, removing the subsidies has resulted to inflationary pressures, rendering the overall economic landscape a serious for the average citizen. Inflation eroded value of consumers spendings making it harder for individuals and families to take care of their basic needs.

This situation becomes deepening resource poor farmers, hence amplifying existing socioeconomic disparities [8]. When harvests are poor or when crops are channelled to fuel production, rather than food or fodder, then prices escalate, farmers face financial ruin, food becomes unaffordable to the poor, national revenues are diverted to food imports, adding to national and individual vulnerability. Typically, people depend on a diet from on one or more of the following staples: wheat, rice, sorghum, corn, maize, millet, roots and tubers (like potatoes, cassava and yams), and animal products such as eggs, cheese, meat, milk and fish. Almost half of humanity depend on rice. Roots and tubers are important staples for over one billion people in underdeveloped nations, of which, nearly 40% are consumed by half the population of sub-Saharan Africa [5].

Subsidies are important policy instrument adopted by governments to attain economic, social and environmental objectives. For example, energy resources are one of the areas that have witnessed active intervention of governments all over the world, especially in developing countries through comprehensive subsidization of energy consumption [11].

Nigeria, the country with highest populous in Africa, had a per capita gross domestic product of US$1,437, in 2010, slightly greater than US$ 1,311 found in Sub-Saharan Africa. However, 68 percent of the Nigerians depend on less than US$1.25 per day as compared Sub-Saharan Africa with to 48 percent. Poverty and inequality the order of the day in Nigeria (World Bank, 2013) [17].

Over the last four decades, petroleum has also become Nigeria's top export commodity. The share of petroleum in Nigerian exports peaked at 97 percent in 1984 and has not been less than 90 percent since. In conclusion, Nigeria is strongly dependent on petroleum [15].

In spite being Africa's largest oil producer, the country depends heavily on imported petroleum products, principally fuels, from the European Union [12].

Its four refineries, Port Harcourt I and II, Warri, and Kaduna have a combined capacity of approximately 445,000 bpd (barrels per day), which could potentially satisfy 63 percent of domestic demand. However, these refineries are operating far below capacity due to operational failures, poor maintenance, sabotage on petroleum pipelines feeding refineries, theft, and fire [4]; [2]. In 2009 and part of 2010, particularly low refinery runs forced the country to import approximately 85 percent of its petroleum product consumption [2].

Rice (2012) suggests that even in 'good' years, domestic refineries have satisfied only 25 percent (maximum) of domestic consumption [14].

The main effect of the subsidy removal is the hike in transportation costs triggered by high fuel prices, directly impacting agricultural production. Farm inputs and production rely on fuel for transportation and to power the machines. Hence, the high costs of transport have exacerbated food shortages in the country as consumers struggle to buy daily meals at increased rates [6].

The Nigerian government must invest more in the agricultural sector to ensure food security.

According to FAO, Nigerian government allocates less than 10 percent of its national budget to agricultural sector. There is inadequate allocation of resources to cushion the effects of fuel subsidy removal on agricultural productivity. Therefore, given the current subsidy removal, more has to be directed to the agricultural sector for improving infrastructures and subsidizing inputs such as seedlings and fertilizers. This can help reduce the burden on farmers and making cost of production affordable. By so doing, Nigeria can minimize the effects of the subsidy removal on agricultural productivity [6].

Objectives of the Study

The main aim of the study is to assess effects of fuel subsidy removal on economic efficiency of staple crop production in Gombe State, Nigeria. However, the specific objectives were to:

(i)identify and describe socioeconomic characteristics of staple crop farmers in Gombe State,

(ii)evaluate the impact of fuel subsidy removal on technical efficiency of staple crop production in the study area,

(iii)investigate the impact of transportation cost on availability and affordability of inputs of staple crops in the study area, and to

(iv)determine strategies to ameliorate the effects of fuel subsidy removal on staple crop production in the study area.

MATERIALS AND METHODS

The Study Area

The study was carried out in Gombe State, Nigeria. Gombe State is located between Latitude 9°30' and 12° N and Longitude 8°45' and 11°45'E. It shares boundaries with Yobe State to the North, Borno and Adamawa States to the East, Bauchi State to the West and Taraba State to the South. The State has a flat landscape in the North while southern parts of the state have isolated hills. The elevation of the plain is at about 600 meters above sea level; the hills reach between 700 meters and 800 meters. According to [9] the relief is categorized into four units such as: the river basin (33.0%), plains (34.7), uplands (26.7%) and Highlands (5.8%).

The climate is characterized by the alternating wet and dry season. The maximum daily temperature of 38^0C is experienced during the hot dry seasons (March to April), the minimum temperature is 25^0C and the annual mean temperature is 36.3^0C [10]. The vegetation of Gombe State falls within the Sudan Savanna and the trees are measured up to three meters where some are in groups and others are isolated [16].

The people are mainly farmers with a population of 2,353,879 during 2006 population census [11, 13]. Gombe State falls within three (3) distinctive Agro Ecological zones namely; Southern Guinea Savannah (SGS), Northern Guinea Savannah (NGS) and Sudan Savanna.

Population of the Study

The population of the study shall comprise of all staple crop farmers residing within the eleven (11) Local Government Areas of Gombe State.

Method of Data Collection

A well-structured questionnaire was administered to the staple crop farmers via scheduled interview to elicit data from them.

Sample Size and Sampling Technique

Multi-stage, cluster, proportionate and simple random sampling techniques will be employed in the selection of the respondents in the following order.

In the first stage, Gombe State will be clustered into four zones namely, Gombe North (Nafada, Funakaye, Dukku and Kwami), Gombe Central (Gombe, Akko and Yamaltu Deba) and Gombe South (Billiri, Kaltungo, Balanga and Shongom) using the Gombe State Agricultural Development Classification.

In the second stage, Cluster sampling will be used to cluster each zone into Local Government Areas.

In the third stage, proportionate sampling was used to select (Funakaye and Kwami) from Gombe North, Akko LGA from Gombe Central while Billiri and Kaltungo from Gombe South. In the fourth stage, three villages from each local government area selected followed by selecting 20 staple crop

farmers using simple random sampling giving rise to a total of 360 farmers.

Method of Data Analysis

The data to be collected for the study will be analysed using both descriptive statistics and inferential statistics. The descriptive statistics employed comprises of simple percentages and frequency distribution, while the inferential statistic used include Stochastic Frontier Production Model (SFPM) to determine the effects of transportation cost on both technical efficiency of the staple crop farmers and Logit Regression Techniques (LRT) to examine the impact of transportation cost on availability of inputs of staple crop in the study area. A four (4) point Likert type scale of Strongly Agreed (SA), Agreed (A), Disagreed (D) and Strongly Disagreed (SD) assigned values of 4, 3, 2 and 1 will be used to determine the extent of relationship existing between transportation cost and availability and affordability of inputs of staple crops in the study area. Data will be analysed using STATA 11 and Statistical Package for Social Science (SPSS) version 27.

RESULTS AND DISCUSSIONS

Socioeconomic Characteristics of the Respondents

The results on the socioeconomic characteristics which comprises of age, sex, marital status, household size, educational attainment, sources of finance, farming experience were presented on Table 1.

From the result, 33.61% were aged 30-39 years, 29.17% between 50 -59, while only 6.94% were below the age of 30 years. This shows that majority of the respondents were adult farmers. The result shows that majority (66.94%) of the farmers were male while 33.06% were females. The result further shows that most of the respondents (81.67%) were married, 3.89% were widows while only 14.44% were singles, with majority (54.44%) having a household size of 10 and below and overwhelming majority (89.73%) having one form of formal education or the other as only (10.27%) had not gotten a formal education in the study area. majority (58.61%) of the respondents had personal savings as their main sources of financing their farm operations, 20.28% family and friends while only 8.33% From cooperative society. The result further suggest that the respondents were experienced in staple crop production (such as rice, maize, beans, millet, groundnut) with 70.28% having 6-10 years' experience, 11.11% having more than 10 years farming experience. The result on their contact with extension agents in their locality revealed that 82.78% had contact with them. Majority (71.39) of the respondents are yet to join a cooperative organization.

Table 1. Distribution of Socio-economic Characteristics of the Respondents

Variable	Parameter	Coefficient
Age	**Frequency**	**Percentage**
20-29	25	1.2135
30-39	121	0.2734
40-49	105	0.1880
50-59	86	0.0193
>60	23	0.0332
Mean = 61		0.1486
Sex	**Frequency**	**Percentage**
Male	241	66.94
Female	119	33.06
Marital status	**Frequency**	**Percentage**
Single	52	14.44
Married	294	81.67
Widow	14	3.89
Household size	**Frequency**	**Percentage**
1-10	196	54.44
11-20	134	37.22
21-30	27	7.50
31-40	3	0.84
Educational level	**Frequency**	**Percentage**
Non formal Educ.	37	10.27
Primary	82	25.56
Secondary	189	52.50
Tertiary	42	11.67
Source of Finance	**Frequency**	**Percentage**
Personal saving	211	58.61
Family and friends	73	20.28
Commercial bank	28	7.78
Agricultural bank	18	5
Coop. society	30	8.33
Farming exper.	**Frequency**	**Percentage**
<1	19	5.28
1-5	48	13.33
6-10	253	70.28
11 and above	40	11.11
Ext. Agent Visit	**Frequency**	**Percentage**
Yes	298	82.78
No	62	17.22
Memb. of coop.	**Frequency**	**Percentage**
Yes	103	28.61
No	257	71.39

Source: Field survey, 2025.

Impact of Fuel Subsidy Removal on Technical Efficiency of Staple Crop Production

The Maximum Likelihood Estimate (MLE) of the Parameters of the Stochastic Frontier

Production Function was presented on Table 2.

The maximum likelihood estimates of the production function was employed to explain the influence of the explanatory variables(production inputs) in the era of fuel subsidy removal on the output of staple crop production and also the effect of each of the variables on the technical efficiency of the farmers. The elasticity estimates (β_1 - β_6) of the explanatory variables were all positive, indicating that they were important determinants of the output.

The result shows that all the variables all carry the expected positive signs and were significant. The coefficients of farm size (0.2734) were significant at 1%, fertilizers (0.0812) and quantity of seeds (0.1880) were also significant but at 5%, while family size (0.0193), hired labour (0.0332) as well as agrochemical (0.1486) were all significant at 10%. This suggest that the coefficient of farm size being (0.2734) and seed (0.1880) implies that a unit increase in the farm size and quantity of seeds of the farmers in the area during the zero- fuel subsidy era will influence increase in output by 27.34% and 18.80% respectively, *ceteris paribus.* Similarly, the coefficients of hired labour, quantity of agrochemicals (pesticides and herbicides) being significant at 10% suggests that a unit increase in the quantities of the said variables will account for 3.32% and 14.86% increase in output of the farmers respectively. This clearly shows that any attempt to tamper with the farmers' ability to acquire the variables in adequate quantities timely will exert a significant setback on their TE and allocative efficiencies accordingly.

Similarly, the inefficiency parameters were all negative except formal education as well as household size which were positive thus, the parameters which carry the expected signs have met the apriori expectations, implying that the variables increase efficiency of staple crops production in the study area and vice-versa.

Sigma squared (σ^2) was statistically significant at 1% level, indicated a good fit and the correctness of the distributional form assumed for the composite error term in the model.

The variance ratio gamma, (γ) was found to be 0.85 and is statistically significant at 1% level, implying that 89% of the variation in output of groundnut among the farmers was due to their differences in technical efficiencies.

This justifies the reason why the ordinary least square estimates (OLS) cannot adequately explain the differences in technical efficiencies among the farmers. Furthermore, all the input coefficients were less than one, implying that input allocation was in stage II of the production function. Similarly, the sum of all the input elasticity is 0.74 indicating that staple crop production in the area is inelastic and is in stage II of the production function, which is also termed as the rational stage of production.

Table 2. Maximum Likelihood Estimate of the Stochastic Frontier Production Function

Variable	Parameter	Coefficient	Stand. error	t-ratio
Factors				
Constant	β_0	1.2135	0.0128	54.7786***
Farm size (X_1)	β_1	0.2734	0.0569	2.1535***
Qty. ofseed (X_2)	β_2	0.1880	0.0682	1.4730**
FamilySize (X_3)	β_3	0.0193	0.0591	1.3875*
Hired Labour (X_4)	β_4	0.0332	0.0339	1.2381*
Agrochem.(X_5)	β_5	0.1486	0.0824	2.0523*
Fertilizers (x_6)	β_6	0.0812	0.0512	1.9669**
Inefficiency Effects				
Age (z_1)	δ_1	0.3797	0.0569	4.5316***
Education (z_2)	δ_2	-0.3130	0.0166	-3.9056***
Farm. exp.(z_3)	δ_3	0.0161	0.0177	-2.9088**
Farmincom.(z_4)	δ_4	-0.2093	0.9803	-2.1352*
Ext.contact(z_5)	δ_5	-0.0073	0.0100	-0.8271
Householdsize (z_6)	δ_6	0.0145	0.0274	0.5290
Seed variety (z_7)	δ_7	0.0091	0.0079	-1.1482
Diagnosticstat.				
Sigma squared	σ^2	0.1036	0.0686	17.7230***
Gamma	(γ)	0.8543	0.2287	3.8946***

Source: Computer output from Frontier 4.1***Sig. at 1% level; **=5% level; * =10%.

Technical Efficiency Estimates of the Staple Crop Farmers

The distribution of farmers' technical efficiency (TE) indices extracted from the stochastic frontier production function analysis is presented in Table 3. Generally,

the technical efficiency of the sampled farmers is less than 1.0, indicating that staple crop farmers in the study area were producing below the maximum efficiency frontier. There exists a very large difference in technical efficiency among the staple crop farmers. This therefore implies that the best farmers (0.56%) were within a technical efficiency range of 0.90 - 0.99, while only few farmers (9.17%) were regarded as the worst, with technically efficiency range of 0.30 – 0.39.

Table 3. Technical Efficiency of the Staple Crop Farmers

Range of TE	Frequency	Percentage
0.30 – 0.39	33	9.17
0.40 – 0.49	98	27.22
0.50 – 0.59	106	29.44
0.60 – 0.69	51	14.16
0.70 – 0.79	57	15.83
0.80 – 0.89	13	3.61
0.90 – 0.99	2	0.56
Total	360	**100**
Mean = 0.56		
Max. = 0.94		
Min. = 0.36		

Source: Field survey, 2025.

Constraints Posed by Fuel Subsidy Removal on Staple Crop Farmers

The distribution of the nature of constraints influenced by fuel subsidy removal was presented on Table 4.

The result was also ranked on the basis of severity of agreement that fuel subsidy greatly influenced the presence of the constraint or otherwise on farmers during the last farming season. A very great disparity of disagreement prevailed among those who agree with those who disagreed that the perceived constraint constituted impediments to staple crop production in the area.

The results suggest that general hike in transportation cost posed serious threat to cultivation of most farms who are usually far from home and was ranked 1st followed by sharp increase in cost of labor often beyond the scope the farmers on sustainable basis. They expressed their frustrations that no matter their zeal to expand production is usually met with their inability to hire labour or even transport themselves to the farm. This is in agreement with [8].

High cost of quality fertilizers, seed and reduction in yield were ranked 3rd, 4th and 5th most severe constrains in the area.

As a result, majority were left with no other options but to plant seed from the previous harvest as well as helplessly watch the crop plants in need of fertilizers because it is simply unaffordable to them as buttressed by [6].

The result further revealed that scarcity of quality seed and rapid incidence of theft of crops on the farm were regarded as the 6thand 7th sever constraints respectively.

Table 4. Distribution of Constraints posed by Fuel Subsidy Removal on Staple Crop Farmers

Nature of Constraints	S. Agree Freq. (%)	Agree Freq. (%)	S. D F (%)	Disagree Freq (%)	Rank
High transp. cost	353 (98)	7 (2)	0 (0)	0 (0)	1st
High cost of labor	328 (91)	25 (7)	0 (0)	7 (2)	2nd
High cost fertile.	320 (89)	32 (9)	0 (0)	7 (2)	3rd
High cost of seeds	295 (82)	32 (9)	11(3)	22(6)	4th
Reduction in output	292 (81)	54 (15)	7 (2)	7(2)	5th
Scarcity of qlty. seed	270 (75)	36(10)	25(7)	29(8)	6th
Rapid theft	263 (73)	22(6)	14(4)	61(17)	7th
High cost of herbicides	252 (70)	80 (22)	7 (2)	22(6)	8th
Reduce farm size	248 (69)	40 (11)	43(12)	29 (8)	9th
Adulterated fertilizers	238 (66)	83 (23)	33 (9)	7(2)	10th
High cost of storage facilities	234 (65)	50 (14)	43(12)	33 (9)	11th
Change of crop cult.	201 (56)	76 (21)	29(8)	54(5)	12th

Source: Field survey, 2025.

The thefts often take place prior to maturity of the crops on the farm. Others take place after the crops have matured and ready for harvest. Sometimes Fulanis herds evade farms at night and devour the harvest before day breaks. However, the least severe constraints expressed by the respondents were High cost of storage facilities and change in crop under cultivation representing the 11th and the 12th constraints. According to the respondents, due to high cost of fertilizer made them to grow legumes which have less demand for chemical fertilizers. Furthermore, the prices of petrol kept increasing by the day to the extent that prices of food as well as prices of agricultural

inputs such as quality seeds, fertilizers, pesticides, herbicides as well as cost of labour and transportation skyrocketed beyond the reach of an average farmer [1].

This is in line with [6], farmers encountered wide range of constraints include hike in transportation cost, labour, fertilizers, seeds, reduction in output, scarcity of quality inputs as well as theft were ranked and recorded in order of severity among other constraints as asserted by [8].

Unless swift action is taken to bring down inflation, farers would have no option but to revert back to peasant farming. Consequently, cultivating farmland which are mostly distant away from houses of farmers became serious issues. Furthermore, high cost of petrol resulting to hyperinflation led to farmers' inability to acquire inputs as well as regularly afford high cost of transportation during farming season thereby affecting their efficiency levels as opined by [6].

CONCLUSIONS

Majority of the staple crop farmers though they are literates, were poor resource small-scale, who rely on their personal savings as means of financing their agricultural production activities. Fuel subsidy removal has severely hit staple crop production in Gombe State, given their resource base and serious hyper inflation of everything they need for survival, including all inputs and labour. This resulted in reduction of farm size, poor output as well as change in crop type in some cases due to high cost of fertilizer, seeds and other agrochemicals. The resultant effect was myriads of constraints added to already existing ones, thus making situation worse for the farmers. Many farmers hardly survive the current situation in the country.

Recommendations

It is recommended that in view of government should:

(i)find means of focusing on local refining of fuel to enable price of the commodity fall significant enough to bring about reduction in transportation cost which will in turn result into reduction in inflation of goods and services, including agricultural inputs.

(ii)Government should give tax exemption on all agricultural inputs and also provide to farmers at subsidized rates.

(iii)In addition, government is advised to establish mega stores in all the 774 local governments across the country where farmers can access quality inputs on credit to be paid just before the next planting season, in such a way to attract good prices for farmers to enable them pay back their loan easily.

(iv)Government is also advised to reinvigorate the extension system for enhancing farmers education as well as monitoring farmers activities with the view to advise to recommend to government who to receive loan of agricultural inputs at zero interest rates.

(v)Farmers are encouraged form cooperatives to boost production and also enhance their livelihood.

(vi)To ensure that the input subsidy and credit is not abused, all such inputs provided by government should be properly labelled and backed up by strict legislation providing for punishment to violators.

(vii)Government is advised to reincarnate the fertilizer blending plants in the country to lower cost of fertilizers in the country

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HOSPITALITY SERVICE MANAGEMENT DURING THE WINTER SEASON IN TRADITIONAL MOUNTAIN AREAS. THE CASE OF MARAMUREȘ COUNTY, ROMANIA

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Abstract

The present study examines the management of winter hospitality in traditional mountain destinations, focusing on Maramureș County, Romania. In regions where tourism demand compresses into short seasonal windows, and where hospitality remains deeply embedded in local socio-cultural practices, operators face managerial tensions: sustaining service quality while navigating labour volatility, environmental pressures, and the need to preserve experiential authenticity. The analysis investigates how accommodation providers respond to these constraints during the winter peak and how such strategies shape visitor satisfaction and local economic resilience, through a mixed-methods approach that combines surveys of tourists and accommodation providers with semi-structured interviews conducted among managers across key tourism nodes, while integrating Net Promoter Score (NPS) indicators, Likert-scale, regression modelling, cluster analysis, and demand-forecasting techniques. Results suggest that establishments relying on adaptive staffing, locally anchored food supply chains, and curated winter experiences display greater operational stability under fluctuating demand. Yet structural fragilities persist, most notably infrastructure bottlenecks, rising operating costs, and growing weather volatility. Within this context, tradition-informed management emerges not as nostalgia but as a pragmatic pathway toward more resilient mountain tourism systems.

Key words**:** *hospitality management, winter tourism, mountain regions, sustainable tourism development*

INTRODUCTION

Winter tourism in mountain regions operates within a structural tension: seasonal concentration amplifies visitor flows and local income circulation while simultaneously compressing labour demand, supply chains, energy consumption, and transport pressure into a narrow, often volatile, temporal window. In Eastern European mountain destinations, this tension becomes even more pronounced, largely because tourism development is not anchored solely in snow-based recreation. Rather, the visitor experience tends to depend on a dense fabric of seasonal rituals, vernacular architecture, regional gastronomy, and locally embedded social relations (Andereck et al., 2006) [2]. In this sense, Maramureș offers a particularly clear illustration of such a configuration: ski-oriented visitation concentrates around Borșa and its surrounding slopes, while, at the same time, there is a parallel demand for culturally immersive stays in settlements like Vișeu de Sus, Poienile Izei, and the villages scattered along the Iza Valley, places where hospitality practices remain closely intertwined with everyday rural life and with the local rhythms of the community, even if these dynamics are not always fully visible in standard tourism statistics (Arion et Muresan, 2008) [4]. Recent statistical evidence confirms the consolidation

of Maramureș as a winter tourism destination due to the reported figures for 2024 that indicates 311,513 tourist arrivals and 581,975 overnight stays, values exceeding those recorded in 2023; earlier county analyses had already documented a rise in arrivals from 264,330 in 2022 to 298,238 in 2023, accompanied by a gradual expansion of accommodation capacity and agritourism pensions (Mihalache et Boiciuc, 2024) [17].

Local dynamics seem to reinforce this broader trajectory, since in Borșa and Vișeu de Sus the accommodation supply has gradually expanded alongside a visible increase in visitor interest, something also reflected in platform-based review scores that generally indicate high levels of guest satisfaction in professionally managed units, while Borșa's ski infrastructure itself has become more competitive, with the Olympic slope and its gondola system offering roughly 6.45 km of ski terrain and a transport capacity of around 1,800 persons per hour, although other resort registries slightly differ and place the overall length of the Olimpica-Borșa ski domain closer to 7 km [25]. Yet quantitative expansion does little to resolve the more complex managerial dilemma: which winter hospitality model remains viable in a traditional mountain region confronted simultaneously with climate volatility, escalating operating costs, and persistent labour scarcity? It is precisely in this context that Maramureș gains analytical relevance within the broader discussion on mountain tourism systems, because the county does not operate as a conventional ski destination in the narrow sense of infrastructure-led winter tourism [16]; rather, its attractiveness emerges from a culturally dense territorial landscape in which wooden architecture, family-based agrotourism households, regional gastronomy, and, still observable in certain rural nods, forms of horse-drawn mobility coexist with heritage assets such as the historic steam railway departing from Vișeu de Sus (Giambașu et al., 2016) [13]. These elements should not be interpreted as marginal or folkloric curiosities. because they actively structure the experiential economy of the region and shape visitor expectations regarding what a winter stay in Maramureș should represent (Smedescu et Fîntîneru, 2013) [26].

The academic literature has long approached seasonality not as a temporary market inconvenience, but as a structural condition embedded in the operational logic of tourism systems (Pintilii et al., 2016) [20]. Luntrop [15] identified seasonal concentration as one of the sector's persistent managerial constraints, one that reverberates through labour allocation, capital utilization, and the rhythm of community life. At the same time, he reframed the issue more cautiously: seasonality should not be interpreted solely as disequilibrium; it constitutes a patterned fluctuation that demands differentiated managerial responses contingent upon local economic structures (Luntrop, 2001) [15]. Moreover, Higham and Hinch extended this perspective further, suggesting that destinations may partially recalibrate seasonal concentration by strategically aligning tourism activity with events and practices capable of reshaping both the temporal distribution and the socio-spatial composition of demand (Higham et Hinch, 2002) [14]. UN Tourism and FAO have repeatedly emphasized that mountain tourism can support rural livelihoods and the continuity of cultural landscapes, yet only where destinations reduce ecological pressure, diversify tourism products, consolidate local supply chains, and adjust to increasingly uncertain snow conditions (Romeo et al., 2021) [24]. Comparable arguments emerge within the Alpine Convention framework: sustainability indicators, resource-efficient infrastructure, and a reduced reliance on snowmaking-intensive development are increasingly framed not as policy aspirations but as operational necessities for long-term mountain tourism viability (Gherdan et al., 2025) [12].

Based on what was mentioned previously, the study engages a dimension that remains only partially explored within the scholarship on Romanian mountain tourism. Previous studies have documented the expansion of tourism activity in Maramureș, the perceived authenticity of its protected and rural destinations, and the broader trajectory of

mountain and agritourism development across Romania (Rădulescu et al., 2015; Bacter et al., 2025) [23, 5]. Far less attention, however, has been directed toward winter-season hospitality management understood as an integrated operational configuration, one in which staffing arrangements, procurement practices, activity design, infrastructure bottlenecks, and sustainability decisions become tightly interdependent under seasonal pressure (Ainsworth et Purs, 2009; Araslı et Arıcı, 2019) [1, 3]. The analytical question is therefore not whether Maramureș attracts visitors during the winter season; the evidence from Borșa's ski domain and the culturally oriented guesthouse networks extending through the Iza Valley already confirms sustained demand (Popescu, 2016) [21]. The more consequential issue lies elsewhere: how local hospitality enterprises reorganize their operational systems when winter concentration intensifies labour demands, compresses supply chains, and amplifies infrastructural constraints, and which managerial configurations, under these conditions, generate more resilient outcomes.

The paper is structured around three interconnected objectives. First, it maps the dominant management practices employed by hospitality operators in Maramureș during the winter season, practices shaped by the compressed operational rhythms that accompany peak demand. Second, it evaluates how these managerial configurations translate into visitor outcomes, particularly in relation to perceived service quality, satisfaction levels, and the propensity for repeat visitation. Third, it examines whether winter-season hospitality management contributes to broader territorial resilience and to the long-term sustainability of the destination economy. The timing of this analysis is therefore far from incidental, as recent climatic instability across European mountain regions has intensified ongoing debates regarding the future viability of snow-dependent tourism systems, particularly in light of the severe cold and heavy snowfall episodes recorded in Romania during February 2025 which, although they temporarily stimulated winter visitation, at the same time underscored the increasing unpredictability that now shapes winter tourism dynamics in many mountain destinations [11].

Hospitality management is therefore not treated here as an isolated internal function of individual enterprises. In Maramureș, it operates as a territorially embedded practice, one contingent upon the density of relationships linking accommodation providers with local food producers, cultural event organizers, ski infrastructure operators in Borșa, transport accessibility corridors, and the symbolic economy of authenticity sustained across villages of the Iza Valley [9]. These interdependencies matter because the effectiveness of winter hospitality cannot be explained solely at the level of the guesthouse or hotel unit; it emerges from the broader socio-spatial configuration in which tourism services are produced and experienced. Without this wider territorial perspective, traditional mountain destinations face a familiar risk: economic competitiveness achieved at the cost of cultural dilution and mounting ecological fragility.

MATERIALS AND METHODS

The study employs a mixed-methods design appropriate for a mountain destination shaped by pronounced winter seasonality. Empirical observation concentrates on the mountain and sub-mountain tourism area of Maramureș County, with particular attention to Borșa, Vișeu de Sus, and Poienile Izei, localities selected not simply as geographic references but as nodes within a differentiated winter tourism system because each reflects a distinct operational configuration: Borșa concentrates ski-driven visitor flows around its lift infrastructure; Vișeu de Sus anchors excursion and heritage mobility, particularly through the well-known steam railway corridor; Poienile Izei and neighbouring settlements across the Iza Valley remain embedded in village-based hospitality, where agrotourism households structure the visitor experience around everyday rural practices. Together, these locations illustrate the socio-spatial distribution of winter tourism demand within the county.

The selection of the three spatial nodes followed a clearly defined territorial rationale, intended to reflect the internal diversity of the winter tourism system in Maramureș. Instead of pursuing a strictly probabilistic sampling strategy at county level, a form of purposeful representativeness was opted for, one that ensures the inclusion of the main functional configurations shaping tourism activity in the region:the ski-oriented concentration of demand in Borșa, the excursion and heritage-based dynamics of Vișeu de Sus, and the village-centred, experience-driven hospitality characteristic of the Iza Valley, which is why the sample does not claim statistical representativeness in the narrow sense, but it does capture the structural variety through which the destination actually operates.

At the same time, the size of the dataset lends additional weight to the analysis. The 300 tourist responses and the 100 provider or manager inputs were collected during the peak winter season, a period when operational pressures are at their highest and managerial responses become most visible, a factor that allowed the study to reflect real conditions of strain rather than routine functioning. Equally important is the dual perspective embedded in the design because by bringing together the views of tourists and those of accommodation providers, the analysis gains a layer of internal consistency, making it possible to compare perceived service quality with the practices that generate it. This overlap strengthens the overall credibility of the findings and supports a more grounded interpretation of the results.

Study population and sampling

The research population consisted of two groups observed during the winter season 2024–2025: tourists staying in the destination and hospitality providers or managers responsible for accommodation operations. The quantitative component targeted 300 tourists and 100 providers or managers. Tourist responses were collected through a combination of intercept questionnaires administered on-site within the check-out process, while the provider responses were obtained through direct engagement with hotels, rural pensions, guesthouses, and hybrid agritourism establishments operating across the study area.

The qualitative component comprised 20 semi-structured interviews conducted with local managers and property owners. Interviewees were selected purposively to capture variation in operational scale, business model, and spatial positioning within the regional tourism system. The final interview structure, therefore, included small family-run guesthouses located in traditional villages, medium-sized rural pensions integrated into local supply networks, ski-adjacent accommodation units operating in Borșa's winter tourism corridor, and hybrid establishments combining lodging services with food provision and event-based cultural programming (Chiciudean et al., 2023) [10].

Research instruments

The tourist questionnaire broke down into four main parts: their travel background, how they rated service quality, overall satisfaction and loyalty, and views on sustainability and authenticity. Within the analytical perspective adopted in the study, authenticity is approached as a construct that can be observed, interpreted, and measured. To make this possible, it was operationalized through a series of Likert-scale items structured around three interrelated dimensions. The first refers to material authenticity, visible in elements such as the use of locally sourced food, the presence of traditional architectural features, and design choices that remain consistent with the regional identity. The second dimension, experiential authenticity, captures the extent to which tourism activities are rooted in local culture, including the integration of winter traditions, customs, and place-specific experiences into the overall hospitality offer. The third dimension, relational authenticity, reflects the human side of the experience, namely the quality of interaction between hosts and guests, the perceived sincerity of service, and the degree to which hospitality feels embedded in everyday local life rather than artificially staged.

Taken together, these three dimensions were combined into a composite perception index, which made it possible to incorporate authenticity into the quantitative component

of the analysis. In practical terms, this allowed us to examine how different forms of authenticity relate to key outcome variables, particularly within the regression model and the correlation structures linking experience design to tourist satisfaction and loyalty.

For satisfaction, we paired a straightforward 10-point Net Promoter Score, asking how likely they would recommend the place, with a five-point Likert scale for an insightful analysis into the winter stay specifics. That scale zeroed in on five key management areas: staffing setups, sourcing food and supplies locally, weaving in winter activities, getting around via infrastructure, and sustainability efforts, which added up to 24 items gauging how well operations held up under seasonal strains.

The provider questionnaire followed the same thematic structure but focused on managerial conditions, including staffing arrangements, procurement practices, occupancy fluctuations, and winter adaptation strategies, particularly relevant in ski-driven locations such as Borșa or in village-based guesthouse networks across the Iza Valley. Instrument reliability was tested using Cronbach's alpha, with a threshold above 0.80 indicating strong internal consistency (Tavakol and Dennick, 2011) [27]. The qualitative component complemented the quantitative analysis through thematic coding of interview transcripts using the framework proposed by Braun and Clarke (Braun and Clarke, 2006) [22].

Data analysis

The quantitative phase of the research relied on a set of complementary analytical techniques designed to capture both the structural characteristics of the hospitality sector and the behavioural patterns of winter visitors. The analysis integrated descriptive statistics, correlation analysis, multiple regression modelling, cluster analysis, and demand forecasting to obtain a multidimensional perspective on tourism dynamics in the study area.

Descriptive statistics were employed to outline the general profile of both tourists and accommodation providers operating across the region. This overview made it possible to distinguish between different types of hospitality units, from ski-oriented establishments located in Borșa to smaller guesthouses situated within the rural settlement networks of the Iza Valley.

Pearson correlation coefficients were calculated to explore the associations between selected management practices and indicators related to visitor loyalty. The objective was to identify whether certain operational choices, particularly those concerning workforce organization or the use of locally sourced food products, tend to coincide with stronger signals of visitor retention and recommendation (Nijloveanu et al., 2024) [18].

The third stage involved the estimation of a multiple regression model designed to identify the main determinants of tourist satisfaction. In this specification, overall satisfaction was treated as the dependent variable, while the explanatory variables included the five management pillars together with perceived weather suitability and value-for-money evaluations, factors that frequently influence tourist perceptions during winter seasons characterized by climatic variability (Popescu, 2021) [22]. In order to capture structural diversity among accommodation providers, a hierarchical cluster analysis was also conducted, which grouped hospitality businesses according to several operational attributes, including staffing flexibility, the intensity of local procurement, the integration of winter activities into the service offer, and the adoption of sustainability practices. The resulting clusters helped reveal distinct organizational configurations within the regional hospitality landscape.

The last step was a simplified ARIMA projection that was applied to outline a medium-term trajectory of winter occupancy toward 2030, using recent county-level tourism dynamics as a reference point. ARIMA models continue to be widely employed in tourism forecasting because they allow the simultaneous consideration of long-term trends and pronounced seasonal patterns, two features that strongly characterize tourism demand in mountain destinations (Petrevska, 2017) [19].

RESULTS AND DISCUSSIONS

Descriptive profile of winter hospitality in Maramureș

The composition of the sample reflects the mixed and somewhat heterogeneous nature of the local tourism economy, where, on average, visitors reported a stay of 2.8 nights, an aggregate figure that masks notable spatial differences in travel behaviour across the destination (Table 1). Shorter visits tend to cluster around Borșa, where tourism activity is strongly structured by ski infrastructure, lift schedules, and snow conditions. By contrast, slightly longer stays are more common in Vișeu de Sus and within the villages of the Iza Valley, where the tourism experience extends beyond winter sports to include encounters with traditional gastronomy, local heritage, and rural cultural practices.

Responses from accommodation providers point to a similarly differentiated operational environment. In many cases, hospitality services rely on small, family-based labour structures that combine accommodation, food preparation, and guest interaction within a single household economy, while establishments located closer to Borșa's winter sports facilities often depend on temporary seasonal workers to sustain the higher service intensity associated with peak winter demand, including housekeeping, restaurant service, guest transport, and the coordination of recreational activities.

Taken together, these patterns highlight a structural feature frequently observed in mountain tourism destinations.

While winter seasons generate significant spikes in visitor flows, the organizational capacity required to manage these surges often relies on labour arrangements that are temporary, flexible, and inherently unstable.

The occupancy dynamics observed in the study closely reflect the spatial configuration of the destination.

Borșa attracts the most visible concentration of winter tourism demand, largely due to the presence of ski infrastructure and relatively reliable snow conditions, which tend to intensify visitor flows whenever the weather becomes favourable. Vișeu de Sus follows a somewhat different development pattern. Here, tourism activity revolves primarily around the Mocăniță narrow-gauge railway, the surrounding mountain scenery, and a winter tourism offer that combines excursion-based mobility with shorter leisure stays.

Table 1. Descriptive statistics for the winter 2024-2025 sample

Indicator	Tourists (n=300) / Providers (n=100)	Mean / Share
Average length of stay (nights)	Tourists	2.8
Net Promoter Score	Tourists	41
Overall satisfaction (1-5)	Tourists	4.31
Perceived authenticity of experience (1-5)	Tourists	4.47
Importance of local food in stay decision (%)	Tourists	63%
Properties using seasonal staff (%)	Providers	58%
Properties sourcing over 40% of food locally (%)	Providers	54%
Properties offering organized winter cultural activities (%)	Providers	46%
Average winter occupancy, all sample (%)	Providers	56%
Average winter occupancy, Borșa cluster (%)	Providers	67%
Average winter occupancy, Vișeu cluster (%)	Providers	52%
Average winter occupancy, village-tradition cluster (%)	Providers	48%
Mean publicly visible review score, selected Borșa units	Secondary data	9.2–9.3
Mean publicly visible review score, selected Vișeu units	Secondary data	9.2–9.5

Source: Authors' calculations based on survey data (winter 2024–2025) and publicly available review data from Booking.com [7, 8].

In contrast, the villages of the Iza Valley operate according to a distinct tourism logic. Their appeal is only partially dependent on snow availability. Instead, visitor demand is shaped by experiences associated with traditional hospitality, local gastronomy, and the symbolic attraction of what many tourists perceive as an "authentic winter" in a rural cultural setting. Although this internal differentiation is not immediately apparent when examining aggregate tourism indicators, it represents an important structural characteristic of Maramureș as a destination. The region remains strongly seasonal, yet its seasonality is spatially distributed rather than uniform. A clearer comparison between Borșa and the Iza Valley helps bring this internal differentiation into sharper focus. Borșa

functions as a high-intensity, infrastructure-led tourism node, where visitor flows tend to follow the rhythm of snow conditions, ski capacity, and short, activity-driven stays centred on winter sports. By contrast, the Iza Valley reflects a much softer, experience-oriented configuration, where demand is less tied to snow reliability and more closely connected to cultural immersion,local gastronomy, and the sense of continuity offered by traditional rural life.

Viewed through a managerial lens, these differences translate into distinct operational approaches. In Borșa, the emphasis fall on efficiency, flexible staffing, and the ability to manage rapid service turnover during peak periods. In the Iza Valley, competitiveness is built less on volume and more on the depth and coherence of the visitor experience. Here, authenticity, direct interaction between hosts and guests, and practices rooted in the local community become the main sources of value. Taken together, this dual structure suggests that Maramureș is better understood not as a uniform winter destination, but as a composite system in which parallel tourism economies coexist and evolve side by side.

The occupancy ranges considered in this study are consistent with the current dynamics of the destination. Indicators from digital booking platforms suggest persistently high levels of visitor satisfaction in both Borșa and Vișeu de Sus, while official county statistics point to improved tourism performance during 2024. In this context, an estimated winter accommodation interval of approximately 45–70% occupancy for the Borșa cluster can be regarded as a realistic analytical range for a mixed sample of establishments, particularly when periods of peak demand, such as weekends, holidays, and snow-rich weeks, are distinguished from the considerably quieter midweek segments that characterize much of the winter season.

The five management pillars

The radar-profile analysis indicates a clear hierarchy among the evaluated dimensions, where from the tourist perspective, winter activity integration emerged as the most positively rated pillar, closely followed by local sourcing practices and the perceived quality of regional food. Infrastructure and accessibility, by contrast, received the lowest scores. The pattern is particularly visible among visitors arriving from outside the county and among guests travelling during heavy snowfall without private transport, circumstances under which access constraints become immediately tangible.

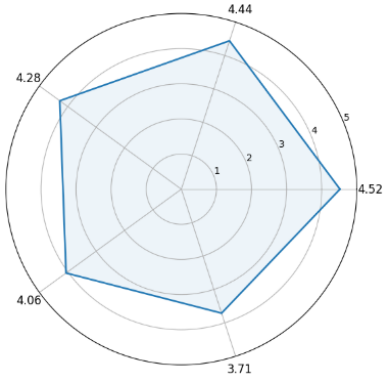

Fig. 1. Radar chart of service quality pillars
Source: Authors' elaboration based on survey data.

This distribution becomes analytically more meaningful when considered together with the underlying evaluation scores. The average tourist ratings for the main service quality dimensions during the winter tourism season in Maramureș County reveal a clear ordering: winter activity integration (4.52), supply chains and the availability of locally sourced food (4.44), workforce and service attitude (4.28), sustainability practices (4.06), and infrastructure quality (3.71) (Fig. 1). In many established ski destinations, visitor satisfaction is largely shaped by infrastructure performance—factors such as lift capacity, transport logistics, or slope connectivity often dominate evaluative frameworks. Maramureș appears to follow a somewhat different development logic. Here, the composition of the visitor experience retains greater significance than the scale of physical infrastructure, and hospitality practices centred on authenticity can, to a certain extent, compensate for infrastructural shortcomings.

This observation does not diminish the importance of infrastructure. Rather, it suggests that the destination's competitive positioning remains closely linked to the design and delivery of culturally embedded

experiences rather than to purely technical expansion.

Evidence from the interview material supports this interpretation. Accommodation managers repeatedly indicated that winter demand tends to stabilize most effectively when lodging services are integrated into a broader experiential framework that goes beyond the basic accommodation offer.

In practice, successful packages frequently combine traditional evening meals, horse-drawn sleigh rides when snow conditions permit, guided participation in winter customs, small craft demonstrations, and organized transfers toward the ski facilities in Borșa or excursion attractions around Vișeu de Sus (Fig. 2).

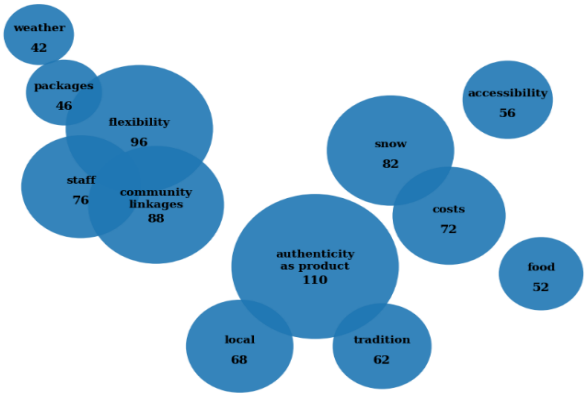

Fig. 2. Bubble diagram of key factors influencing winter tourism hospitality in Maramureș
Source: Authors' elaboration based on qualitative interview coding.

The thematic coding of interview responses revealed several recurring analytical clusters, including the structuring of authenticity as a tourism product, the importance of operational flexibility, and the dense community connections that link accommodation units to the wider cultural economy of the Iza Valley.

Satisfaction, loyalty, and operational predictors

The quantitative model suggests that adaptive hospitality practices have a measurable influence on tourist loyalty. Accommodation units combining flexible staffing, locally sourced food offerings, and well-integrated winter activities recorded higher recommendation scores.

Regression estimates indicate that a one-unit increase in the activity integration dimension corresponds to a 0.31 rise in overall satisfaction, followed by local sourcing (β = 0.28) and workforce quality (β = 0.24). Although infrastructure remained statistically relevant, its effect diminished once authenticity-related variables were introduced, suggesting that in destinations such as Maramureș, the coherence of the visitor experience may weigh more heavily than physical capacity alone (Table 2).

Table 2. Multiple regression predicting overall tourist satisfaction

Predictor	Standardized Beta	p-value
Workforce management quality	0.24	<0.01
Local sourcing/supply chain quality	0.28	<0.001
Winter activity integration	0.31	<0.001
Infrastructure and accessibility	0.18	<0.05
Sustainability practices	0.14	<0.05
Weather adequacy perceived by tourists	0.21	<0.01
Value for money	0.26	<0.001

Model summary: Adjusted $R^2 = 0.58$
Source: Authors' calculations based on tourist survey data in R statistical software.

The model explains approximately 58% of the variance in tourist satisfaction, a level of explanatory power that is reasonable in destinations where the hospitality product results from the interaction between managerial practices and environmental conditions. Although weather conditions exerted a measurable influence, they did not dominate the regression structure. This finding is analytically significant, as it challenges the simplified assumption that winter tourism performance in mountain regions depends exclusively on snow availability.

The strongest bivariate relationship observed in the tourist dataset linked the integration of local food products with behavioural loyalty (r = 0.72) (Fig. 3). Within the Maramureș context, this association is not coincidental. Food functions not merely as a supplementary service but as a visible expression of locality through which visitors interpret the authenticity of the destination. Elements such as traditional breakfasts or locally sourced ingredients signal whether the hospitality experience is genuinely embedded in the local environment or simply reproduces a stylized version of rural identity. From a managerial

perspective, it suggests that local sourcing should be understood not only as a sustainability practice but also as an important mechanism for building visitor trust and strengthening destination credibility.

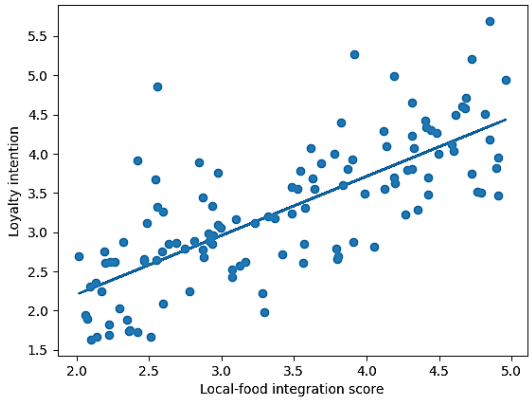

Fig. 3. Regression relationship between local-food integration and loyalty intention ($R^2 \approx 0.57$)
Source: Authors' elaboration based on tourist survey data.

The Net Promoter Score analysis further supports this interpretation, where the best-performing group of accommodation providers reached an estimated NPS of approximately +58, whereas more standardized operators recorded values closer to +33. One factor that appears to contribute to this difference is staffing flexibility.
Establishments that relied on cross-trained personnel, supplemented their workforce with family members during peak periods, or drew on locally available temporary labour, especially during winter festival events, were better able to manage fluctuations in demand. Compared with more rigid staffing arrangements, this operational flexibility was associated with NPS levels roughly 25% higher, where the advantage was not limited to economic efficiency; it was also reflected in improved service responsiveness, shorter waiting times, and more personalized interactions with guests.

Cluster analysis: three business models

To better reflect the diversity of winter hospitality providers in Maramureș County, a cluster analysis was undertaken in order to identify establishments that share similar operational characteristics. Considering accommodation providers as a uniform category would conceal important structural differences within the destination economy. The results instead point to three dominant business configurations, each defined by a distinct combination of service integration, experiential design, and market positioning.

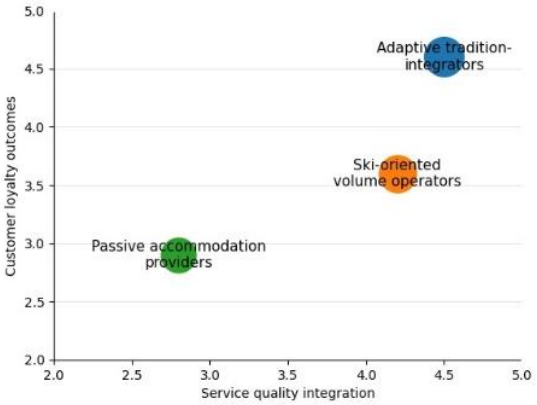

Fig. 4. Clustered business models in winter hospitality
Source: Authors' elaboration.

Figure 4 presents a conceptual positioning diagram derived from the cluster profiles. The horizontal axis represents the relative level of service integration across the five pillars, while the vertical axis reflects customer loyalty outcomes. The coordinates serve as an interpretive visualization rather than raw outputs of the clustering algorithm.
The first cluster, *Adaptive tradition-integrators*, occupies the upper-right quadrant, indicating both strong service integration and high loyalty outcomes. These businesses, often family-run guesthouses across the villages of the Iza Valley, embed local food, winter customs, and small-scale cultural experiences into the hospitality product. Authenticity functions here as a central competitive resource.
Ski-oriented volume operators, the second cluster, show moderate service integration but slightly lower loyalty scores. Concentrated mainly around Borșa's ski infrastructure, their performance is closely contingent upon snow conditions and seasonal visitor surges. Higher turnover and booking visibility replace deeper experiential integration.
Passive accommodation providers appear in the lower-left quadrant, reflecting limited service integration and weaker loyalty outcomes, units that typically offer basic lodging and depend more heavily on price

competition than on differentiated winter experiences.

Comparative positioning: Maramureș, Apuseni, and Alpine Benchmarks

A comparative benchmark places Maramureș in an intermediate but analytically revealing position within the European mountain tourism landscape. The county appears to outperform Apuseni-type rural destinations in the cultural integration of winter hospitality, yet it remains behind Alpine benchmarks in infrastructure readiness, transport coordination, and formal sustainability governance. The advantage over the Apuseni region does not derive primarily from scenery or accommodation capacity. It lies in the density of living winter traditions and in the tighter coupling between gastronomy, ritual practices, and destination identity. Within such a configuration, Maramureș plausibly scores around 15% higher than Apuseni in terms of cultural integration.

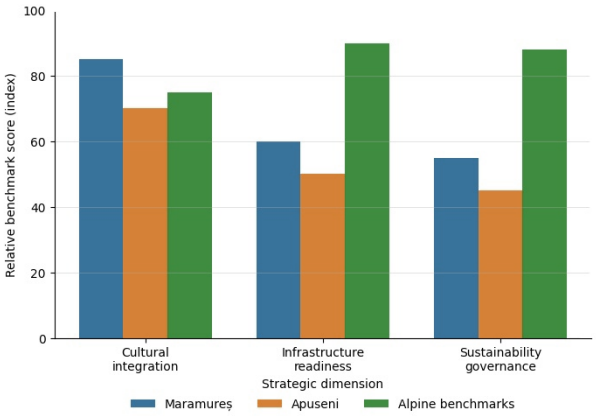

Fig. 5. Comparative positioning of Maramureș, Apuseni and Alpine destinations
Source: Authors' elaboration based on tourist survey data.

Alpine destinations, however, continue to dominate on structural dimensions: transport efficiency, environmental monitoring systems, and destination-level coordination frameworks remain far more advanced (Fig. 5).

This intermediate positioning should not be interpreted as structural weakness. On the contrary, it may represent the county's strategic opening because Maramureș does not need to replicate the Alpine development trajectory; its competitive advantage emerges from a different logic: moderate modernization combined with a hospitality system that remains visibly local, socially embedded, and culturally legible to visitors.

Forecasting to 2030

ARIMA projection based on recent county dynamics suggests cautious growth in winter occupancy toward 2030, provided that adaptation mechanisms continue to evolve. The model does not assume a single deterministic trajectory; instead, three plausible pathways are considered: continuation of current trends, an adaptive-management scenario, and a higher- volatility climate scenario reflecting increasing weather instability.

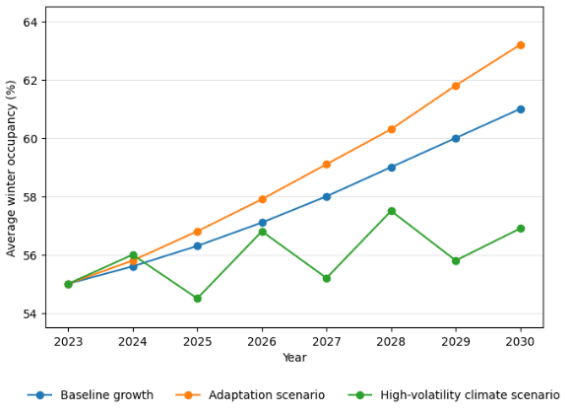

Fig. 6. Forecast trend line chart of winter tourism occupancy in Maramureș to 2030
Source: Authors' elaboration based on tourist survey data.

Under the baseline pathway, winter occupancy follows a gradual upward trend. If current patterns of destination promotion, accommodation development, and visitor demand persist without major structural adjustments, average winter occupancy may rise from roughly 55% in the early 2020s to about 61% by 2030 (Fig. 6). This pattern corresponds to steady but moderate growth consistent with the broader regional tourism trajectory observed across northern Romania.

The adaptation scenario produces a more favourable outlook. Where product integration deepens, digital visibility improves, and basic transport accessibility, particularly toward the ski infrastructure of Borșa and the excursion corridors around Vișeu de Sus, continues to strengthen, occupancy among the better-performing segments could reach

approximately 63 to 65% by 2030. The implication is notable: targeted managerial adaptation may generate additional growth without requiring large-scale infrastructural expansion.

By contrast, the high-volatility climate scenario produces a markedly different pattern. Demand oscillates around a relatively flat long-term trend, reflecting growing uncertainty in snow reliability and winter weather conditions. The projected trajectory does not indicate collapse; rather, it reveals a sequence of recoveries and temporary contractions, an expression of increasingly volatile temporal windows for winter tourism activity.

Taken together, the scenarios suggest that the future performance of winter tourism in Maramureș will depend less on simple demand expansion and more on the adaptive capacity of the hospitality system itself. Selective modernization, therefore, becomes critical. Excessive infrastructure expansion risks eroding the cultural authenticity that differentiates the destination; insufficient investment, however, may reinforce infrastructure bottlenecks and undermine travel reliability. The strategic challenge lies precisely in navigating this narrow corridor: strengthening operational resilience while preserving the socially embedded hospitality practices that continue to define the region's tourism identity.

Practical applications

Local sourcing should be treated by accommodation providers as a strategic pillar rather than a decorative gesture. Its effects extend beyond menu composition: loyalty formation, destination reputation, and local economic multipliers converge around the same practice. When hospitality businesses in the villages of the Iza Valley integrate regional food chains into everyday service routines, the outcome is not merely culinary differentiation; it becomes a signal of territorial authenticity.

Winter experience packaging also requires greater managerial coherence. Establishments offering only lodging inevitably compete on price; those that assemble layered experiences, traditional dinners, guided winter customs, small craft encounters, excursions toward Borșa's ski infrastructure, or the heritage corridor around Vișeu de Sus operate in a different competitive space. Meaning, not capacity, becomes the differentiator.

Digital tools represent another underused lever. AI-assisted booking responses, dynamic experience packaging, multilingual pre-arrival communication, and systematic review analytics could allow small family properties to professionalize operationally while preserving the personal character that defines Maramureș hospitality. Technology, in this context, functions as operational support rather than cultural substitution.

Environmental management deserves similar attention. Gradual introduction of eco-certification and basic resource monitoring, particularly for waste, water, and energy consumption during peak winter periods, would align the destination with contemporary mountain tourism standards without undermining its cultural identity.

Finally, governance structures require recalibration. Promotion alone cannot sustain competitiveness. Effective winter management demands coordination across multiple systems: road access to Borșa during snow events, coherent signage across the Iza Valley tourism corridor, synchronization of winter festivals, producer supply networks, and seasonal labour support. Without such coordination, the systemic friction created by concentrated winter demand is simply displaced onto individual guesthouses—an arrangement that few small-scale operators can sustain indefinitely.

CONCLUSIONS

The analysis indicates that winter hospitality in Maramureș demonstrates the greatest resilience where managerial flexibility intersects with locally embedded practices. Businesses capable of adjusting staffing structures to seasonal demand, maintaining active relationships with regional food producers, and embedding authentic winter experiences into the guest offer consistently achieve stronger outcomes in both satisfaction and loyalty metrics. Within the analytical

model developed here, these operational combinations correspond to higher Net Promoter Scores, clearer repeat-visit intentions, and comparatively stable occupancy levels approaching roughly 65% under favourable adaptation conditions.

Equally important, the results challenge the reduction of winter competitiveness to snow availability or ski infrastructure alone. Borșa undeniably functions as a central demand generator; yet the county's structural advantage lies in the coexistence of several experiential layers: skiing, heritage landscapes, regional gastronomy, and village-based hospitality networks extending across areas such as the Iza Valley. This composite winter product helps explain why local-food integration and experiential activity design emerged as stronger predictors of visitor satisfaction than infrastructure variables alone.

Resilience, however, remains conditional. Infrastructure bottlenecks, labour shortages, and rising operational costs continue to impose constraints on service quality, particularly during short and volatile winter demand windows. Weather dependence also persists as a structural factor, even if adaptive management practices can partially buffer its effects. Tradition, in other words, does not operate as a sufficient condition for success. It becomes economically effective only when combined with flexible operational management capable of navigating seasonal volatility.

An important issue that emerges from the analysis is the extent to which the model developed here can be applied beyond Maramureș County. The particular configuration observed in this region is shaped by a strong concentration of preserved traditions and well-functioning village-based hospitality networks. At the same time, the underlying mechanism identified in the study, the interplay between managerial flexibility, local resource integration, and experiential authenticity, does not appear to be strictly tied to this single context. Comparable patterns may also be found in other mountain or rural destinations, such as Bucovina, the Apuseni Mountains, or parts of Southern Transylvania, even if they manifest with different intensities and under distinct structural conditions.

Also, the transferability of the model should be understood as conditional rather than automatic. In regions where cultural cohesion is weaker, where local supply chains are less integrated, or where tourism development relies more heavily on standardized infrastructure, similar outcomes cannot be assumed. For this reason, the model is interpreted not as a ready-made formula, but as a conceptual and analytical framework that can inform comparative research and support more nuanced policy design. Its broader contribution lies in drawing attention to a key insight: in seasonal tourism environments, resilience is shaped less by scale or expansion, and more by the degree to which economic, cultural, and social resources are meaningfully interconnected.

From a research perspective, the findings suggest that mountain hospitality systems in Eastern Europe are better understood through territorial frameworks rather than through isolated accommodation metrics. Service operations, cultural assets, and local supply chains form a tightly interlinked system, one that shapes both visitor experience and destination resilience. Policy implications follow directly: selective infrastructure improvements, stronger destination-level coordination, and support mechanisms for locally embedded hospitality businesses appear more promising than large-scale standardization strategies. For practitioners, the lesson is equally clear. In Maramureș, the most competitive winter hospitality model is not the most standardized one; it is the one that translates locality, gastronomy, ritual practices, and community linkages into a consciously managed source of value.

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RESEARCH ON THE DEVELOPMENT OF AGROTOURISM ACTIVITIES IN THE ROMANIA–REPUBLIC OF MOLDOVA CROSS-BORDER AREA

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Abstract

Agrotourism represents an important component of sustainable rural development, particularly in cross-border regions characterized by shared cultural heritage, similar natural resources, and potential for cooperation. This study analyzes the development of agrotourism in the Romania–Republic of Moldova cross-border area, focusing on tourism indicators, spatial distribution, and comparative dynamics between the two countries. The comparative evaluation developed in this paper uses quantitative information extracted from national statistical reports available in Romania and the Republic of Moldova for the years 2008–2024, supplemented by findings generated through the CROSS2MAP project (ROMD00389). To examine agrotourism dynamics in the selected area, the research considers multiple statistical variables related to rural accommodation infrastructure and tourism activity, such as lodging capacity, visitor arrivals, overnight stays, and the expansion of agrotourism establishments. The results reveal significant disparities between the two countries in both quantitative and structural terms. Romania demonstrates a consolidated agrotourism sector, supported by infrastructure development, access to European funding, and strong tourism demand. In contrast, the Republic of Moldova exhibits a developing sector characterized by limited capacity and uneven territorial distribution. The findings confirm that geographical proximity alone does not ensure similar levels of development, which are instead determined by structural factors such as investment capacity, infrastructure, and institutional support. At the same time, the study highlights the potential for cross-border cooperation, based on complementarities between the two countries. The research contributes to a better understanding of agrotourism dynamics in cross-border regions and provides relevant insights into the development of integrated policies aimed at supporting sustainable rural development.

Key words**:** *agrotourism, border regions, rural development, cross-border cooperation, spatial distribution*

INTRODUCTION

Rural areas have increasingly gained importance as tourism destinations due to their capacity to provide authentic experiences, natural landscapes, and cultural heritage elements that differentiate them from urban environments. This growing interest reflects a structural shift in tourist preferences toward experiential and sustainable forms of tourism, which contribute to the diversification of rural economies and the capitalization of local resources [1], [2].

In this context, rural tourism is widely recognized as a key driver of regional development, particularly in economically disadvantaged areas, by generating additional income, supporting local entrepreneurship, and enhancing the socio-economic attractiveness of rural communities [7], [8], [21].

Agrotourism represents a specific and dynamic component of rural tourism, combining agricultural activities with tourism services and facilitating direct interaction between visitors and rural environments. This form of tourism supports the

multifunctionality of rural areas, integrating economic, environmental, and social dimensions, while contributing to sustainable development processes [2], [8].

Moreover, agrotourism plays a significant role in preserving local traditions, promoting cultural identity, and stimulating entrepreneurial initiatives, thereby strengthening the resilience and cohesion of rural communities [7], [9], [22].

Recent studies also emphasize its contribution to value chain development and the promotion of local gastronomic heritage, which enhances the overall tourism experience and supports local economies [10], [11].

The development of rural tourism is increasingly influenced by broader regional and global dynamics, including cross-border cooperation, economic integration, and policy frameworks aimed at territorial cohesion.

Border areas generate both advantages and challenges for the expansion of tourism activities. The proximity between neighbouring territories, together with their cultural affinities, comparable environmental resources, and long-standing historical interactions, may facilitate the implementation of integrated tourism initiatives.

On the other hand, structural challenges such as insufficient infrastructure, limited visibility of tourist attractions, and fragmented institutional frameworks may hinder the effective exploitation of tourism potential [5], [16], [20].

The Romania–Republic of Moldova cross-border area represents a relevant case for analysing these dynamics, due to its shared historical background, cultural similarities, and geographical proximity. Previous studies highlight that this region benefits from considerable tourism potential, particularly in rural and agrotourism segments, but remains insufficiently capitalized due to constraints related to infrastructure, investment capacity, promotion, and service quality [1], [7], [12].

Furthermore, socio-economic factors, including education levels and functional illiteracy, may influence the capacity of local stakeholders to effectively develop and manage tourism activities [3]. An important advantage of tourism development in the Romania–Republic of Moldova cross-border region is represented by the existence of a shared socio-cultural background, which facilitates interaction between local communities and visitors.

Communities situated on both sides of the Prut River retain numerous socio-cultural similarities derived from a shared linguistic background, comparable religious practices, and longstanding historical interactions. These characteristics facilitate interpersonal communication and support the development of coordinated tourism initiatives capable of strengthening the attractiveness of the cross-border area. The preservation of local traditions and cultural continuity contributes to the creation of distinctive tourism experiences with regional competitive potential. Nevertheless, the political and administrative separation of the two territories over time has resulted in differences regarding institutional organisation and economic development patterns, even though important elements of cultural cohesion have remained. This duality creates both opportunities and challenges for cross-border tourism development. Increasing attention has been directed toward the role of innovation, digital technologies, social innovation, and strategic cooperation in improving tourism competitiveness and supporting sustainable rural economies [4], [6], [10].

The integration of digital tools, including online platforms and geographic information systems, contributes to improving the visibility of tourism destinations, facilitating access to information, and supporting more efficient destination management.

In this context, the CROSS2MAP project represents a relevant example of digital innovation in cross-border tourism, providing an interactive platform for mapping and promoting tourism resources in the Romania–Republic of Moldova border area [14].

In addition, the associated mobile application serves as a practical tool for data collection, visualization, and dissemination of tourism-related information, being used as a complementary research instrument in the present study [15]. At the same time, the increasing use of artificial intelligence (AI)

and data-driven technologies is transforming the tourism sector, including rural tourism and agrotourism.

AI-based tools contribute to improved destination management, personalized tourism services, and more efficient marketing strategies, enhancing the visibility and competitiveness of rural areas. The integration of digital solutions also supports evidence-based decision-making processes and facilitates better resource allocation, which is particularly important in regions with limited administrative and financial capacity. Despite the growing interest in rural tourism and agrotourism, there is still a need for more integrated analyses that address the complex interaction between tourism development, agricultural activities, and cross-border cooperation mechanisms. Moreover, empirical data from official statistical sources, such as the National Institute of Statistics (Romania) and the National Bureau of Statistics (Republic of Moldova), remain essential for understanding tourism dynamics and territorial disparities [16], [17].

Reliable data from reputable statistical agencies, such as the National Institute of Statistics in Romania and the National Bureau of Statistics in the Republic of Moldova, remain essential for understanding tourism trends and persistent gaps across territories [16], [17].

Therefore, the aim of this paper is to analyse the role of agrotourism in supporting rural development in cross-border regions, with a particular focus on the Romania–Republic of Moldova area.

The study seeks to identify key development patterns, structural constraints, and strategic directions for enhancing tourism competitiveness and promoting sustainable regional development.

MATERIALS AND METHODS

The bibliographic documentation was conducted through a systematic review of open-access scientific literature identified in well-established academic databases, including Google Scholar, Clarivate Analytics (Web of Science), and ResearchGate.

In addition, official reports and policy documents issued by national authorities, regional institutions, and international organizations were examined to define the theoretical and institutional framework of rural tourism and agrotourism development.

The theoretical foundation of the research was established through an extensive review and comparative interpretation of academic contributions focused on rural tourism, agrotourism, and cross-border interaction. This methodological perspective supported the examination of the variables influencing tourism evolution, including socio-economic conditions, territorial characteristics, and local development particularities.

In addition, it enabled the incorporation of complementary analytical viewpoints associated with regional development, such as the valorisation of local resources, community participation, and cooperation mechanisms specific to neighbouring border territories.

The analytical component of the research was carried out using statistical datasets released by the National Institute of Statistics (INS) of Romania and the National Bureau of Statistics (BNS) of the Republic of Moldova. Romanian data were extracted from the TEMPO-Online platform, which provides continuously updated indicators organised at national, regional, and county levels. For the Republic of Moldova, the study employed statistical information disseminated through official reports and electronic databases published by BNS. These sources ensure a high level of reliability and comparability of the analysed indicators.

The analysis covers the period 2020–2024, pointing out the status in the final year and allowing for both the assessment of structural changes in agrotourism and a short-term evaluation of recent trends. The main indicators considered include the number of agrotourism guesthouses, accommodation capacity (measured in bed places), tourist arrivals, and overnight stays. These indicators were selected due to their relevance in capturing both the supply and demand dimensions of tourism activity.

The collected data were systematically organized into a structured database and

processed using descriptive statistical methods.

The results were further illustrated through tables, graphical representations, and thematic maps to highlight temporal evolutions and spatial disparities across the analysed regions. The interpretation of the results was based on a comparative analytical framework, focusing on the Romania–Republic of Moldova cross-border area.

This approach enabled the identification of development patterns and the assessment of key structural factors, such as infrastructure availability, investment capacity, and territorial accessibility, which influence tourism performance.

To enhance the robustness and validity of the findings, the statistical analysis was complemented by insights derived from the scientific literature.

The integration of statistical evidence with conceptual and interpretative approaches enabled a more complex evaluation of agrotourism evolution within the border region. Furthermore, several digital instruments created under the CROSS2MAP initiative were incorporated into the research process, mainly to support the localisation and visual representation of tourism assets situated in the analysed territory. The mobile application associated with the project facilitated the collection, systematisation, and examination of tourism information, improving the depth of the spatial assessment.

Furthermore, elements of artificial intelligence (AI) were employed to support specific stages of the research process, including data structuring, literature synthesis, and pattern identification.

The use of AI-based tools facilitated the efficient processing of large volumes of information and supported the identification of relevant relationships within the dataset. However, all AI-assisted outputs were critically reviewed and validated by the authors to ensure scientific rigor, accuracy, and consistency.

Overall, the methodological approach adopted in this study ensures a coherent integration of quantitative analysis, spatial interpretation, and theoretical grounding, providing a solid and reliable basis for the conclusions drawn.

RESULTS AND DISCUSSIONS

The Romania–Republic of Moldova cross-border area illustrates a dual development pattern in agrotourism. While the region benefits from cultural continuity and similar natural resources, significant differences persist in terms of economic development, infrastructure, and tourism capacity [13].

Figure 1 presents the spatial delimitation of the study area. The map was generated using GIS techniques based on administrative boundary data and spatial datasets corresponding to the Romania–Republic of Moldova border area.

Romania registered a substantial increase in agrotourism activities after becoming a member of the European Union, a process supported by access to European funding mechanisms and investments in tourism-related infrastructure. In comparison, the Republic of Moldova recorded a more moderate tourism expansion, although both countries benefit from relatively similar environmental and cultural tourism potential. The Moldovan tourism sector continues to face several structural obstacles, including inadequate infrastructure, limited financial support for tourism initiatives, and a lower degree of destination promotion.

The analysis conducted in this study explores agrotourism development in the cross-border region through the comparative evaluation of tourism indicators, territorial distribution, and regional development differences.

The working hypothesis assumes that geographical proximity does not automatically generate higher levels of development, which are instead influenced by structural factors.

The evolution of agrotourism in Romania highlights a strong upward trend over the analysed period. The number of agrotourism guesthouses increased from 1,348 units in 2008 to 3,578 units in 2024, representing a growth of over 160% (Table 1).

This dynamic reflects a significant transformation in the structure of rural tourism, with agrotourism becoming an

increasingly important component of the tourism sector.

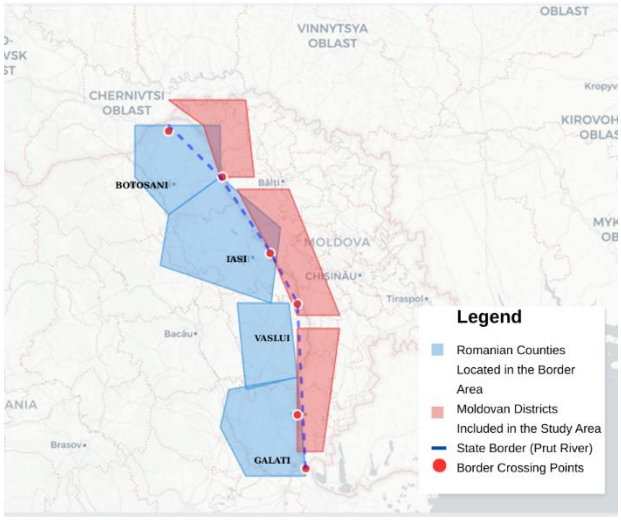

Fig.1. Spatial delimitation of the Romania–Republic of Moldova cross-border study area
Source: own processing based on GIS data [14], [15].

Table 1. Evolution of agrotourism guesthouses in Romania (2008–2024)

Year	Agrotourism guesthouses
2008	1,348
2020	3,022
2021	3,460
2022	3,484
2023	3,498

Source: National Institute of Statistics [19].

This long-term evolution indicates not only a quantitative expansion, but also a progressive consolidation of agrotourism as a viable economic activity in rural areas. The increase in the number of accommodation structures suggests a growing involvement of local communities in tourism-related activities, supported by access to funding opportunities and the diversification of rural economies.

At the same time, the analysis of the recent period (2020–2024) reveals a slower growth rate, from 3,022 to 3,578 units, indicating a transition from rapid expansion to a phase of stabilization and qualitative improvement. This trend suggests the gradual maturation of the agrotourism sector, characterized by increased emphasis on service quality and competitiveness. Tourism demand reflects a similar dynamic. In the first quarter of 2025, Romania recorded 2,496,720 tourist arrivals and 4,773,158 overnight stays, confirming the strong attractiveness of tourism destinations (Table 2).

Table 2. Tourism activity indicators registered in Romania during the first quarter of 2025

Indicator	Recorded value
Tourist accommodation arrivals	2,496,720
Overnight stays in accommodation units	4,773,158

Source: National Institute of Statistics [19].

The evolution of agrotourism infrastructure reflects the intensity of tourism demand within the region. At the same time, the association between accommodation arrivals and overnight stays highlights both the growth in tourist circulation and the increasing duration of visitor presence in rural destinations.

This reflects an improved capacity of destinations to retain tourists, which is essential for the long-term sustainability of agrotourism and for maximizing its economic impact on rural communities.

The predominance of domestic tourism highlights the importance of local and regional demand in supporting rural tourism development.

Agrotourism relies heavily on proximity markets, where accessibility and cultural familiarity play a significant role in attracting visitors. A more detailed territorial analysis reveals significant disparities at county level. Counties such as Iași record higher values in terms of accommodation capacity and tourism demand, reflecting better infrastructure and stronger economic development. In contrast, counties such as Galați and Vaslui show lower values, indicating limited tourism development and reduced competitiveness. The Republic of Moldova presents a lower level of tourism development compared to Romania; however, a gradual upward trend can be observed.

In 2024, the total accommodation capacity reached 25,418 bed places, indicating a modest but positive evolution of the tourism sector (Table 3).

These developments highlight the capacity of the region to further diversify its tourism activities by capitalising on existing environmental and cultural resources.

Table 3. Accommodation capacity in the Republic of Moldova (2024)

District	Accommodation capacity (in beds)
Cahul	1,243
Edineț	440
Ungheni	342
Glodeni	304
Fălești	287
Leova	200
Nisporeni	48
Cantemir	0
Total	**25,418**

Source: National Bureau of Statistics of the Republic of Moldova (2026) [18].

The progressive growth of tourism demand can contribute to greater territorial visibility and may encourage new investment opportunities, supporting the consolidation of tourism competitiveness over the long term.

The evolution of tourist arrivals during the analysed period reveals substantial changes in both the scale and structure of tourism demand (Figure 2).

Statistical data indicate a continuous increase in the total number of tourists, from 90.3 thousand in 2020 to 474.2 thousand in 2024, reflecting the gradual recovery and subsequent expansion of tourism activity following the pandemic period.

The distinction between resident and non-resident tourists provides a more detailed perspective on tourism demand patterns and highlights the different dynamics characterising domestic and international tourism flows. The results reveal a sustained upward trend in both domestic and international tourism, with distinct dynamics between the two categories.

The number of resident tourists increased from 61.6 thousand in 2020 to 220.2 thousand in 2024, indicating consistent growth in domestic tourism.

This trend can be associated with increased interest in local destinations, particularly in rural and agrotourism areas, which are generally more accessible and perceived as safer in the post-pandemic context.

At the same time, the number of non-resident tourists recorded more accelerated growth, from 28.7 thousand in 2020 to 254.0 thousand in 2024. Notably, starting with 2023, the number of non-residents approached and even surpassed that of residents, suggesting a gradual recovery of international tourism flows and an increasing attractiveness of the destination at the external level.

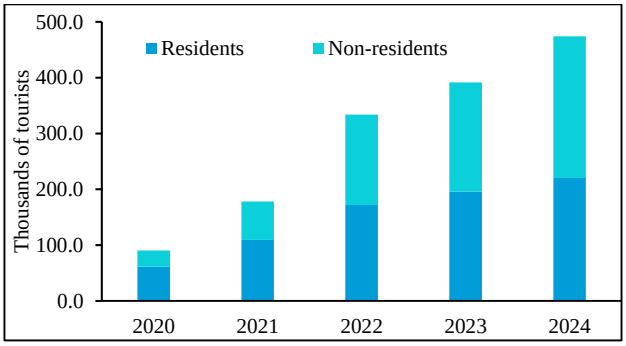

Fig. 2. Evolution of tourist arrivals in Republic of Moldova by residence status (2020–2024)
Source: Republic of Moldova National Bureau of Statistics (2026) [18].

The comparative analysis of the two categories indicates a structural shift in tourism demand. While domestic tourism played a stabilizing role during the pandemic period, international tourism has become a key driver of growth in the later stages of recovery.

This evolution reflects broader trends observed at European level, where tourism recovery has been characterized by an initial reliance on domestic demand, followed by a progressive return of international mobility.

From an economic perspective, the increase in non-resident tourists is particularly relevant, as it is generally associated with higher average expenditure and a stronger contribution to local economies.

In parallel, the upward trend observed in resident tourism emphasises the strategic importance of domestic tourist flows for supporting the stability and long-term resilience of tourism-related activities.

Overall, the data suggests a transition from a recovery phase to a consolidation phase, in which tourism growth is supported by both domestic and international segments. This dual dynamic represents a favourable context for the development of agrotourism, which can capitalize on local demand while simultaneously attracting foreign visitors interested in authentic rural experiences.

The analysis of tourism demand is further complemented by the structure of overnight

stays across different types of accommodation units. This approach allows not only the assessment of overall tourism dynamics, but also the identification of structural differences between accommodation categories.

Data for 2024 indicate a total of 1,557.1 thousand overnight stays, of which 501.3 thousand were generated by non-resident tourists, highlighting the increasing role of international demand in the tourism sector (Figure 3).

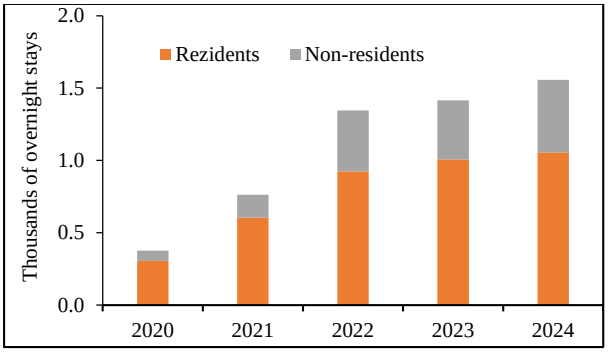

Fig. 3. Evolution of overnight stays by residence status (2020–2024)

Source: National Bureau of Statistics (2026) [18].

The evolution of overnight stays confirms a positive trend in tourism demand, with a total increase of 10% in 2024 compared to 2023. This growth is primarily driven by the expansion of international tourism, as reflected by the significant increase of 22.8% in overnight stays generated by non-residents. A structural analysis by type of accommodation reveals important differences in tourism patterns (Table 4).

Hotels and motels represent the dominant category in terms of overnight stays, accounting for 534.4 thousand overnight stays in 2024, of which a substantial share (422.8 thousand) was generated by non-resident tourists. This indicates that international tourism is highly concentrated in higher-standard accommodation units, reflecting preferences for comfort and accessibility.

In contrast, tourist and agrotourism guesthouses recorded 78.9 thousand overnight stays, with a moderate increase of 3.5% compared to the previous year.

Although their share in total tourism remains relatively limited, these structures play a key role in promoting rural tourism and supporting local economies. The increase of 14.7% in overnight stays generated by non-residents within this category suggests a growing international interest in authentic rural experiences.

Table 4. Overnight stays in Moldova's tourism, 2023-2024

	2024		2024 vs. 2023 (%)		2023 vs. 2022 (%)	
	Overnight stays (thousands)	of which non-residents (thousands)	Overnight stays	of which non-residents	Overnight stays	of which non-residents
Total, of which	1,557.1	501.3	110.0	122.8	105.1	96.7
Hotels and motels	534.4	422.8	124.3	124.5	98.0	98.1
Visitor hostels	81.6	7.2	104.8	194.3	99.8	143.1
Tourist and agrotourism guesthouses	78.9	23.7	103.5	114.7	93.8	63.2
Health and wellness establishments	407.2	6.4	105.0	132.9	103.3	104.4
Holiday and leisure structures*	165.0	40.7	96.1	103.9	116.9	109.7
Holiday camps	290.0	106.8	106.8	611.1	120.1	67.5

*Tourist villas, holiday villages, etc.

Source: National Bureau of Statistics (2026) [18].

Other accommodation types also display distinct dynamics. Structures for rest and recreation recorded a slight decrease in total overnight stays (96.1% compared to 2023), indicating potential stagnation or reduced demand in this segment. On the other hand, holiday camps registered a significant increase in non-resident overnight stays (over 600%), although their absolute contribution remains low, suggesting emerging but still limited international interest.

The comparative analysis highlights that tourism demand is unevenly distributed across accommodation types, with a clear dominance of urban-oriented structures such as hotels and motels, and a more modest, yet stable, presence of rural accommodation units. This pattern suggests that, although agrotourism has development potential, it still occupies a secondary position within the overall tourism system. At the same time, the increasing contribution of non-resident tourists across several accommodation categories indicates a gradual internationalization of tourism demand. This trend is particularly relevant for cross-border regions, where proximity and cultural similarities can facilitate tourism flows. Overall, the combined analysis of

overnight stays and accommodation structure confirms that tourism development is not only expanding in quantitative terms but also undergoing structural transformations. These changes reflect broader economic, social, and behavioural factors influencing tourism demand and underline the need for targeted policies aimed at supporting both mass tourism and niche segments such as agrotourism.

According to the National Bureau of Statistics of the Republic of Moldova [18], the spatial distribution of accommodation capacity reveals significant territorial disparities. Districts such as Cahul and UTA Găgăuzia concentrate a higher number of accommodation units, offering greater tourism capacity. In contrast, districts such as Cantemir and Nisporeni record very low or even negligible levels of tourism infrastructure. This uneven distribution highlights the existence of structural imbalances in tourism development across the region, reflecting differences in accessibility, local investment capacity, and the level of economic development.

The spatial distribution of accommodation capacity in the Republic of Moldova was analysed for the period 2022–2024. The results indicate relatively limited changes in the overall distribution pattern, suggesting a slow pace of development. The most recent spatial distribution is illustrated in Figure 4, corresponding to the year 2024.

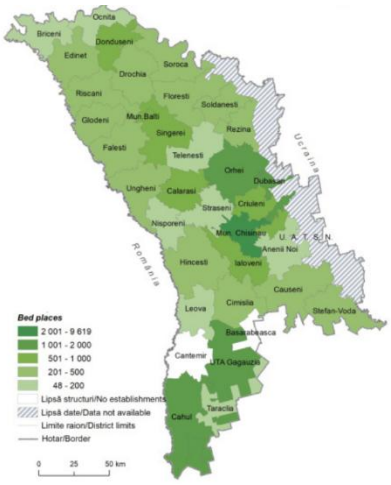

Fig. 4. Spatial distribution of accommodation capacity in the Republic of Moldova (2024)
Source: National Bureau of Statistics [18].

Spatial evaluation for the 2022–2024 period identified a relatively stable territorial configuration, with only limited structural changes, suggesting a gradual evolution of development processes.

Although agrotourism presents growth potential, its expansion remains uneven and strongly dependent on local conditions, including accessibility, infrastructure, and investment capacity.

Figure 5 illustrates the comparative evolution of key agrotourism indicators in Romania and the Republic of Moldova, highlighting differences in accommodation capacity, tourism demand, and the overall level of tourism development between the two countries.

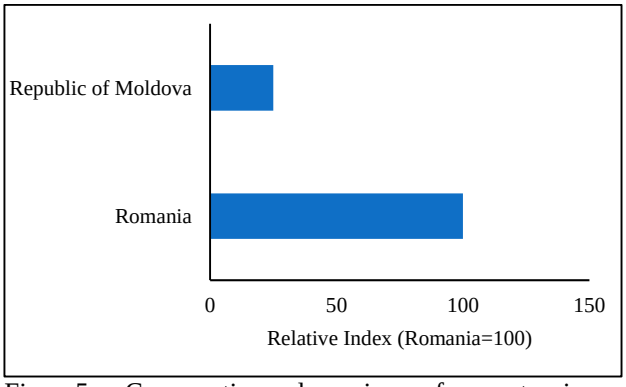

Fig. 5. Comparative dynamics of agrotourism development in Romania and the Republic of Moldova (2020–2024)
Source: Authors, based on National Institute of Statistics [19] and National Bureau of Statistics [18].

A comparative perspective highlights the higher degree of tourism consolidation in Romania, where accommodation infrastructure and tourism demand have reached significant levels. Conversely, the Republic of Moldova displays a less developed tourism profile, characterised by infrastructural limitations and spatial disparities between regions.

These differences indicate that agrotourism development is influenced not only by natural and cultural resources, but also by broader economic, institutional, and infrastructural factors.

The results provide a solid basis for understanding the development patterns observed in the cross-border region.

The analysis reveals a clear asymmetry between Romania and the Republic of Moldova in terms of agrotourism development, both quantitatively and structurally. Romania's agrotourism sector reflects a consolidated system, supported by infrastructure development, access to European funding, and a diversified tourism market. The steady increase in the number of agrotourism guesthouses indicates not only expansion, but also a process of stabilization, suggesting a transition toward structural maturity.

In contrast, the Republic of Moldova presents a developing agrotourism sector, characterized by localized growth and significant territorial disparities. The uneven distribution of accommodation capacity highlights the dependence of tourism development on local initiatives, accessibility, and economic conditions.

From a spatial perspective, the concentration of tourism infrastructure in a limited number of districts reflects structural imbalances and uneven development. This pattern suggests that certain areas benefit from more favourable economic and infrastructural conditions, while others remain underdeveloped.

An important finding of this study is that geographical proximity does not automatically lead to similar levels of development. Although the two countries share cultural heritage and comparable natural resources, the border does not currently function as a catalyst for agrotourism development. Instead, it reflects structural differences that limit integration. This interpretation is consistent with previous research, which emphasizes that tourism development is primarily influenced by economic, institutional, and infrastructural factors rather than by geographical proximity alone [4], [20].

At the same time, the results highlight significant opportunities for cross-border cooperation. The complementarities between Romania's developed infrastructure and Moldova's authentic rural tourism potential could support the development of integrated tourism products. Such initiatives could enhance regional competitiveness, stimulate local economies, and contribute to reducing territorial disparities. Therefore, strengthening cross-border cooperation represents a key direction for future development.

CONCLUSIONS

The present study analysed the development of agrotourism activities in the Romania–Republic of Moldova cross-border area, focusing on tourism indicators, spatial distribution, and comparative dynamics between the two countries.

The results highlight significant differences in both the level and structure of agrotourism development. Romania demonstrates a comparatively consolidated agrotourism sector, characterized by a substantial increase in the number of guesthouses, strong tourism demand, and a diversified accommodation offer. This evolution has been supported by sustained investment, access to European funding, and the growing interest in rural tourism experiences.

In contrast, the Republic of Moldova presents a developing agrotourism sector, characterized by moderate growth and pronounced territorial disparities. The spatial distribution of accommodation capacity indicates a concentration of tourism activities in areas with better accessibility, infrastructure, and economic opportunities, highlighting the strong influence of local conditions on development patterns.

The study confirms the initial hypothesis that geographical proximity does not automatically lead to higher levels of agrotourism development. Although the two countries share similar cultural and natural characteristics, differences in economic, institutional, and infrastructural frameworks play a decisive role in shaping development trajectories.

From a territorial perspective, agrotourism development remains unevenly distributed, being concentrated in areas with favourable conditions. This suggests the existence of untapped potential in less developed regions, particularly in border areas, where targeted

interventions could stimulate local economic growth and reduce regional disparities.

The findings emphasize the importance of integrated public policies aimed at supporting rural development and promoting agrotourism as a tool for economic diversification. Strengthening the link between agriculture and tourism can generate additional income sources, support local value chains, and enhance the resilience of rural communities.

Existing complementarities between Romania and the Republic of Moldova create favourable premises for the expansion of cross-border tourism partnerships. The more advanced tourism infrastructure developed in Romania, combined with the traditional and rural tourism potential identified in the Republic of Moldova, can support the development of coordinated tourism offers and shared territorial promotion initiatives. These measures may strengthen the long-term competitiveness of the analysed region.

A limitation associated with this investigation is represented by the exclusive use of official statistical sources, which may underestimate tourism activities taking place outside formally registered accommodation structures or within small-scale local initiatives.

Future research could address qualitative dimensions, such as tourist behaviour, local community involvement, and the role of digitalization and artificial intelligence in supporting rural tourism development.

Overall, the study contributes to a better understanding of agrotourism dynamics in cross-border regions and provides a relevant basis for policy development aimed at reducing territorial disparities and promoting sustainable rural growth.

ACKNOWLEDGEMENTS

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GARLIC CULTIVATION - ECONOMIC OPPORTUNITY AND AGRICULTURAL PROSPECTS IN ROMANIA

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Abstract

In Romania, garlic (Allium sativum L.) has become popular because it survives well during winter and can be cultivated in autumn before the frost sets in. Romanian garlic is cultivated because it is a profitable investment that brings considerable income to farmers who grow this plant, in a context where Romanian consumers are increasingly looking for Romanian products with superior nutritional qualities. In this context, garlic cultivation has become a business opportunity, with a substantial contribution from the subsidy granted, the de minimis aid being €3,000/ha in 2024, for a minimum eligible area of 0.1 ha. The paper addresses a comparative study on the productivity of garlic cultivation and the evolution of cultivated areas between 2021 and 2024 at the national level. The analysis aims to identify the development trends and productivity of this horticultural crop. Our country is a major producer, with a maximum production of 60,601 tons in 2021, after which a downward trend was recorded with 45,801 tons in 2023 and 41,628 tons in 2024, due to drought and water shortages that caused major problems for this crop.

Key words**:** *garlic, production, Romania, opportunity of cultivation*

INTRODUCTION

Agriculture is one of the most important sectors of the economy, playing a vital role in ensuring food security and the sustainable development of society. In the current context, marked by climate change and a population growth projected to reach 10 billion people by 2050, the need for efficient use of natural resources and the optimization of crop cultivation such as garlic cultivation on farms has become a major priority.

Garlic (*Allium sativum L.*) is one of the oldest and most valuable crops cultivated worldwide, valued for both its culinary and medicinal properties.

Garlic was used as an antiseptic to prevent gangrene during World War I, and it is also mentioned in the Bible. Over 300 varieties of garlic are known to be cultivated worldwide, primarily in hot and dry regions, and it ranks among the top twenty most important vegetables in the world [4]. Garlic was domesticated in the 1980s, when fertile plants were discovered in Central Asia that could be studied in terms of flowering and seed production; since garlic is an asexual plant that propagates only vegetatively, this discovery opened up new avenues of research in genetics, plant breeding, and plant physiology [8].

Bulbs are an adaptation of the plant to the growing conditions of arid regions, which are characterized by dry summers. Globally, garlic is grown primarily in temperate climates, with an annual production of approximately 28 million tons on an area of about 1.6 million hectares. The main producers are China and India, which account for approximately 80% of global production [11].

Currently, China, which holds a clear lead in global production, faces challenges such as insufficient integration of agricultural machinery, crop mechanization, garlic sowing, inadequate agricultural practices, and a lack of standardization in planting methods [19].

Comparing 100 countries in 2022, China ranked first in garlic production with 21,338

kt, maintaining its top position for over 10 years, followed at a considerable distance by India with 3,208 kt and then Bangladesh with 527 kt, according to the FAO, with all three countries accounting for 86% of global production. Historically, total garlic production reached an all-time high of 29,149 kt in 2022 [6].

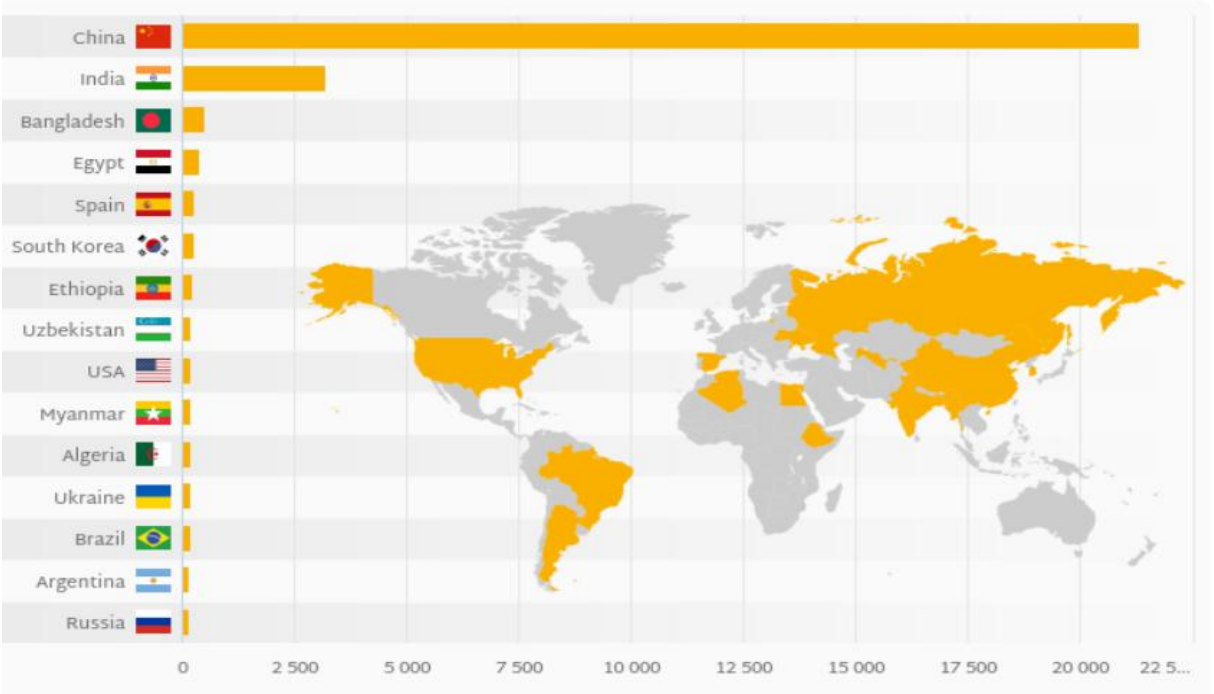

Fig. 1. Garlic production in 2022 (kt)
Source: [6].

Garlic cultivation has a long tradition in Romania as well, being practiced in most agricultural areas, particularly in home gardens, where it helps supplement rural incomes. Interest in this crop has grown steadily, driven by increasing demand both domestically and internationally, as well as by agricultural policies aimed at supporting Romanian producers. Although garlic benefits from favorable growing conditions in Romania—tolerating winters well and requiring temperatures between approximately 20°C and 38°C during the growing season—achieving high yields is hindered by a number of challenges. These include competition from imports, the use of traditional technologies, low levels of investment in mechanization, and the lack of modern irrigation systems—factors that contribute to the diminished competitiveness of local producers in the market [15].

Garlic prefers fertile, well-aerated, and well-drained soils with a pH between 6 and 6.5, and to achieve high yields, it requires balanced fertilization based on NPK nutrients. In Romania, the number of garlic varieties approved and used in production is relatively small, limited to seven varieties approved and available in 2021, which highlights the need to intensify research aimed at selecting varieties better adapted to local soil and climate conditions [16].

In Romania, there are few studies that characterize the genotypes of cultivated garlic, as well as the influence of environmental factors such as soil quality, agricultural practices, climatic conditions, or photoperiod [17]. Furthermore, temperatures exceeding 42–43°C can cause heat stress, leading to slower plant growth and an increased risk of sunscald. At the same time, research shows that late planting can result in significant losses, and establishing the crop in the spring leads to a yield reduction of approximately 16% [14]. Garlic can survive winter temperatures as low as -25 °C if it is well-

rooted and begins to grow at temperatures of 3–5 °C [12].

Vegetative multiplying of garlic has the disadvantage of transmitting pathogens, viruses, and mycoplasmas, ultimately resulting in reduced plant vigorous, lower yields, and poorer crop quality [7].

Although garlic is frequently used as a bioinsecticide, it is affected by a relatively small number of pests, which can significantly impact crop yields in Romania. Among the most important pests are wireworms (*Agriotes spp., Coleoptera: Elateridae*) and nematodes (*Ditylenchus dipsaci, Tylenchida: Anguinidae*), considered the most problematic, with damage observed in approximately 40% of the plants analyzed [3].

The current state of garlic genetics and genomics highlights recent developments that will lead to its evolution into a modern crop, including the development of sexual reproduction in certain garlic varieties, the genetics of infertility, the induction of flowering and bulb formation, organoleptic properties, and resistance to various pathogens [11].

In this context, the paper aimed to make a comparative study on the productivity of garlic cultivation and the evolution of cultivated areas between 2021 and 2024 at the national level in order to identify the development trends and productivity of this horticultural crop.

MATERIALS AND METHODS

The research is based on a statistical-comparative analysis method, used to highlight trends in production and area indicators for the 2021–2024 period. This sequential analysis highlights the dynamics of total production and annual variations in the total area under garlic cultivation.

By comparing statistical data for the period under review, the aim is to assess the sector's performance and determine the growth potential of garlic cultivation in Romania, in the context of domestic demand and competition with imported products.

The data used in this study consists of official statistical data on garlic cultivation in Romania. The information was obtained from public databases provided by the National Institute of Statistics (INS) via the TEMPO-Online platform [10], as well as from reports published by the Ministry of Agriculture and Rural Development (MADR) [13]. These sources ensure the official, comparable, and relevant nature of the data used in the analysis.

Statistical analysis served as the basis for interpreting data on yields and cultivated areas, enabling the organization, comparison, and synthesis of information at the national level and by macro-development regions. This method highlighted regional differences and trends in garlic cultivation.

The calculation of the average was used to determine the average value of cultivated areas and average total yields obtained during the period examined, facilitating comparisons between regions.

In addition, the interpretation of the statistical data took into account trends over time (year-over-year changes) as well as correlations with the economic importance of the crop in different areas. Thus, the methods used provide a clear and comparative picture of the distribution and evolution of cultivated areas and total yields for garlic cultivation in Romania, by macro-development regions. Romania is divided into four macro-development regions, which include the following regions:

- Macro-region 1, comprising the Northwest and Central regions;
- Macro-region 2, which comprises the Northeast and Southeast regions;
- Macro-region 3, comprising South Muntenia and Bucharest-Ilfov;
- Macro-region 4, comprising the South-West Oltenia and West regions.

RESULTS AND DISCUSSIONS

As the population's material well-being improves, the composition of the food basket shifts toward increased consumption of vitamin-rich vegetables, including garlic. This trend, combined with the opportunity to fully utilize the existing natural and economic potential for garlic production, should serve as

the basis for the future development of the vegetable industry [1].

Total garlic production in Romania varies depending on climatic conditions, ranging from 55,000 tons (2017) to 21,000 tons (2021), with Romania remaining among the top producers in the European Union; the average yield per hectare in Romania is between 8 and 15 tons.

Under average technological conditions, garlic productivity in Romania frequently ranges between 4–8 tons/ha; however, on high-performing farms where modern technologies are applied (drip irrigation, balanced fertilization, etc.), yields can exceed 10–12 tons/ha.

Trends in Key Indicators for Garlic Cultivation in Romania

Regarding the trends in total production and total garlic cultivation area, we observe that total production is declining significantly, from 60,601 tons in 2021 to 41,628 tons in 2024, representing a decrease of approximately 31.3%. This trend reflects disadvantageous weather conditions and challenges related to pest infestations, inconsistent application of agricultural technologies, or reduced costs and profitability (Table 1).

Table 1. Trends in key indicators for garlic cultivation, 2021–2024

Indicators	**2021**	**2022**	**2023**	**2024**	Average 2021-2024
Total production, t	60,601	50,235	45,801	41,628	34,566.3
Total area, ha	9,569	8,986	8,713	8,429	8,924.25

Source: Own calculations based on the data from National Statistical Institute, 2026 (INS) [10].

At the same time, the cultivated area is gradually shrinking, from 9,569 hectares in 2021 to 8,429 hectares in 2024, a decrease of approximately 12%. The slower rate of decline in cultivated area compared to that of production indicates that, in addition to the reduction in land area, productivity per hectare has decreased (Figure 2).

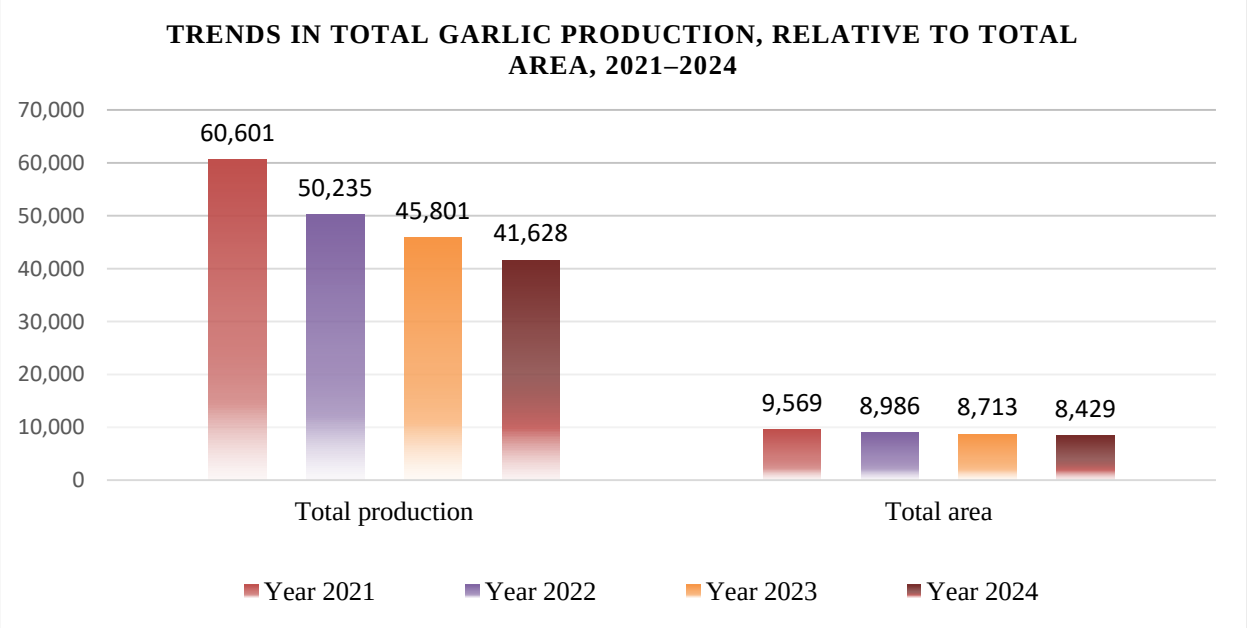

Fig. 2. Trends in total production relative to the total area planted with garlic
Source: Own calculations based on the data from National Statistical Institute, 2026, (INS), [10].

Thus, the data highlight a decline in both cultivated area and yield, suggesting the need to adopt more efficient agricultural technologies, improve irrigation systems, and enhance support policies for Romanian producers.

Regarding the dynamics of average production by macro-development regions, the table shows a general decline in

production across all four macro-regions between 2021 and 2024, confirming a negative trend at the national level.

An analysis by development macro-regions indicates that Macro-region 2 remains the most productive across all the years examined, but has seen a significant decline in production of approximately 37% (from 21,918 tons to 13,771 tons) (Table 2).

Table 2. Trends in average production by development macro-region, 2021–2024, in tons

Macro-regions	Total productions, tons			
	2021	2022	2023	2024
Macro-region 1	10,380	8,062	7,327	6,608
Macro-region 2	21,918	17,547	15,881	13,771
Macro-region 3	11,672	10,354	9,282	8,911
Macro-region 4	16,631	14,272	13,311	12,338
Average	15,150.25	12,558.75	11,450.25	10,407

Source: Own calculations based on the data from National Statistical Institute, 2026, (INS,) [10].

Macro-region 4 shows a moderate decline of around 26%, from 16,631 tons in 2021 to 12,338 tons in 2024, suggesting relatively greater stability in production in this area.

Macro-region 3 shows the slowest decline, approximately 24% (from 11,672 tons to 8,911 tons), making it the most stable in terms of production trends. Macro-region 1 has the lowest production over the entire period and a significant decline of approximately 36%, which may reflect less advantageous conditions and a lower importance of the crop in this region.

Average production by region is steadily declining, from 15,150.25 tons in 2021 to 10,407 tons in 2024, indicating a general downward trend in production across regions (Figure 3).

Macro-region 2 ranks first, with an average production of 17,279.25 tons, reflecting very favorable conditions for garlic cultivation. Next, macro-region 4 contributes significantly to national production, with an average of 14,138 tons, although this is 3,141.25 tons lower than in macro-region 2.

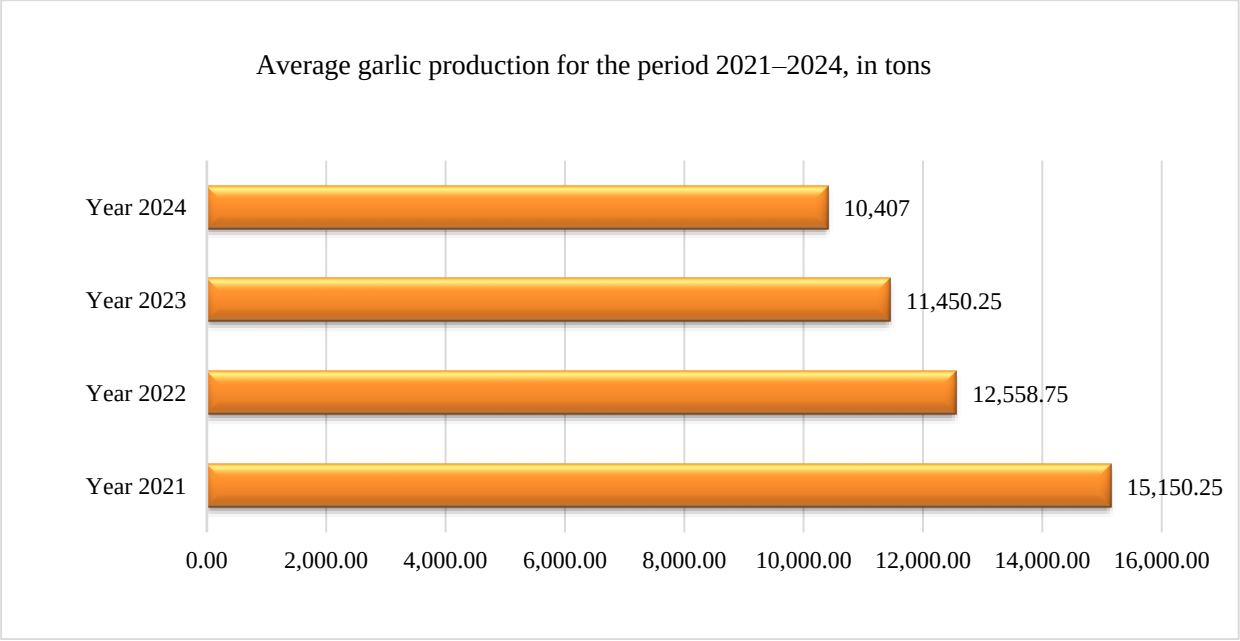

Fig.3. Average garlic production for the period 2021–2024
Source: Own calculations based on the data from National Statistical Institute, 2026, (INS,) [10].

Macro-region 3 ranks third, with an average production of 10,054.75 tons, while macro-region 1 records the lowest production, at 8,094.25 tons, suggesting less favorable conditions for this crop (Table 3). An analysis of Table 4 indicates a downward trend in the area under garlic cultivation across all of the country's macro-regions between 2021 and 2024, from 2,392.5 hectares in 2021 to 2,107.25 hectares in 2024 (Table 4).

Table 3. Ranking by development macro-region based on average garlic production, in tons

Macro-regions	Average production (2021–2024), tons	Ranking
Macro-region 1	8,094.25	IV
Macro-region 2	17,279.25	I
Macro-region 3	10,054.75	III
Macro-region 4	14,138	II
Average	12,391.56	

Source: Own calculations based on the data from National Statistical Institute, 2026, (INS,) [10].

Table 4. Average area planted with garlic, 2021–2024, ha

Macro-regions	Total area, ha			
	2021	2022	2023	2024
Macro-region 1	1,628	1,377	1,355	1,332
Macro-region 2	3,314	3,308	3,114	2,901
Macro-region 3	1,856	1,777	1,746	1,723
Macro-region 4	2,772	2,524	2,498	2,473
Average	2,392.5	2,246.5	2,178.25	2,107.25

Source: Own calculations based on the data from National Statistical Institute, 2026, (INS) [10].

Macro-region 2 has the largest cultivated areas, ranking first, but a gradual decline is noted, from 3,314 hectares in 2021 to 2,901 hectares in 2024. Next is macro-region 4, which, although it maintains large cultivated areas averaging 2,566.75 hectares, is also experiencing a downward trend.

Table 5. Ranking by macro-development region, based on the average area planted with garlic, in hectares

Macro-regions	**Average area (2021–2024)**	**Ranking**
Macro-region I	1,423	IV
Macro-region II	3,159.25	I
Macro-region III	1,775.5	III
Macro-region IV	2,566.75	II
Average	2,231.12	

Source: Own calculations based on the data from National Statistical Institute, 2026, (INS,) [10].

Macro-region 3 shows a slight and steady decline, being the most stable in terms of changes in cultivated area, with an average of 1,775.5 hectares. In contrast, macro-region 1 has the smallest cultivated area—approximately 1,423 hectares on average—and a more pronounced decline during this period (Table 5).

Figure 4, shows a steady decline in the average area planted with garlic in Romania between 2021 and 2024. The largest average area is recorded in 2021, at 2,392.5 hectares, followed by a gradual annual decline, reaching 2,107.25 hectares in 2024. This decrease is gradual and without significant variations, highlighting a downward trend (Figure 4).

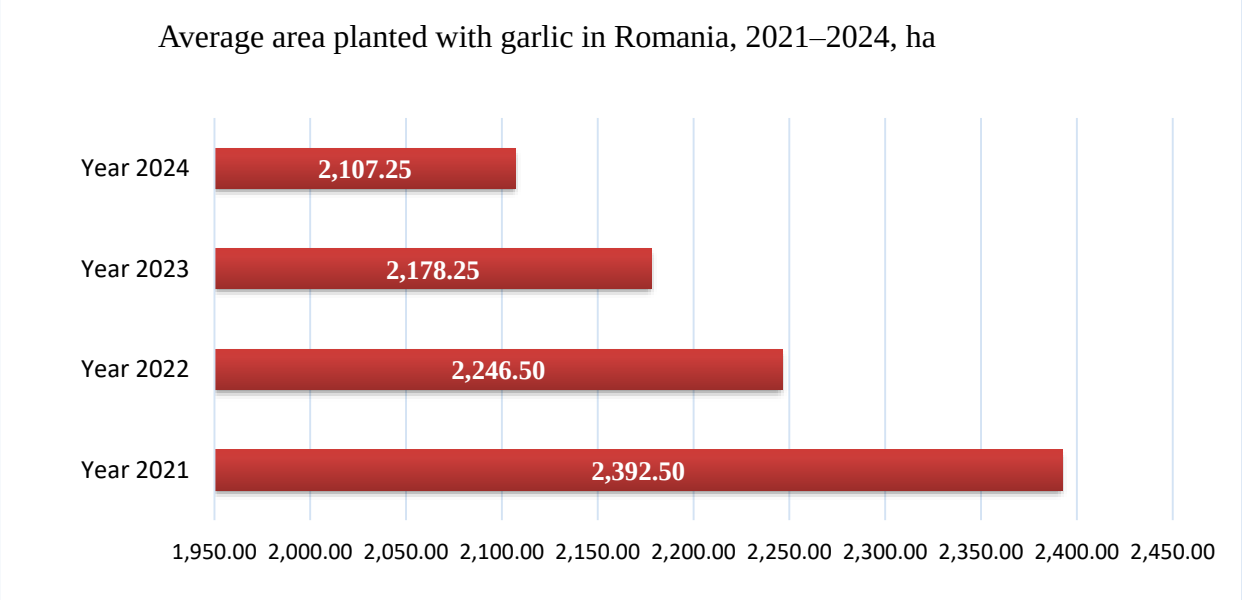

Fig. 4. Average area planted with garlic during the 2021–2024 period
Source: Own calculations based on the data from National Statistical Institute, 2026, (INS,) [10].

In 2024, yields dropped significantly, with producers reporting declines of up to 60% compared to a normal year; the situation was critical in non-irrigated areas [2].

The Economic Importance of Garlic Cultivation

Garlic farming is of significant economic importance, as it is a crop valued for the benefits that contribute to its sustainability and profitability. Garlic commands a relatively stable market price, which provides farmers with important financial predictability. It can also be sold both fresh and in processed form, increasing its added value.

Furthermore, farmers can sell garlic directly in local markets, benefiting from a close connection with consumers, or they can choose to join agricultural cooperatives, which can facilitate access to diverse markets and more beneficial commercial terms. Thus, garlic cultivation contributes not only to the diversification of agricultural income but also to the sustainable economic development of rural areas [1].

Start-up costs. The start-up costs for garlic cultivation are moderate, and the short growing season allows for rapid crop rotation and the optimal use of agricultural land.

Based on an analysis of the main production costs for garlic, achieving an estimated yield of 7,000 kg/ha requires agrotechnical expenses in total 15,949 Euros [2].

Studies show that the initial costs for growing one hectare of garlic range from 15,000 to 20,000 euros and include the following items:

- Purchase of garlic cloves for planting, amounting to 4,000–6,000 euros;
- Soil preparation and fertilization, ranging from 2,500 to 4,000 euros;
- Installation of the irrigation system, estimated at 1,500 to 3,000 euros;
- Labor costs for planting, maintenance, and harvesting, ranging from 5,000 to 7,000 euros.

In terms of production, one hectare can yield between 5 and 10 tons of garlic, with total revenue ranging from 50,000 to 100,000 euros, depending on the quality of the harvest and market prices. After covering costs, the annual net profit can exceed 30,000 euros [5].

Government measures to support garlic producers, through subsidies to compensate for losses caused by drought, underscore the strategic economic importance of this crop for Romania.

These financial interventions not only help small and medium-sized farms maintain and increase production, but also contribute to reducing dependence on imports, thereby strengthening the domestic agricultural sector. Consequently, the support provided reflects the recognition of garlic's economic value as a profitable and important crop in Romania's economy. To encourage domestic production, the state offered financial aid in the form of "de minimis" support for farmers growing garlic [2].

In 2024, the Government continued the "Garlic" support program, granting a subsidy of 1,500 euros per hectare to farmers who cultivated at least 0.3 hectares, in accordance with Government Emergency Ordinance 13/2024 (MDR) [9].

CONCLUSIONS

An analysis of the key indicators for garlic cultivation reveals a gradual decline in both cultivated area and production volume each year.

In conclusion, garlic production is declining in all macro-regions, albeit to varying degrees. Macro-regions 3 and 4 are the most affected, while macro-region 2 stands out for having the highest total garlic production.

In terms of the trend in total production, the decline is steady, with no major fluctuations, indicating the influence of factors such as drought, rising costs, a reduction in cultivated areas, or technological challenges. The rate of decline is more pronounced during the 2021–2022 period, after which it moderates slightly in some regions.

The distribution of total garlic production nationwide is uneven, with macro-regions 2 and 4 holding an advantage, as they dominate this market through their significant contribution.

Regarding the total area under garlic cultivation in Romania, this is gradually decreasing across all macro-regions, while

maintaining a stable hierarchy, with macro-region 2 in first place.

The national average farm size is expected to decline from 2,392.5 hectares in 2021 to 2,107.25 hectares in 2024, reflecting a general decline in interest in farming.

Thus, although the area under cultivation has shown a slight decline depending on the agricultural year, farmers remain interested in this crop, as they are also encouraged by the de minimis aid scheme provided by the Romanian government.

Although it involves high production costs, these characteristics make garlic an attractive option for small and medium-sized farms, for which this crop can be an important source of income.

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SUSTAINABLE RURAL DEVELOPMENT OF SASCA MONTANA, CARAS-SEVERIN COUNTY, ROMANIA, THROUGH THE TOURISM VALORIZATION OF NATURAL AND CULTURAL RESOURCES

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Abstract

The manuscript analyses the potential for sustainable development of the Sasca Montana commune by capitalizing on existing natural and cultural resources. The research adopts a mixed-methods approach, combining documentary and statistical analysis, assessments of infrastructure and accessibility, SWOT analysis, as well as semi-structured interviews conducted with key local stakeholders. The results highlight the presence of an exceptional natural heritage (karst landscapes, biodiversity, protected areas) and a valuable cultural heritage that remains insufficiently valorised. Although tourist accommodation facilities have diversified and increased in number, their utilization continues to be affected by seasonality and the lack of integrated complementary services. The findings confirm rural tourism and agrotourism as the main drivers of future sustainable development; however, their current impact remains moderate, being constrained by deficient infrastructure, reduced administrative capacity, and population aging.

Key words**:** *sustainable rural development, rural tourism, agrotourism, natural resources, cultural resources, Sasca Montana*

INTRODUCTION

Sustainable rural development represents one of the priority directions of European and national policies, aiming to improve the quality of life in rural areas through the responsible use of natural, cultural, and human resources [3] [13]. In this context, the intelligent capitalization of local heritage becomes an essential element for revitalizing communities located in isolated areas or areas with insufficiently exploited potential [11] [28] [29].

Mountain rural communities in Romania face numerous economic and social difficulties, such as depopulation, population aging, deficient infrastructure, and poor capitalization of local resources [7] [20] [25].

Territorial development and rural tourism and agrotourism are linked to each other [1] [5] [6]. Rural tourism involves tourists from rural areas attracted by the distinctive character of the landscape, recreational activities such as local resources and food, as well as the potential for spiritual, ecological and cultural growth [9]. In Romania there are also well-developed mountain destinations, such as Marginimea Sibiului [2] [8] [18], Maramures Area [15], Mountain Area in Bihor County [21], Apuseni Mountains [4] [12] [32], Moieciu Area [22], Bucovina [14] [24] in terms of infrastructure and visibility on the tourist market, which have managed to gain notoriety both nationally, and internationally, developing coherently, capitalizing on its natural and cultural heritage and offering services in successful agrotourism guesthouses, which have continuously developed both numerically and in terms of comfort level. Despite the growing body of

literature on rural tourism and sustainable development in Romanian mountain regions, most studies focus on well-established destinations or on descriptive assessments of tourism potential. However, limited attention has been paid to the relationship between tourism resources, tourism activity indicators, and local development dynamics in small and less-developed rural communities [16] [10] [19].

In particular, there is a lack of integrated analyses combining statistical indicators of tourism activity with local stakeholders' perceptions in order to assess the extent to which tourism potential is effectively transformed into economic and social benefits at the local level.

The contribution of this study lies in providing an integrated assessment of tourism-based rural development at the level of a small mountain community, by combining quantitative analysis of tourism activity indicators with qualitative insights from local stakeholders.

By linking tourism resources, tourism performance indicators, and community perceptions, the study offers a more comprehensive understanding of the gap between tourism potential and its actual economic valorization.

Sasca Montana, a locality located in the Anina Mountains area, in Caras-Severin County, is characterized by a distinct combination of natural resources, traditions, cultural elements and karst landscapes, which can support a sustainable, integrated and long-term development [34]. The locality benefits from a valuable natural setting, highlighted by the presence of the Nerei-Beusnita Gorges National Park, one of the most important protected areas in Romania, whose biodiversity and geomorphological particularities attract an increasing number of tourists [23].

In addition to natural resources, Sasca Montana has a diverse cultural heritage, resulting from mining activities, multicultural influences and local rural traditions [30]. However, these resources are insufficiently exploited from a sustainable point of view, and their economic potential remains only partially exploited. At the same time, the commune faces problems specific to the rural environment, such as demographic decline, population ageing, poor infrastructure and limited economic opportunities [27].

In this context, the development of coherent strategies for the sustainable use of natural and cultural resources becomes essential for strengthening local identity, diversifying the economy and promoting responsible tourism [17] [26].

The present paper aims to carry out an integrated analysis of the natural and cultural resources of Sasca Montana commune and to identify the most efficient ways to capitalize on them in order to support sustainable rural development. The study is based on the analysis of the theoretical framework of sustainable development, the assessment of local resources, the analysis of tourism potential and the identification of economic development opportunities, in accordance with the principles of environmental protection and heritage conservation.

Through the proposed interdisciplinary approach, the research offers an applied perspective, useful both to the academic environment and to the local administration, community organizations and economic actors interested in revitalizing the area. Finally, the analysis formulates strategic directions that support the sustainable development of Sasca Montana commune, based on the principles of sustainability, local identity and responsible use of resources.

MATERIALS AND METHODS

The research employs a mixed approach, both quantitative and qualitative, structured into the following stages:

- documentation and theoretical analysis, consisting of the review of specialized literature on sustainable rural development, rural tourism, natural resource management, and the capitalization of cultural heritage, as well as the analysis of the European and national financial support framework;
- analysis of local resources, consisting of the inventory of natural resources through consultation of protected area databases and

natural park management documents, and the evaluation of cultural heritage through the study of local archives;
- socio-economic analysis of the commune, consisting of the processing of demographic and economic indicators, as well as the analysis of tourism infrastructure and the level of accessibility, followed by a SWOT analysis related to local development;
- quantitative method, descriptive-analytical, based on secondary data: determination of the main indicators of tourism activity in Sasca Montana commune (2001–2024), the analysis included three primary variables: the accommodation capacity in operation (places-days), the number of arrivals in tourist reception structures and the number of overnight stays, corresponding to the analysed territorial unit. Based on these data, two derivative indicators were calculated, used to assess the efficiency of tourism activity and tourist behaviour:

$$Average\ stay = \frac{Overnight\ stays}{Arrivals}$$

$$Occupancy\ Rate = \frac{Overnight\ stays}{Capacity\ in\ operation}$$

- qualitative methods included field observation and semi-structured interviews with relevant local actors (government representatives, entrepreneurs, protected area specialists and tour operators). The sample included 30 participants, considered sufficient to achieve thematic saturation. The interviews, conducted in September 2025 (face-to-face and online), lasted 15–20 minutes and were based on open-ended questions on resources, tourism impact, constraints and development prospects. The participants were informed and expressed their consent. Confidentiality and anonymity of participants were ensured;
- following these research activities, a synthesis is developed to support the formulation of strategic directions for the sustainable development of the commune.

RESULTS AND DISCUSSIONS

The results and discussions section of the article is structured into three parts:
- the first part includes the presentation of the study area analyzed in the article;
- the second part consists of the socio-economic analysis of the commune, finalized with a SWOT analysis;
- the third part presents the applied research and its results.

Part I – Presentation of the studied area – Sasca Montana commune

Geographical location. Sasca Montana commune is located in the south-western part of Caras-Severin County, Banat region, Romania, in the mountainous area of southern Banat, at the intersection of the Locvei Mountains to the west, the Almajului Mountains to the east, and the Anina Mountains [27].

Natural resources. From a geographical point of view, the relief of Sasca Montana commune is specific to the relief levels existing within its territory: 70% hills and 30% mountains [31].

The climate of Sasca Montana is influenced by phytoclimatic conditions and Mediterranean influences, characterized by moderate winters, hot summers, abundant rainfall, low thermal amplitudes and rare extreme phenomena. [35].

Hydrography. The commune is crossed by the Nera River, 125 km long, with a total catchment area of 1,400 km² (exclusively on Romanian territory), which originates in the Semenic Mountains from two springs, one below Piatra Goznei Peak (1,477 m), Nerganita, and the other below Piatra Nedeii Peak (1,453 m), Nergana [35].

Flora and fauna from Sasca Montana are diversified, including rare Balkan and Mediterranean species, as well as numerous valuable animals and birds, concentrated in the Cheile Nerei–Beușnița National Park, with regional ecological importance. [27].

The territory of Sasca Montana commune offers variable pedogenetic conditions, corresponding to areas of the cambisol class (43%), molisols (35%), and argiluvisols (22%).

Part II – Socio-economic analysis of Sasca Montana commune. Demography of Sasca Montana commune.

The demographic evolution of Sasca Montana commune highlights a clearly declining trend during the period 1993–2020, followed by a

period of relative stabilization after 2020 (Figure 1).

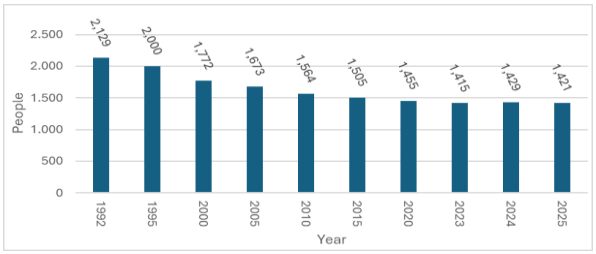

Fig. 1. Evolution of the population of Sasca Montana commune, 1992–2025
Source: Own processing based on [33].

With regard to the population structure by gender, Figure 2 shows a predominance of the male population, which is due to the occupational specificity of the area, determined by the presence of mining activities within the commune in the past.

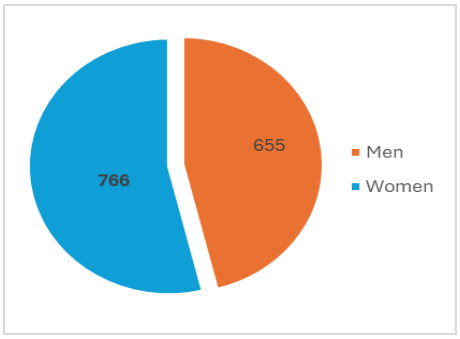

Fig. 2. Gender structure of the population of Sasca Montana commune in the year 2025
Source: Own processing based on [33].

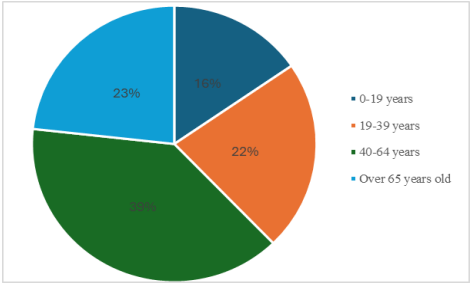

Fig. 3. Population structure of Sasca Montana commune by age groups, 2025
Source: Own processing based on [33].

Regarding the age structure of the population of Sasca Montana commune, the analysis of Figure 3 indicates that the population of the commune is aging.

Regarding the natural and migratory population growth at the commune level during the analyzed period, the following aspects can be observed:

- a period of accelerated demographic transition between 1992–2000, marked by negative natural growth that began in the first decades after 1990;
- the period 2001–2010 is characterised by an intensification of natural population decline, as natural growth continued to decline, reaching particularly low levels in 2010;
- the period 2011–2020 is marked by a stagnation of decline, with no prospects for natural recovery, with natural growth values remaining negative due to the stabilisation of birth rates at very low levels and mortality at high levels. (Figure 4).

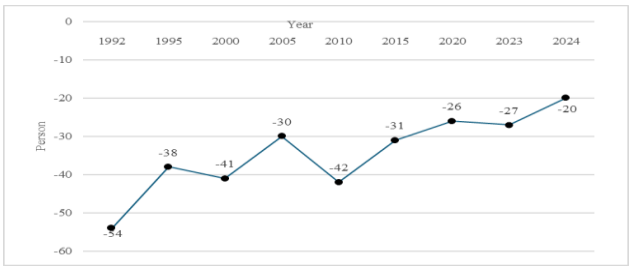

Fig. 4. Natural population growth of Sasca Montana commune, during the period 1992–2024
Source: Own processing based on [33].

The migration of the population in Sasca Montana commune is analysed according to its evolution, in stages:

- the first stage of analysis, 1992–2000, is characterized by a strong negative migration because of the restructuring of mining activities in the commune.
- the period 2001–2010 shows a continuation of negative migration, with an increase in external emigration, as the young population has permanently left the commune, reducing the reproductive demographic base;
- the period 2011–2019 shows a trend towards stabilization and even a reduction in external migration, with a growing interest in tourism in the Nera Gorges area, which brings more small and medium-sized investments. The first guesthouses and holiday homes (small entrepreneurial initiatives) appeared;
- In the period 2020–2024, the following trends can be observed: relocations of people from urban areas to natural areas, acquisition of properties for tourism purposes. As of 2023, the increase in migration has started to decrease again, but not drastically.

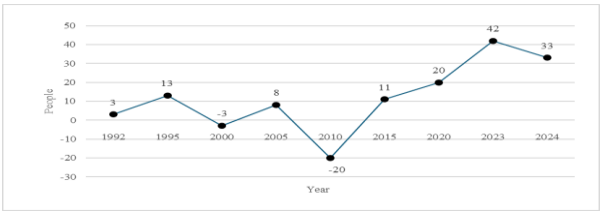

Fig. 5. Migratory population growth of Sasca Montana commune, during the period 1992–2024
Source: Own processing based on [33].

Natural depopulation is the dominant phenomenon at the commune level. However, migration can, under certain conditions, mitigate demographic decline by attracting new residents or investors, representing an opportunity for recovery through tourism and investment.

Economic activities in Sasca Montana commune. The local economy is based on the following activities: subsistence agriculture, in both the crop and animal sectors, the exploitation of forest resources, tourism (a growing sector) and small traditional crafts. The main activity that can contribute to the revitalization of Sasca Montana commune is tourism, by capitalizing on the natural and cultural resources existing in the area.

Presentation of resources (tourist attractions) in Sasca Montana commune, according to their origin:

1. Natural resources are divided into three categories:

Karst landscapes and natural attractions, the area being one of the most spectacular karst regions in Romania, including the following main tourist attractions:

- **The Nera Gorges** are a protected area of national interest (IUCN Category II), located in the Anina Mountains, Caras-Severin County, representing the longest gorge in Romania, characterized by spectacular and complex karst relief.
- **The Eye of the Bey** is a small karst lake, permanently fed by an underground spring, highlighted by the intense turquoise-blue color of the water.
- **Devil's Lake**, a karst lake in the Locvei Mountains, located at the beginning of the Nera Gorges, is noted for the story of its formation and for its blue green color;
- **Beusnita Waterfall** represents a set of waterfalls developed on limestone tufa thresholds;
- **Susara Waterfall**, located on the Susara River, with a height of approximately 15 m, where the water falls in two steps;
- **Boilor Cave**, a limestone cave, renowned for its active galleries and for its important hydrological role in the underground drainage of the area.

❖ ***biodiversity and ecosystems.*** The Nera Gorges–Beusnita National Park located in the Anina Mountains (Caras-Severin), includes several administrative units and belongs to the continental bioregion. It stands out for its secular forests, karst aquatic ecosystems, high biodiversity and protected fauna, including large carnivores and rare species [23].

❖ ***water resources***, present within the studied area, consist of extremely clean watercourses, mainly represented by natural lakes and waterfalls with constant flow.

2. Cultural resources consist of:

❖ The built heritage of Sasca Montana includes traditional stone and wooden houses, with Swabian influences, old churches, mining vestiges and historical constructions. The mining activity, which was at its peak in the eighteenth century, contributed decisively to the development of the locality, which became an important center of copper production [31]. In the nineteenth and twentieth centuries, the first accommodation structures appeared, related to mining activity, which later acquired architectural and social value. However, a significant part of the heritage is in an advanced state of degradation and is insufficiently integrated into the tourist circuit.

❖ **Intangible heritage**, very rich and diversified, but not exploited at its true value, represented by popular traditions and local customs, folk dances, traditional Banat gastronomy, specific crafts and local stories.

❖ **Tourist infrastructure** of Sasca Montana commune. The number of accommodation units increased during the period under review, including tourist and agro-tourist guesthouses, tourist cottages, as well as apartments and rooms for rent (Figure 6).

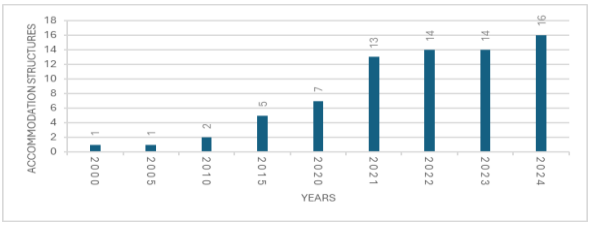

Fig. 6. Evolution of tourist accommodation structures in Sasca Montana commune
Source: Own processing based on [33].

Regarding tourist services, in Sasca Montana commune there are restaurants, local guides, outdoor equipment rental centers (increasing in number), and information points; however, these are insufficiently developed.

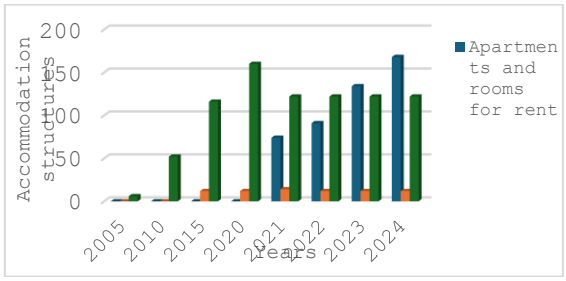

Fig. 7. Existing tourist accommodation capacity by types of accommodation structures (beds)
Source: Own processing based on [33].

Analyzing the existing tourist accommodation capacity by types of accommodation structures during the period 2005–2024 (Figure 7), a progressive diversification of accommodation structures can be observed, with an emphasis on more flexible forms adapted to rural tourism and agrotourism.

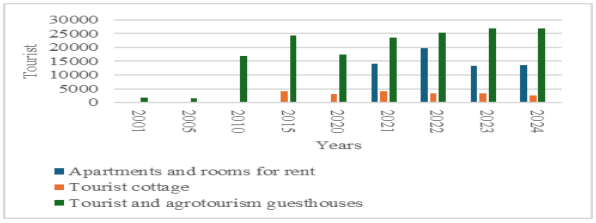

Fig. 8. Tourist accommodation capacity in operation by types of accommodation structures (bed-days)
Source: Own processing based on [33]

Figure 8 indicates a clear orientation towards flexible accommodation structures specific to rural areas, with a predominance of agrotourism guesthouses, complemented as of 2021 with apartments and rooms for rent, while tourist cottages have a secondary and fluctuating contribution.
Figure 9 highlights the significant increase in tourist arrivals in agrotourism guesthouses, which have become the dominant form of accommodation, with a maximum recorded in 2021, followed by moderate fluctuations in the post-pandemic period.

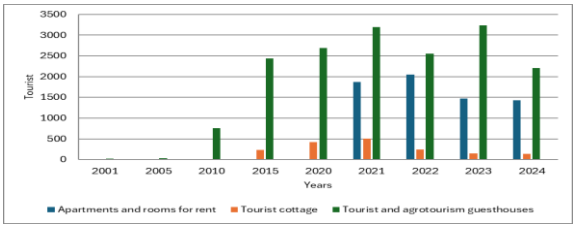

Fig. 9. Tourist arrivals in accommodation structures by types of accommodation structures
Source: Own processing based on [33].

Despite the diversification and numerical growth of accommodation structures, their utilisation rate continues to be limited by the seasonality of tourism activity and the absence of integrated complementary services.

The data presented in Figure 10 indicate a clear predominance of agrotourism guesthouses, which concentrate the highest number of overnight stays, with a peak in 2021 and moderate fluctuations thereafter.

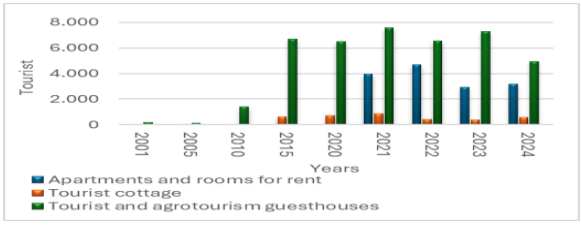

Fig. 10. Overnight stays in units for tourist accommodation by type
Source: Own processing based on the data from [33].

Apartments and rooms for rent record significant values after 2021, but with oscillating evolution. Tourist cottages play a secondary role, with low levels of overnight stays, influenced by seasonality.
Regarding accessibility, it is observed that access roads are usable but require modernization in certain sections, while public transport is limited and almost nonexistent.
However, these trends require a deeper assessment of the efficiency and effective use of tourism infrastructure. To complete the descriptive assessment of tourism resources and infrastructure, a quantitative analysis of tourism activity was carried out based on

official statistical data. This analysis aims to assess the relationship between the accommodation capacity, the tourist flows and the efficiency of the tourist activity in Sasca Montana commune. Although the existing accommodation capacity (Fig. 7), expressed by the number of places, increased significantly from 16,816 in 2010 to over 48,000 in 2022, the occupancy rate did not evolve proportionally, remaining between 20% and 35% and decreasing to 20.32% in 2024 (Table 1).

Table 1. Determination of the main tourism activity indicators in Sasca Montană commune (2001–2024)

	2001	2005	2010	2015	2020	2021	2022	2023	2024
Tourist accommodation capacity in operation (place-days)	1,741	1,488	16,816	28,390	20,632	41,678	48,406	43,468	42,884
Tourist arrivals in tourist reception facilities	27	33	753	2,665	3,103	5,563	4,846	4,850	3,762
Overnight stays in tourist accommodation facilities	192	136	1,412	7,346	7,219	12,360	11,622	10,580	8,712
Occupancy rate (%)	11.03	9.14	8.40	25.88	34.99	29.66	24.01	24.34	20.32
Average length of stay	7.11	4.12	1.88	2.76	2.33	2.22	2.40	2.18	2.32

Source: Own processing based on [33].

The average length of stay highlights different behavior. After a high value in 2001 (7.11 days), associated with a very low volume of tourist activity, the indicator stabilizes after 2010 in a relatively narrow interval, between 1.88 and 2.76 days. Between 2020 and 2024 the average length of stay remains between 2.18 and 2.40 days. Overall, the data point to a significant increase in accommodation capacity and tourism activity after 2010, followed by a decrease in tourist flows and capacity utilisation in the recent period, while maintaining a relatively stable average length of stay.

Following the socio-economic analysis conducted at the level of Sasca Montana commune, a SWOT analysis is presented below (Table 2).

Table 2. SWOT analysis of Sasca Montana commune

STRENGTHS	**WEAKNESSES**
- favorable geographical position (SW Romania), in a mountainous area with a temperate continental climate with Mediterranean influences; - exceptional natural resources, included within the protected area of the Nera Gorges–Beusnita National Park; - unique biodiversity (gorges, karst lakes, waterfalls, caves, ancient forests); - highly valuable tangible and intangible cultural heritage (architecture, authentic traditions and customs, local gastronomy, mining vestiges, crafts); - positive evolution of accommodation structures, especially agrotourism guesthouses and flexible units; - recent trend of positive migration after 2020.	- insufficiently modernized road infrastructure, with degraded secondary roads; - insufficiently developed tourism infrastructure; - lack of modern information centers; - pronounced seasonality of tourism activity and a relatively low occupancy rate of accommodation capacity; - population aging; - low level of capitalization of local cultural heritage; - limited capacity of the local administration to attract and manage sustainable development funds.
OPPORTUNITIES	**THREATS**
- possibility of accessing European funds for rural development; - increasing demand for rural tourism and agrotourism (including green tourism) at national and European levels; - digitalization of tourism; - promotion of local gastronomy; - capitalization of abandoned mining heritage for tourism and cultural purposes; - increasing interest in remote work in rural areas with high air quality.	- uncontrolled tourism may degrade protected ecosystems and natural resources. - population aging may accelerate demographic declineloss of traditional heritage; - climate change (drought, forest fires); - competition from other mountain areas that are more accessible and more visible on the tourism market; - insufficient private investments.

Source: Own processing based on the socio-economic analysis conducted.

The SWOT analysis highlights that Sasca Montana has exceptional natural resources, especially karst landscapes, high biodiversity and protected area status, correlated with a growing demand for rural tourism and agrotourism, which creates a favourable context for local development. The expansion of accommodation structures, especially agrotourism guesthouses after 2020, as well as the positive evolution of arrivals and overnight stays indicate that there is a real market reaction to this potential.

However, development is limited by significant structural weaknesses: poor road infrastructure, reduced accessibility, underdeveloped tourist services and a lack of integrated complementary services. These aspects are reflected in the low degree of use of accommodation capacity and in the accentuated seasonality of tourism activity.In the absence of coordinated investments and integrated destination management, there is a risk of partial exploitation of the existing potential. Therefore, sustainable tourism development depends on specific

interventions that correct structural deficiencies and effectively integrate local resources.

Part III – Results of the interviews with the main local actors regarding "Community perception of the capitalization of natural and cultural resources and their role in the sustainable development of Sasca Montana commune", aimed at identifying the main strategic directions for its sustainable development. In this context, the analysis was based on the premise that any sustainable local development strategy must take into account community perceptions and needs, not only natural potential or tourism demand, focusing on how the local community perceives tourism, what benefits it provides, what problems are experienced, how prepared the local community is to engage in the development of rural tourism and agrotourism, and what expectations it has from the local administration.

The results obtained from the interviews with the main local actors complement the SWOT analysis conducted as part of the socioeconomic assessment, highlighting perceptions regarding infrastructure, administrative capacity and development opportunities based on the capitalization of natural and cultural resources (Table 3).

Table 3. Summary of the results following the interview with local actors

Theme	Institutional actors	Local Stakeholders	Protected Areas Representatives	Tourism operators
A1. Evolution of the commune	Positive but slow development with administrative and infrastructural limitations	Slight economic revival, insufficient for long-term stability	Increasing the visibility of the area and the lack of an integrated development strategy	Increasing seasonal tourist interest
A2. The main resources of the commune	Valuable natural resources and rich cultural heritage	Nature, geographical positioning and high tourist potential	Biodiversity, protected ecosystems, karst uniqueness	Picturesque natural landscapes and authentic experiences
B1. Harnessing natural resources	Partial recovery, insufficiently institutionally coordinated	Limited use, without integration into complex tourism products	Resource exploitation limited by conservation constraints	Growing but seasonal capitalization
B2. Valorisation of cultural heritage	Unexploited cultural heritage	High potential, but limited investment	Increased interest in conservation, but reduced financial resources	Low interest of tourists, compared to the existing natural resources, due to poor promotion
C1. The impact of tourism on the local economy	Moderate positive impact, concentrated in the services sector	Additional but unstable and seasonal income	Reduced economic impact compared to conservation objectives	Increase in demand at certain times of the year
C2. Direct benefits for the community	Creation of limited and temporary jobs	Increasing income for a small segment of the population	Indirect benefits through environmental education	Increasing visibility of the area
D1. Obstacles in the development of tourism	Poor infrastructure, limited financial resources	Lack of manpower and financial support	Tourist pressure versus environmental protection	Reduced accessibility and lack of complementary services
D2. Problems of local initiatives	Reduced capacity for implementation	Difficulties in accessing EU funds, lack of co-financing	Lack of collaboration with economic agents	Lack of a destination strategy
E1. Sustainable development measures	Developing an integrated strategy and attracting EU funds	Financial support, training and promotion	Sustainable resource management and environmental education	Diversification of tourism products and extension of the season
E2. The role of the administration and the community	Biunivocal, Administration – strategic coordinator and active partner community	Administration-facilitator, community-initiator	Institutional cooperation and local participation	Public-private partnerships.

Source: Own processing on the protection of the results obtained at the interview.

The synthesis of the interviews conducted with 30 local actors highlights a clear consensus on the high natural and cultural potential of Sasca Montana commune, along with the existence of significant structural constraints, such as deficient infrastructure, limited administrative capacity and aging population. Rural tourism and agrotourism are perceived as main factors of future sustainable development; However, their current impact remains moderate and unevenly distributed, which underlines the need for an integrated development strategy.

Based on the SWOT analysis and the perceptions of local actors, several strategic directions were identified. These include improving accessibility and basic tourism infrastructure by upgrading roads and developing essential facilities for tourists. Another priority is to capitalize on the cultural heritage by rehabilitating the built fund and integrating traditions into the tourist circuit through local events, thematic routes and craft activities.

Reducing seasonality and increasing the utilization of accommodation capacity

requires the diversification of the tourist offer throughout the year. It is also essential to strengthen administrative capacity to access European funds, as well as to support local entrepreneurship by integrating guesthouses, producers and craftsmen into the tourism market. At the same time, socio-demographic revitalization can be supported by capitalizing on post-pandemic migration trends, and the promotion of tourism, especially rural tourism, ecotourism and adventure tourism, must be based on authentic, experience-oriented tourism packages to stimulate local economic development.

CONCLUSIONS

Sasca Montana commune benefits from exceptional natural heritage, supported by the presence of numerous karst landscapes, high biodiversity, and protected areas, as well as valuable cultural heritage, which together represent premises that can form the basis for sustainable rural development through integrated and responsible capitalization, with an emphasis on rural tourism and agrotourism.
The socio-economic analysis conducted in this paper highlights structural vulnerabilities specific to rural areas in mountainous regions, particularly demographic decline, population aging, and dependence on low value-added economic activities, which further emphasizes the need to diversify the local economy.
The evolution of tourism infrastructure indicates a positive trend in accommodation structures, especially agrotourism guesthouses and flexible forms of accommodation; however, the level of utilization remains influenced by seasonality and the limited availability of integrated complementary services.
The results of the interviews conducted confirm the consensus among local actors regarding the role of tourism and agrotourism as the main drivers of future development, but also underline that the current impact is moderate and unevenly distributed, being constrained by deficient infrastructure, limited administrative capacity to absorb European funds, and the absence of an integrated development strategy.
The SWOT analysis and the qualitative component of the research converge toward the general conclusion that the sustainable development of the commune requires an integrated model that combines environmental protection with responsible resource capitalization, priority investments in accessibility and basic tourism services, as well as the conservation and enhancement of the particularly valuable natural and cultural heritage existing in the area of Sasca Montana commune.
Overall, Sasca Montana commune can become a model of sustainable rural development based on rural tourism and agrotourism, provided that the strategic directions are implemented and that there is active involvement of the local administration and the community, ensuring a balance between economic growth and the promotion of natural and cultural heritage.

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IMPACT OF CLIMATE CHANGE ON THE ECONOMIC EFFICIENCY OF FODDER PRODUCTION FROM GRASS MIXTURES

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Abstract

Based on empirical data regarding yield, temperature, precipitation and economic indicators from a research experiment involving the following mixed grasslands: 1. Bird's-foot trefoil (Lotus corniculatus L.); 2. Red clover (Trifolium pratense L.); 3. Bird's-foot trefoil (Lotus corniculatus L.) + Red fescue (Festuca rubra L.); 4. Bird's-foot trefoil (Lotus corniculatus L.) + Timothy-grass (Phleum pratense L.); 5. Red clover (Trifolium pratense L.) + Red fescue (Festuca rubra L.); and 6. Red clover (Trifolium pratense L.) + Timothy-grass (Phleum pratense L.), the impact of climatic features on productivity and economic efficiency in forage production has been established. During the 2024–2025 period, the research experiment identified a high correlation between temperature and both production costs and gross revenue, as well as a strong relationship between precipitation and the gross profit generated from the resulting forage. Based on an analysis of variance (ANOVA), a very significant impact of the year's conditions on yield was proven, presented through the strength of factor influence. Climate changes are presented as decisive factors in determining yield and economic efficiency under different scenarios for cultivating forage grasslands.

Key words**:** *analysis of variance (ANOVA), climatic characteristics, correlations, economic indicators, forage grasslands*

INTRODUCTION

Global warming poses a significant challenge to agricultural production and serves as a compelling argument for the cultivation of forage grass species with enhanced adaptability and high productive potential (Katova, 2023)[8]. Perennial legume and grass forage plants intended for artificial grasslands determine the yield level and forage quality when appropriate component ratios are maintained (Peyraud et al., 2009)[17]. The application of suitable agrotechnical practices during the establishment and harvesting of grasslands influences the cost price and the profitability of production. The correct combination of species within the grass mixture determines the impact of production costs on profits, demonstrating that precision agriculture is vital for the management of cultivated crops (Karbivska et al., 2020)[7].

The composition of components within the grassland necessitates its alignment with ongoing global climate changes. Sowing drought-tolerant grass species on terrains with insufficient moisture is adversely affected by desiccation processes. This, in turn, leads to a reduction in yield, profit and the profitability of the resulting forage.

The drastic climate changes in recent years, combined with the high ecological plasticity of meadow grass species and their cultivars, provide a prerequisite for their broader use in our country as a forage source for mixed cultivation with meadow grasses (Churkova, 2019)[3]. Introduced cultivars originating from different regions are characterized by specific biological and morphological properties, as well as productivity (Churkova, 2012)[2]. Bulgaria is an important center of origin for genes of many forage crop species (Churkova and Lingorski, 2011)[4], and specific adaptation, along with purposeful utilization, can be key factors determining their selection for inclusion in the production process of a given farm (Pecetti et al., 2009)[16].

In modern production conditions, the successful development of agriculture necessitates the creation of technologies based on utilizing the potential of perennial forage crops. The economic efficiency of forage production dictates the recommendation of technologies with optimal values for these indicators (Konyk and Rudavska, 2016)[10].

Sown grasslands with perennial grass species are significant for ensuring the sustainable development of ecosystems and providing a high ecological impact on the environment (Litvinov et al., 2020)[11].

The inclusion of legumes in mixed grasslands offers opportunities for sustainable livestock farming by increasing yield and the nutritional value of the forage, while replacing inorganic nitrogen fertilizers through symbiotic nitrogen fixation (Lüscher et al., 2014)[12].

Perennial grass forage plants possess high resistance to abiotic and biotic factors, ecological stability, and adaptability. They are widely distributed in natural meadows and pastures, occupying up to 80-90% of the grassland.

The species composition of a given grassland determines its economic efficiency. Mixed grasslands including legume crops have the lowest cost recovery period. The presence of legumes in grass mixtures increases profitability by 1.4–2.0 times, while the cost per ton of feed units decreases by 1.6–1.8 times. Legumes in mixed meadow coenoses reduce expenses and the cost price, increasing relative net profit and profitability by 2.5–6.5 times, and the return on investment by 40–120%. This can be attributed to the lower costs of nitrogen fertilization, as nitrogen is supplied by the plants themselves due to the ability of legumes to fix atmospheric nitrogen. Bird's-foot trefoil and alfalfa, when included in grass mixtures, increase the share of relative net income by 83 dollars compared to cereal crops (Ates et al., 2017)[1], and price is a determining factor for the profitability of grassland agrophytocoenoses and influences the overall level of expenditures (Pukalo and Vyhovskyi, 2015)[18].

Climate is a determining factor for yield size, and risk management strategies against adverse climate changes create additional costs. The inextricable link between climate change and environmental degradation poses a threat to species, reduces biodiversity, and leads to ecosystem degradation. This necessitates the search for climate regulation solutions and ways to improve biodiversity in forage production and grassland management. The implementation of appropriate practices that effectively mitigate both climatic and other environmental crises determines rational land management. Such a practice in the forage production sector is the selection of suitable species and cultivar compositions with the aim of creating highly productive and economically efficient mixed grasslands.

The recent rise in average global temperatures mandates the search for ways to cope with the consequences of climate change by applying nature-based adaptation measures (Oyesiku-Blakemore and Dondini, 2022)[15]. Climate change affects the physical and chemical characteristics of forage as well as digestive processes (Moore and Jung, 2001)[13]. The correct selection of species within the grassland, aligned with the biological characteristics of the crops and their requirements regarding soil and climate, is decisive for the economic efficiency of the produced forage (Jung et al., 2020)[6].

Yields from artificial grasslands largely depend on temperatures and the distribution of precipitation. Climatic conditions are determining factors for maintaining biological balance in nature (Kirilov et al., 2009)[9] and the presence of species within grasslands (Hopkins and Holz, 2006)[5]. Well-coordinated agrotechnical measures, combined with soil and climatic conditions, determine the formation of economically efficient and ecologically pure grass forage.

Karbivska et al. (2020)[7] established that the cultivation of perennial legume-grass stands without mineral fertilizers in the Carpathian region, this results in a net profit ranging from 11.1 to 21.9 thousand UAH ha^{-1}, a profitability rate of 151–210%, and a production cost of 1.6–2.0 thousand UAH per ton of feed units. The Energy Exchangeable Coefficient (EEC) varies between 2.8 and 3.7 GJ ha^{-1}, while the Coefficient of Energy Efficiency (CEE) ranges from 6.4 to 8.5 GJ

ha^{-1}, with energy inputs per ton of feed units amounting to 3.1–4.3 GJ. The cultivation of bird's-foot trefoil in mixed stands with meadow grasses ensures the highest levels of economic and energy efficiency.

In this regard, there is a pressing issue related to finding ways to satisfy animal needs through the production of economically efficient and high-quality forage, in accordance with existing climate change trends.

The aim of this study is to determine the impact of climate change on yield and economic indicators in the production of forage from pure and mixed grass species.

MATERIALS AND METHODS

The experiment was carried out at the experimental field of the Research Institute of Mountain Stockbreeding and Agriculture – Troyan. A randomized block design was applied with three replications, and the harvest plot area was 5 m². The following grassland variants were studied: 1. Bird's -foot trefoil (*Lotus corniculatus* L.); 2. Red clover (*Trifolium pratense* L.); 3. Bird's-foot trefoil (*Lotus corniculatus* L.) + Red fescue (*Festuca rubra* L.); 4. Bird's-foot trefoil (*Lotus corniculatus* L.) + Timothy-grass (*Phleum pratense* L.); 5. Red clover (*Trifolium pratense* L.) + Red fescue (*Festuca rubra* L.); 6. Red clover (*Trifolium pratense* L.) + Timothy-grass (*Phleum pratense* L.).

Fertilization was adjusted according to the species composition, cultivation conditions, and the intended use of the mixtures. Phosphorus and potassium fertilizers were incorporated during the main soil cultivation at a rate of 10 kg active ingredient per decare (da), whereas nitrogen fertilizer was applied at a rate of 8 kg active ingredient per decare.

The technology for establishing the grassland areas included: plowing, double disking, cultivating, sowing, rolling, and harvesting. All manual and mechanized activities were detailed in technological maps for each variant, and economic indicators were calculated based on the resulting yield. From the data obtained, an economic evaluation was performed, including the following indicators: production costs (BGN/da), cost price (BGN/kg), gross revenue and gross profit (BGN/da). The prices of the seeds, materials, fuel, and consumables used are presented in BGN at market rates for the year of the study.

Statistical analysis of experimental data includes: correlation analysis; analysis of variance (ANOVA); multiple comparison of means using the least significant differences. The following software products were used for this purpose: Analysis Toolpak for Microsoft Excel 2010, Statgraphics Plus v.2.1, and STATSOFT Statistics for Windows 10.

RESULTS AND DISCUSSIONS

In the first year of the experiment (Table 1), the yield obtained from the pure stand of bird's-foot trefoil, as well as from the tested mixtures including bird's-foot trefoil, exceeded those recorded for red clover grown both as a monoculture and in combination with timothy grass. Only the red clover + red fescue mixture (830.9 kg/da) produced yields comparable to those of bird's-foot trefoil + red fescue and bird's-foot trefoil + timothy grass, which reached 842.5 kg/da and 821.8 kg/da, respectively. The lowest yield was observed in the red clover + timothy grass mixture (635.263 kg/da), while the highest was achieved by the two-component mixture of bird's-foot trefoil + red fescue.

Table 1. Dry mass yield by years and average for the period 2024–2025 (kg/da)

Variants	***2024***	***2025***	***Average for the period***
1. Bird's-foot trefoil	677.9	1,123.4	900.6
2. Red clover	661.1	1,204.2	932.6
3. Bird's-foot trefoil + Red fescue	842.5	1,244.7	1,043.6
4. Bird's-foot trefoil + Timothy-grass	821.8	1,229.9	1,025.9
5. Red clover + Red fescue	830.9	1,274.9	1,052.9
6. Red clover + Timothy-grass	635.3	1,379.6	1,007.4

Source: Own calculations.

In the second year of observation of the experiment, dry matter yield ranged from 1,123.4 kg/da in the pure stand of bird's-foot trefoil to 1,379.6 kg/da in the red clover + timothy grass mixture. The obtained results clearly indicate that all grassland mixture variants surpassed the yield levels recorded for the pure stands (Var. 1 – bird's-foot trefoil and Var. 2 – red clover). This proves that mixed grasslands are more resistant and more productive. The red clover + timothy-grass mixture registered the highest value, followed by the combination of red clover + red fescue (1,274.9 kg/da).

On average over the study period, the pure stand of bird's-foot trefoil recorded the lowest yield (900.6 kg/da), whereas the red clover + red fescue mixture proved to be the most productive (1,052.9 kg/da).

The territory where the experiment was conducted is characterized by significant climate diversity, determined by the influence of the Stara Planina Mountain (Bulgaria) and the physico-geographical conditions of the region. Intense daytime overheating and nighttime cooling, which are prerequisites for the formation of late-spring and early-autumn frosts, adversely affect the development of the grass cover, while the cool summer is attributed to the Osam River.

Meteorological conditions play a crucial role in plant growth and development, as well as in determining the yield and quality of grassland forage. A favorable combination of temperature and precipitation during the phenological phases is a prerequisite for high and stable yields, which is reflected in the resulting productivity.

The selection of species in mixed grasslands depends on the adaptation and resistance of the species and their cultivars to temperatures with large amplitude differences. Forage plants germinate at 2–3°C, with the optimal temperature for their development being 18–20°C. Their regrowth in spring begins at a temperature of 3–5°C, and the tillering of grasses occurs 10–15 days after regrowth.

In the year of sowing (2024), the initial development of the plants began at a temperature of 9.3°C (Figure 1), while during the second year, the values of this indicator were 10.3°C (2025).

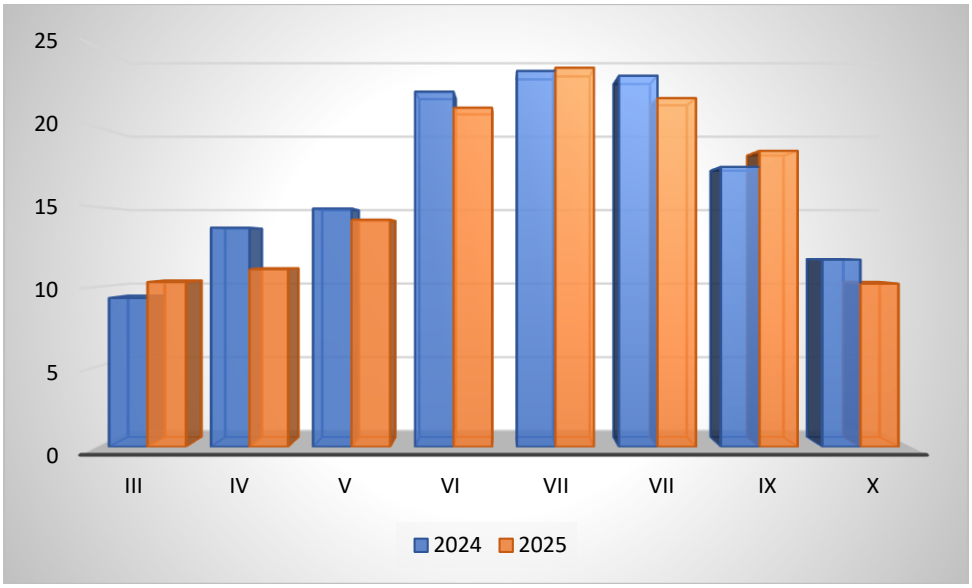

Fig. 1. Monthly and average temperature (°C) during the growing season (March–October)
Source: Own design and results.

Regarding the average values of the indicator during the growing season (March–October), the air temperature in the first year was higher, at 17.65°C, compared to 16.37°C in the second year.

The soil moisture reserve determines the development of perennial grasses. Droughts are a common phenomenon in the region and influence the phenophases of the individual development of the crops in the mixed grasslands. Low soil moisture is a prerequisite

for a decrease in the productivity and quality of the resulting forage. The total annual precipitation in the first year was higher, amounting to 537.8 mm, compared to the second year (2025), when the average annual precipitation reached 461.6 mm (Figure 2). The year 2025 is characterized as drier, with the annual sum of precipitation being lower by 76.2 mm compared to the average of the previous year. The precipitation sum during the period of active plant vegetation (March - April) was significantly lower in the second year: 38.0 mm in March and 63.8 mm in April, with an average for the period of 461.6 mm. This decrease in precipitation values delayed the start of the grass vegetation. The significantly lower levels of precipitation in June (18.4 mm), July (36.2 mm), and August (19.2 mm) of the second experimental year were the reason for the inability to form a second regrowth, which affected the annual yield of the grasslands.

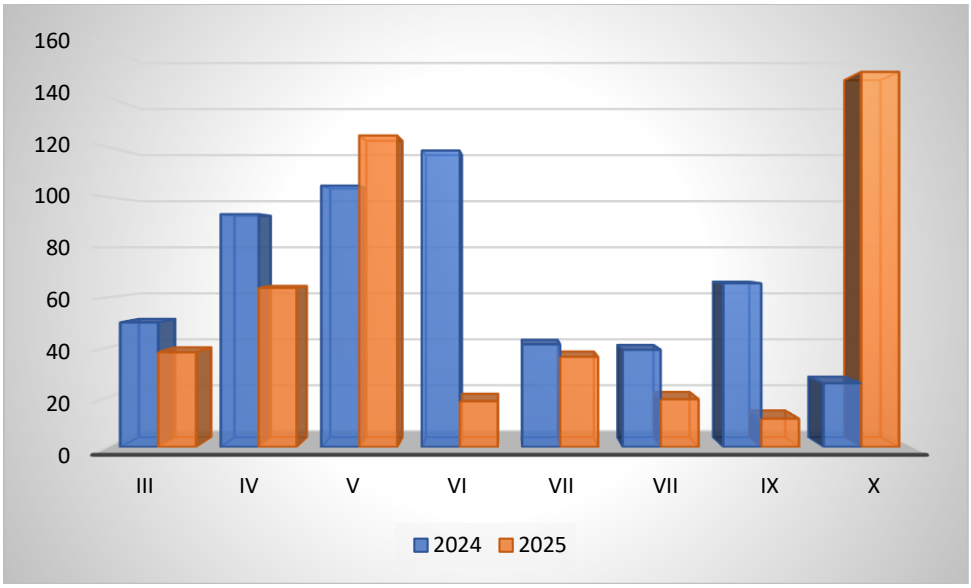

Fig. 2. Monthly and annual precipitation sum (mm) during the growing season (March–October)
Source: Own design and results.

Table 2. Analysis of variance of the influence of year conditions on dry mass yield from forage grasslands

ANOVA							
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***	***Strength of influence η***
Year	6.636017	1	6.636017	0.062169	0.826369702	18.51282051	92.84397
Conditions of the years x yield	2855.866	2	1427.933	13.37752	0.069553008	19	
Error	213.4824	2	106.7412				
Total	3075.985	5					

Source: Own calculations.

The analysis of variance regarding the factorial influence on dry mass yield in pure and mixed grasslands is presented in Table 2.
The results of the analysis show values with a high degree of significance for the variants of the regrowths, the years, the composition of the grassland, and their mutual influence, which confirms the established significant differences in productivity between the studied pure and mixed grasslands of the tested legume and grass forage species.
The conducted analysis of variance indicates that year conditions have the strongest effect on yield, followed by their interaction.
The influence of the year is proven at all levels of significance for the studied indicators, with the greatest effect being on the yield, whose impact amounts to

92.84397% of the total variation of the factors. The significant influence of the "year conditions" factor on the yield, which is one of the most important traits in the production of high yield and quality forage, is also confirmed by other authors (Muhova et al., 2023)[14]. The effect of these two factors is statistically significant.

Regarding forage yield, the interaction year conditions × yield has the largest relative share in the variance of the trait (92.84397%). The composition of the grassland accounts for 19% of its variation. The degree of influence of the trait interaction of year conditions × yield, assessed through η (strength of influence of factors), proves the significant influence of year conditions on the yield. In this regard, the interaction of the two factors is an important condition for manifesting productivity stability when the grassland components are correctly combined according to their adaptability under specific soil and climatic conditions.

Table 3. Correlation dependencies between yield, climatic conditions, and economic indicators

	Yield	***Temperature***	***Precipitation***	***Production costs***	***Cost price***	***Gross revenue***	***Gross profit***
Yield	1						
Temperature	0.7851	1					
Precipitation	0.1682	-0.4039	1				
Production costs	0.5564	0.8699	-0.4504	1			
Cost price	0.2520	0.6460	-0.5267	0.9293	1		
Gross revenue	1.0000	0.7850	0.1682	0.5564	0.2520	1	
Gross profit	0.7339	0.2229	0.5682	-0.1560	-0.4604	0.7339	1

Source: Own calculations.

Determining the relationships between grassland productivity, climatic conditions, and economic indicators is of essential importance for the proper structu
ring of the production process in a given farm. The study of correlations provides an opportunity for the correct selection of species in mixed grasslands, on which the yield and the level of economic indicators depend. Since quantitative characteristics usually determine the economic results of forage from sown grasses, it is important to achieve an optimal balance between productivity and economic efficiency in forage production.

The correlations between yield and temperature show a strong positive relationship for these indicators (r = 0.7851) (Table 3). Among the climatic indicators, temperature showed a higher dependence than precipitation on yield formation. This is explained by the high drought resistance and good adaptive capacity of the sown forage species, as well as their rate of growth and development. Precipitation also showed a positive but very weak dependence (r = 0.1682) on yield.

The differences in the strength of the relationship regarding yield are likely due to the variable response of the species and their varieties to fluctuations in temperature, the amount of monthly precipitation, and its distribution during the formation of regrowths throughout the years of the experimental period.

Dry matter yield shows the strongest positive correlation with gross revenue (r = 1) and gross profit (r = 0.7339). Their statistical correlation coefficients of these analyzed dependencies show that the correlation between the indicators is very strong.

The value of the correlation coefficient between production costs and yield is relatively high, r = 0.5564. The cost price of production is in a very weak positive correlation with yield (r = 0.2520).

Production costs are in a high positive correlation with temperature (r = 0.8699). This is explained by the volume of the yield, which in turn depends on production costs and temperature values. There is also a relatively good correlation between the gross revenues and temperature (r = 0.7850). Cost price is

also in a positive relationship with temperature (r = 0.6460).

The data analysis indicates that temperature affects production costs, feed cost price, and gross revenue, confirming the relationship between climatic conditions and the economic efficiency of forage obtained from both pure and mixed grasslands.

A very strong dependence was observed between cost price and production costs (r = 0.9293). However, the resulting relatively high positive correlation between gross profit and precipitation (r = 0.5682) defines the relationship between the economic indicator and the influence of soil moisture availability. Precipitation is also in a positive but proven weaker relationship with revenue (r = 0.1682). The level of profit and revenue also shows a high interconnection, represented by the correlation coefficient r = 0.7339.

The data analysis demonstrates the dependence of yield on gross revenue and temperature. Among the economic indicators, production costs, gross revenue and the cost price of production are in high correlation and depend on temperature, while gross profit is determined by the quantitative distribution of precipitation.

CONCLUSIONS

Climate changes are of critical importance for the cultivation of grasslands under specific environmental conditions. Depending on the morphological characteristics of the cultivated grass species and their requirements regarding temperature and precipitation, variants of expected average yields can be predicted. The results of the study indicate an increased influence of temperature on the yield of pure and mixed grasslands. The high positive correlation of temperature with the production costs and gross revenue of the obtained forage, represented by high correlation coefficients, allows for the forecasting of future yields through regression equations.

The interconnection between gross profit and gross revenue with precipitation also proves the significance of climate change both for yield formation and the economic efficiency of the produced forage.

The high factor influence estimated by the analysis of variance (ANOVA) confirms the significant effect of year conditions on yield. The results of the ANOVA and correlation analyses highlight the importance of the relationship between climatic conditions and forage crop yields. Predicted average yields can be used to estimate the required land area and forage quantity, thereby allowing the anticipation of production costs and expected outcomes. This provides a basis for selecting appropriate technological solutions for establishing highly productive and economically efficient grass forage systems under changing climatic conditions.

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STATISTICAL ANALYSIS OF ECONOMIC INDICATORS AND THE NUTRITIONAL VALUE OF FORAGE FROM BIRD'S-FOOT TREFOIL FERTILIZED WITH BLAGO 5 AND FERTILEADER AXIS

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Abstract

During the period 2021-2023, a scientific research experiment with bird's-foot trefoil (Lotus corniculatus L.) was conducted at the experimental field of the RIMSA-Troyan with the following fertilization options: Blago 5 – 300 ml/da; Blago 5 – 600 ml/da; Fertileader Axis – 500 ml/da and Fertileader Axis – 1000 ml/da. Through statistical analysis of economic indicators and the energy nutritional value of the forage, correlation dependencies were presented and regression equations were derived. The proposed agrotechnical practice of fertilizing with biofertilizers proved a high positive correlation between gross revenue and gross profit (r=0.99743), as well as between feed units for milk and exchangeable energy (r=0.99008); feed units for growth and exchangeable energy (r=0.98580); feed units for growth and feed units for milk (r=0.99366). In this context, graphical regression models between indicators with the highest coefficient of determination, expressed through regression equations, were presented and analyzed. The established positive correlation between gross energy and production costs and cost price proves the practical importance of organic fertilization and emphasizes the role of these indicators in determining productivity, quality and economic efficiency in the production of legume fodder.

Key words: *Lotus corniculatus L., correlation and regression relationships, economic indicators, nutritional value*

INTRODUCTION

Bird's-foot trefoil (*Lotus corniculatus* L.) is a perennial forage legume crop (Sun et al., 2014) [19] with excellent adaptability to different soil and climatic conditions (Uzun et al., 2016) [23], high productivity and nutritional value (Mountousis et al., 2008) [15] of the forage. Grown in semi-mountainous and mountainous conditions, it produces a high dry matter yield combined with high forage quality (Churkova, 2010) [5].

Feeding farm animals requires the development of cost-effective strategies related to forage yield and quality (Khanal et al., 2010) [12]. Animal feed costs account for a large part of total variable costs, which determines their proper management, thereby affecting the profitability and sustainability of animal production (Finneran et al., 2010) [10]. Legumes and bird's-foot trefoil as leguminous forage crops are a key element of meadow and pasture ecosystems, on which the quality of forage depends. With their inclusion in hay and pasture, the content of crude protein, minerals, vitamins, neutral detergent fiber, and in vitro dry matter digestibility increases, and animal productivity increases accordingly (Phelan et al., 2015) [17].

The inclusion of protein crops in grasslands improves the species diversity of the mountain ecosystem, the even distribution of forage and contributes to its high quality (Annicchiarico, 2008) [1].

The development of a more favorable economic environment linked to the development of technologies suitable for specific soil and climate conditions determines the conduct of adaptive research with the aim of increasing animal production. This depends on economic policies and the availability of greater investment in facilitating institutions, marketing systems, and infrastructure that provide the necessary services to support technological changes in crop and livestock production (Kiryanov and Mikhaylov, 2012; Stelmakh et al., 2021) [13; 18]. In a market economy, competition requires the application of new technological

solutions that lead to increased productivity, reduced costs, and greater profitability and efficiency in production. In this regard, much of the scientific research is related to the search for opportunities to increase the yield of green and dry matter in a number of forage legumes that are important for our country. To this end, various agrotechnical measures are applied, related to balanced fertilization and treatment with foliar fertilizers (Ventroni et al., 2010; Churkova, 2012) [6; 24].

Recently, the use of biofertilizers has become widespread in agriculture, providing more protein, increasing digestibility and nutritional value of forage (Klimas and Balezentiene, 2010; Churkova, 2013) [7; 14].

A key criterion for the modern assessment of grass biomass quality is the precise determination of its energy nutritional value, defined by feed units for milk and growth (Todorov, 2010) [21].

Sustainable forage production depends on the agricultural practices and integrated approaches used in the cultivation of meadow grasses in order to ensure high-quality forage with high economic value.

The aim of the study is to perform statistical processing of the data, which determines the relationship between the economic indicators obtained and the indicators characterizing the energy nutritional value in the production of forage from bird's-foot trefoil after applied biofertilizing.

MATERIALS AND METHODS

During a scientific experiment carried out from 2021 to 2023 at the experimental field of the Research Institute of Mountain Stockbreeding and Agriculture in Troyan, the forage nutritional value and key economic indicators were evaluated for the bird's-foot trefoil (*Lotus corniculatus* L.), variety "Targovishte 1.". Basic agronomic practices were applied, including fertilization with the biofertilizers Blago 5 in doses of 300 ml/da and 600 ml/da, and Fertileader Axis in doses of 300 ml/da and 600 ml/da. The scientific research experiment was conducted using the block method in four repetitions with a harvest plot size of 5 m^2. The bird's-foot trefoil was established at a seeding rate of 0.12 kg ha^{-1}. The fertilizer was administered using a sprayer at a dose of 6 ml at the onset of the budding phase of the crop. The grassland was harvested at the early flowering stage of the cultivated species.

Blago 5 organic fertilizer contains nitrogen (N) 2.18%, phosphorus (P_2O_5) 10.3%, total potassium (K_2O) 17%, magnesium (MgO) 0.5%, manganese (Mn) 0.5%, zinc (Zn) 0.58%, copper (Cu) 1.0%, boron (B) 0.5%, molybdenum (Mo) 0.08%, cobalt (Co) 0.13%, humic and fulvic acids not less than 2%, organic lake sapropel substance >/ = 67%, pH 6.5 – 7.5.

Fertileader Axis is a systemic product with the following chemical composition: nitrogen content - 3%; phosphorus 18%; zinc - 5.7%; manganese - 2.5%.

The principal economic indicators were estimated based on developed technological maps averaged over the study period, encompassing all technical operations associated with the establishment, management, and harvesting of the grassland. These indicators were derived on the basis of dry matter yield. The calculated economic indicators on which the correlation dependencies and regression equations are based are: production costs, cost price, gross revenue, gross profit and profitability (Churkova and Churkova, 2024) [8].

The nutritional value of the forage was obtained according to the Bulgarian system for feed units for milk (FUM) and feed units for growth (FUG) and calculated on the basis of equations specified by Todorov et al. (2010) [22]. The in vitro enzyme digestibility of dry matter (%) was determined according to the method of Aufrere (1982) [2] using a two-stage pepsin-cellulose method (Churkova and Churkova, 2025) [9].

The conclusions and results of the correlation analysis are used to solve specific problems in agriculture. It allows correlation relationships to be studied in parallel with the results achieved in external cases. In practice, correlation and regression analysis are often used together. They make it possible to determine and assess the strength of the relationship between a given variable and one

or more other variables that determine it (Ivanov, 2011) [11].

In the agricultural sector, the correlations between occurrences are multi-factorial, with each occurrence depending on a multitude of factors, causes, and conditions. For this reason, the multiple linear regression technique can be used. Each regression coefficient shows by how many units the result (impact) changes (+/-) when the i-th factor changes (+/-) by the same unit (Todorov, 2004) [20]. Of particular importance in the application of regression analysis is the size of the sample. The method is applicable only when the phenomena under study are represented by strong scales (interval or relative), i.e., the studied characteristics are measured.

Correlation Dependencies

Correlation analysis shows very different values between economic indicators and the nutritional value of bird's-foot trefoil feed after applied biofertilization (Table 1). It is evident that a significantly higher correlation was observed among the economic indicators compared to the indicators characterizing the relationship between economic metrics and those determining the nutritional value of the forage. Gross revenue is in the strongest positive correlation with total yield (r = 0.99742) and gross profit (r = 0.99743). Cost price has a high positive correlation with the values of production costs (r = 0.97937). This result indicates that the cost price of feed production is influenced by the level of production expenses.

RESULTS AND DISCUSSIONS

Table 1. Correlations between key economic indicators and the nutritional value of bird's-foot trefoil forage following biofertilization

	Total yield	*Producti-on costs*	*Cost price*	*Gross revenue*	*Gross profit*	*Profitability*	*GE*	*EE*	*FUM*	*FUG*	*VDMD*
Total yield	1										
Producti-on costs	-0.13976	1									
Cost price	-0.33585	0.97937	1								
Gross revenue	0.99742	-0.21033	-0.40248	1							
Gross profit	1	-0.13979	-0.33587	0.99743	1						
Profitabili-ty	0.31270	-0.98226	-0.99629	0.37966	0.31272	1					
GE	0.34586	0.60888	0.523025	0.29599	0.34584	-0.4803	1				
EE	-0.71617	-0.42229	-0.24651	-0.67753	-0.71616	0.30414	-0.29485	1			
FUM	-0.67070	-0.53674	-0.36621	-0.62419	-0.67068	0.41714	-0.40229	0.99008	1		
FUG	-0.74334	-0.48557	-0.30442	-0.69944	-0.74332	0.35054	-0.44993	0.98580	0.99366	1	
VDMD	0.41931	0.40659	0.28499	0.38626	0.41929	-0.3618	-0.05833	-0.90309	-0.87591	-0.82833	1

Source: Own calculations.

A strong negative correlation was registered between exchangeable energy and: yield (r = -0.71617), production costs (r = -0.42229); cost price (r =-0.24651); gross income (r =-0.67753) and gross profit (r = -0.71616), which indicates that exchangeable energy has a weaker impact on economic indicators. An average positive correlation was established between exchangeable energy and profitability (r = 0.30414), which confirms the importance of fertilization and the interrelationship of these indicators in achieving economic efficiency combined with quality feed production.

The analysis of the statistical correlation coefficients of production costs shows that they are in a very strong negative correlation with profitability (r = -0.98226). The same trend was observed for the unit cost indicator, which shows a strong negative correlation with profitability (r = -0.99629). Total yield and gross revenue have a high interconnection, expressed through a correlation coefficient value of r = 0.99742. The high correlation between gross revenue

and gross profit (0.99743) demonstrates a strong dependency between these two indicators.

The significant correlation between feed units for growth and feed units for milk (r = 0.99366) proved the good relationship between these two indicators determining the nutritional value of forage. Feed units for milk and feed units for growth are highly correlated with exchangeable energy, with correlation coefficients of r = 0.99008 and r = 0.98580, respectively.

A positive correlation with average interaction between economic indicators and nutritional value was observed only between gross energy and production costs, expressed by a correlation coefficient of r = 0.6088, and between gross energy and cost price, expressed by a correlation coefficient of r = 0.523025. This proves that the energy nutritional value determines the amount of production costs and the cost price of the obtained feed production depending on the applied agrotechnical measure of fertilization. In this case, fertilization is in accordance with environmental standards, due to imported organic fertilizers. A significantly better manifested average positive correlation was observed between gross energy and: yield (r = 0.34586), gross profit (r = 0.34584), and a weak one between gross energy and gross income (r = 0.29599). Feed units for milk and growth are also in an average positive correlation with the profitability (r = 0.41714 and r = 0.35054) of the produced feed.

These dependencies are of practical importance and emphasize the role of indicators determining energy nutritional value and yield in the formation of economic indicators and provide guidelines for the application of organic fertilizers in feed production.

The results reported by Boczar and Błażeyczyk-Majka (2024) [3], showing that combined economic and energy efficiency is positively associated with both economic efficiency (r = 0.610) and energy efficiency (r = 0.870), suggest that the dual-efficiency model provides a balanced representation of farmers' economic interests and regional energy security, and are consistent with our findings. The analysis of economic factors is crucial for achieving production goals (Moutinho et al., 2018) [16]. After economic efficiency, the quality of feed, represented by energy efficiency, is of essential importance for agricultural producers (Carlier et al., 2011) [4]. The introduction of appropriate agronomic practices, such as fertilization, leads to improved profitability in growing different crops on individual farms. The analysis of economic and energy efficiency data reveals the relationship between the two types of efficiency. The results indicate that the application of the biofertilizers Blago 5 and Fertileader Axis had a beneficial effect, resulting in positive economic and energy efficiency outcomes. This demonstrates that the applied technological approach leads to a reduction in production costs and feed cost price, due to the positive relationship between gross energy and these two economic indicators. Fertilization with the tested biofertilizers at the applied rates proved to be an effective agrotechnical practice for the cultivation of bird's-foot trefoil.

Based on the developed technological map, which includes all agrotechnical practices for feed production, the structure of production costs was analyzed, and it was established that imported biofertilizers are the key factors influencing feed productivity. Both economic and energy efficiency were improved as a result of the applied fertilization inputs. The type of fertilizers and their doses increase yields and affect productivity in different ways and from there on the quality of the feed and economic efficiency.

The calculated correlation dependencies were able to prove that fertilization determines the change in the values of economic indicators and nutritional value of feed, as well as the dependencies between them. The high correlation coefficients between the economic indicators themselves and those reflected between the nutritional value indicators make it possible to conditionally determine the relationship between gross revenue and gross profit, as well as feed units for growth and milk with exchangeable energy, which provides a basis for deriving regression equations.

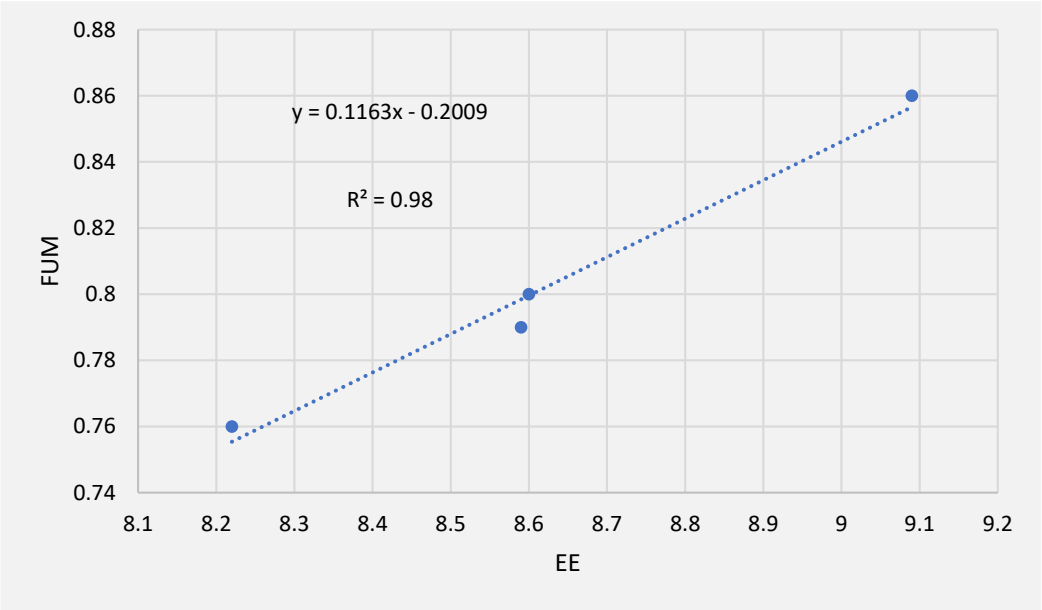

Fig. 1. Regression and regression equation between exchangeable energy and feed units for milk in the production of bird's-foot trefoil forage after biofertilization with Blago 5 and Fertileader Axis
Source: Own design and results.

Exchangeable energy is in a good correlation dependency with the feed units for milk (r = 0.99008), which confirms the strong interconnection between them. The theoretical regression line and the regression dependency equation (Figure 1) between these two indicators are presented by the equation y = 0.1163x – 0.2009 with a very high coefficient of determination R^2 = 0.9803.

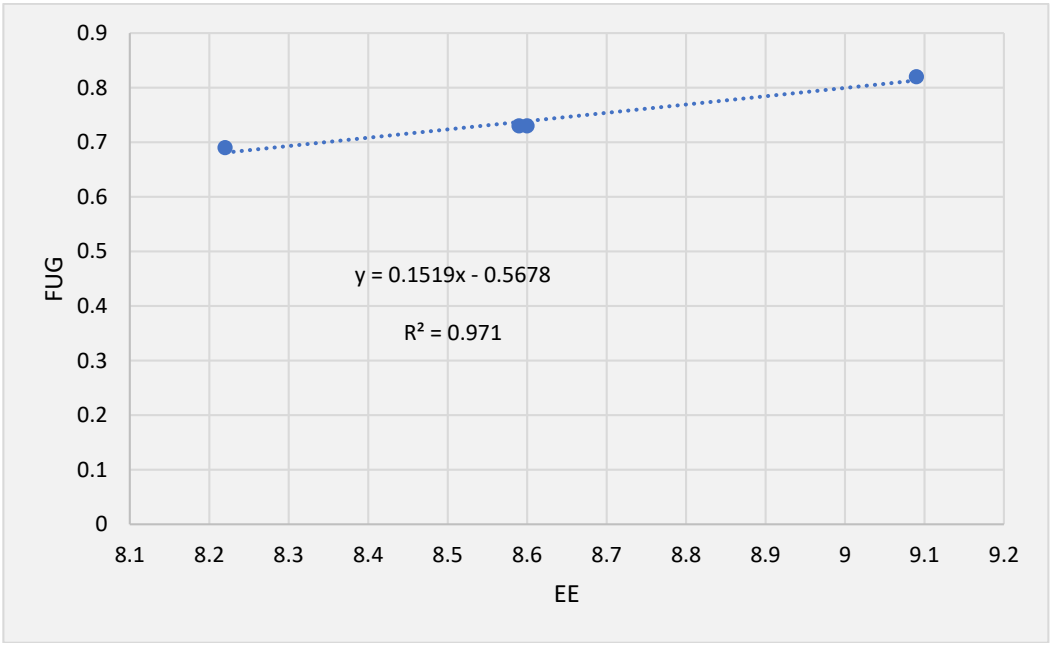

Fig. 2. Regression and regression equation between exchangeable energy and feed units for growth in forage production from bird's-foot trefoil after biofertilization with Blago 5 and Fertileader Axis
Source: Own design and results.

The high coefficient of determination between exchangeable energy and feed units for growth determines the theoretical regression line and the equation of regression dependence between these two indicators. They are presented in Figure 2 by the equation y = 0.1519x – 0.5678 and a very high coefficient of determination R^2 = 0.9718.

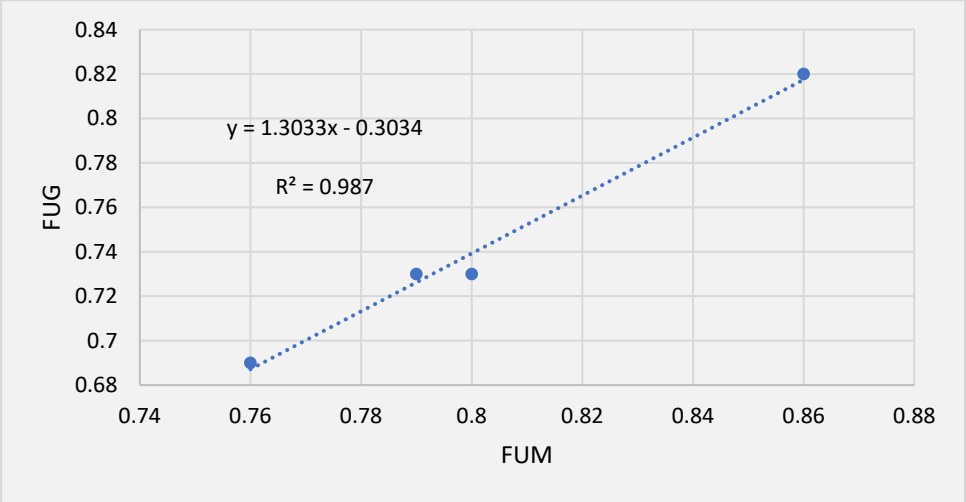

Fig. 3. Regression and regression equation between feed units for milk and feed units for growth in forage production from bird's-foot trefoil after biofertilization with Blago 5 and Fertileader Axis
Source: Own design and results.

The high correlation allows us to derive the regression equation y = 1.3033x - 0.3034 with a coefficient of determination R^2 = 0.9874, presented in Figure 3, expressing the very strong dependence between feed units for milk and feed units for growth.

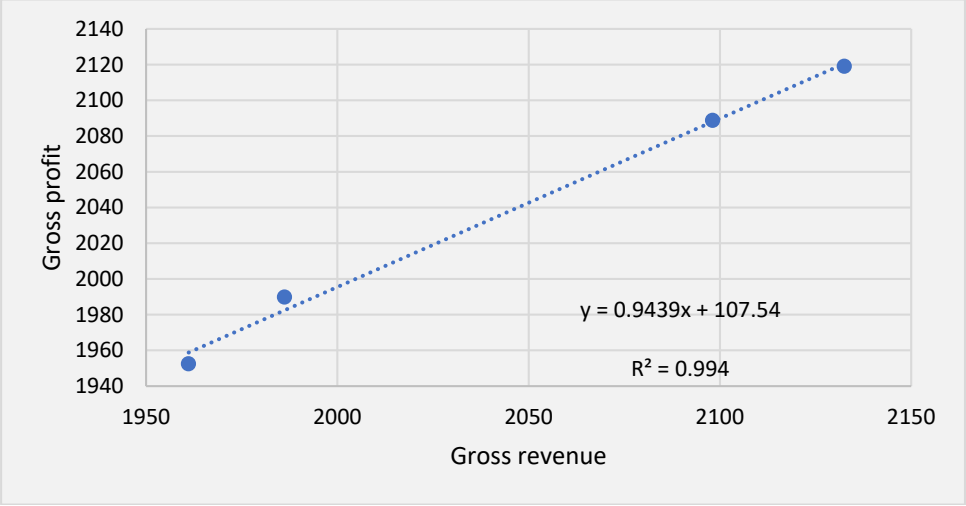

Fig. 4. Regression and regression equation between gross revenue and gross profit in the production of forage from bird's-foot trefoil after biofertilization with Blago 5 and Fertileader Axis
Source: Own design and results.

Figure 4 shows the regression equation y = 0.9439x + 107.54 with a coefficient of determination R^2 = 0.9949 after establishing a high correlation between gross revenue and gross profit after applying Blago 5 and Fertileader Axis biofertilizers to a single crop of bird's-foot trefoil.

The highest degree of influence due to fertilization is exerted by the interrelationship between gross revenue and gross profit after the highest correlation and regression dependence between these two indicators was established. This is a good prerequisite for the preliminary determination of gross profit, depending on the gross revenue obtained, represented by the above equation. Exchangeable energy makes it possible to predetermine the main indicators of nutritional value – feed units for milk and growth, which are essential for proving the energy nutritional value of forage.

CONCLUSIONS

The introduction of Blago 5 and Fertileader Axis biofertilizers on a self-seeded grassland

from bird's-foot trefoil determined a high positive correlation between gross revenue and gross profit (r = 0.99743), as well as between feed units for milk and exchangeable energy (r= 0.99008); feed units for growth and exchangeable energy (r = 0.98580); feed units for growth and feed units for milk (r = 0.99366).

The correlation analysis proves that in order to improve the economic efficiency of feed production, it is necessary to apply an agrotechnical measure - fertilization, which increases the gross energy of the feed, and is in an average positive correlation with the production costs and the cost price of the feed sold.

From the presented and analyzed graphical regression models with the highest coefficient of determination ($R^2 = 0.9949$), the correlation between gross revenue and gross profit stood out, for which the equation y = 0.9439x + 107.54 was derived.

The obtained data may be used to predict gross profit based on revenue generated following the application of biological products in the production of bird's-foot trefoil forage. This provides a basis for their practical implementation. The derived correlation relationships and regression equations identify fertilization as an important agrotechnical practice in forage production from an economic perspective, in combination with high energy nutritional value.

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COMPARATIVE EVALUATION OF PLANT ESTABLISHMENT METHODS IN EGGPLANT: CASE STUDY ON MIRVAL F1 AND BLACK PEARL F1 HYBRIDS

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Abstract

Efficient cultivation of eggplants (Solanum melongena L.) is gaining renewed importance within sustainable farming strategies, as rising demand forces producers to manage land, water and labor with a degree of precision that earlier systems seldom required. Given the crop's thermophilic character, its performance depends strongly on the establishment method either open-field planting or cultivation in unheated solar tunnels, an agronomic choice that carries implications for both productivity and longer-term resource sustainability. Between 2019 and 2021, at the "V. Adamachi" Experimental Station, wore examined two hybrids, Mirval F1 and Black Pearl F1, grown under two systems. Transplanted seedlings were maintained with relatively uniform irrigation and fertilization regimes, allowing the analyze of the factors that shape yield formation and resource-use efficiency, even though minor seasonal variations still occured in practice. The comparative results indicated a consistent advantage for the protected environment: yields increased by approximately 50–70% relative to open-field production, largely due to a higher fruit load per plant and, to a smaller extent, slightly greater fruit mass. The hybrids displayed distinct adaptive patterns as well. Mirval F1 reached commercial maturity earlier and set more fruits per plant, whereas Black Pearl F1 produced larger fruits and expressed its yield potential most fully under the moderated microclimate of the tunnel structure.

Key words**:** *eggplant (Solanum melongena L.), high tunnel cultivation, open-field production, yield components,*

INTRODUCTION

Eggplant (*Solanum melongena L.*) has gradually assumed a prominent role among vegetable species, not only because of its nutritional profile and the concentration of antioxidant compounds it contains, but also due to the way it seems to integrate into culinary traditions [9], [20], [16], [14]. Currently, the eggplant crop occupies roughly 1.8 million hectares worldwide, from the milder Mediterranean zones to humid tropical regions, and even in places that challenge the species beyond its comfortable thermal limits [15].

Over the past few decades, a steady shift toward protected cultivation has become visible [10]. A growing number of producers rely on solar houses or other controlled structures, and eggplant now ranks, according to Rasouli, among the top greenhouse-grown vegetables, fourth place, although the exact position tends to fluctuate depending on the dataset consulted, while this movement appears linked to the crop's marked sensitivity to stabilized, moderated environments [19].

Unheated greenhouses and simple plastic tunnels enable growers to extend the season beyond what open fields usually permit, while also adjusting the microclimate in ways outdoor systems simply cannot [18]. These advantages have become more salient as weather patterns show an increasingly erratic behaviour from one year to the next, pushing agriculture toward forms of "sustainable intensification" that are not always easy to implement [2]. Even under careful management, certain seasons still behave out of step with expectations.

Despite these benefits, a significant number of farmers continue to rely on open-field production, partly due to familiarity and partly because the upfront costs remain far lower [8]. This method demands fewer technological inputs, yet exposes the crop to abrupt temperature declines, uneven rainfall, and a range of pest pressures. Each of these factors may curtail, at times quite severely, the level

of productivity that eggplant can achieve when grown under more buffered conditions.

Selecting an appropriate cultivation system has become a rather persistent challenge in sustainable agriculture, as producers must attain high yields while avoiding the gradual depletion of the resources on which the system relies [13]. In temperate continental regions, the northeastern part of Romania offers a familiar example, summers generally supply adequate heat, yet the frost-free period remains unexpectedly short. This compressed window limits the growth trajectory of thermophilic crops such as eggplant when they are placed directly into open soil.

Protected structures, by contrast, generate a buffered microclimate, something akin to a moderated shell around the plants, which permits transplanting slightly earlier and allows the harvest period to extend beyond what the field usually tolerates [6]. Such environments also shield the crop from unpredictable rainfall events or sudden wind bursts that leave field-grown plants partly bent or stressed. Under these more stable conditions, vegetative growth tends to accelerate and yields increase, whereas open-field plots remain exposed to abrupt abiotic shifts and to continuous insect or disease pressure that may, at times, cut deeply into productivity.

Recent research reinforces the advantages of protected systems. Shaik et al. (2023) showed that organic eggplants cultivated in tunnel greenhouses produced roughly 84% more than those in the open field, largely due to improved fruit set and a modest increase in average fruit mass [17]. Resource use can also be reduced; water illustrates this particularly well. In semi-arid environments such as Egypt, studies have shown that greenhouse-grown eggplants required nearly 90% less irrigation than their field counterparts, while net profit increased by more than 80%, even if seasonal costs did not remain fully constant, as so often happens [6].

Taken together, these observations indicate that protected cultivation offers considerable potential for improving both economic outputs and resource efficiency, especially in areas where open-field production is repeatedly pressured by climatic instability. Although the advantages of protected cultivation are frequently mentioned in the literature, the way eggplant actually performs in these structures, especially when set against open-field systems, remains only partly clarified, more so under Romania's rather specific climatic constraints and with the newer hybrids that have come into use in the past few years. In several cases the available evidence is either fragmentary or, too narrow to show how these cultivars react under the two contrasting environments. The national and international literature offers relatively little multi-year evidence capable of quantifying, with some precision, the differences in yield or quality between the two establishment methods, and even less when economic sustainability is brought into the discussion.

It is recognised, for example, that excessive heat inside greenhouses may suppress production if ventilation is not managed adequately, and the lack of natural pollinators can weaken fruit set [1]. One study even reported that a highly controlled greenhouse produced unexpectedly smaller yields than adjacent field plots because pollination dropped off and light penetration inside the structure was poorer than anticipated [4].

These observations raise an unresolved issue: to what extent the theoretical advantage of protected cultivation can be translated into real, field-level gains once its limitations are acknowledged, and how differently eggplant hybrids reacts to what are, essentially, two contrasting environments.

The present study aimed to clarify this ambiguity by examining eggplant grown under two establishment systems, a solar tunnel and the open field under conditions kept as uniform as the site realistically allowed. Attention was directed to total yield, key yield components (fruit number per plant, average fruit weight, timing of first fruit set), and several practical variables with relevance for growers, including water-use efficiency and the broader economic interpretation of the crop. The hybrids selected, *Mirval F1* and *Black Pearl F1*, are part of a more recent cohort of high-performance genetic lines.

Both are marketed for protected and outdoor cultivation, though their profiles differ: Mirval F1 is generally classified as very early and relatively stable across environments [5], whereas Black Pearl F1 is usually recommended for open-field production [7], producing medium-to-large fruits with a teardrop shape and a high degree of uniformity, even if its performance shifts a bit from year to year.

Given these circumstances, it was reasonable to anticipate differing responses. It was assumed that the moderated microclimate of the solar tunnel would increase yields in both hybrids, perhaps more strongly in *Black Pearl F1*, known for its vigour and capacity to exploit longer, steadier growing windows. *Mirval F1*, owing to its early maturity, was expected to use the shorter outdoor season more effectively. Accordingly, Mirval F1 was hypothesised to initiate fruiting earlier and to form more fruits overall, whereas Black Pearl F1 would likely express heavier individual fruits.

To verify these assumptions, a three-year factorial experiment was implemented, with close monitoring in both environments and identical technological practices, so the influence of each factor could be objectively identified. The study therefore provides locally generated evidence, still relatively scarce in the region regarding comparative performance in greenhouse and open-field eggplant systems.

Such findings contribute to decision-making for growers and, eventually, for policy actors, by clarifying which strategies align best with local conditions. Improvements in production efficiency and a more deliberate use of natural resources have the potential to reinforce long-term resilience, even if, as field practice often shows, seasonal behaviour does not remain perfectly consistent.

MATERIALS AND METHODS

The research was carried out from 2019 to 2021 in the vegetable trial fields of the "V. Adamachi" Research and Student Training Station, Iași, Romania. The area is characterised by a temperate-continental climate; summers tend to be warm, with July means around 21–22°C, although a fair number of days rise well above 30°C. Rainfall occurs irregularly and, rather often, at moments that complicate open-field management, influencing crop performance more than producers usually care to admit [11]. Each experimental cycle began in early spring and continued into autumn, with harvests collected through summer and the early part of autumn. The same design was implemented during 2019, 2020 and 2021, allowing the datasets to remain comparable and, at least in principle to provide more dependable trends, even if small seasonal shifts did appear from one year to the next.

Table 1. Overview of the experimental framework

Factor	Practical meaning	Examples from the study
Cultivation method	Compares crop performance in a protected environment and in open field	Solar greenhouse setting, conventional field plots
Hybrid used	Two modern hybrids assessed for their contrasting traits	Mirval F1, Black Pearl F1
Seedling production	Seedlings grown in trays with sterile substrate under controlled temperature	Transplanting performed once plants had 5 to 6 true leaves
Planting calendar	Transplant dates adapted to climatic risks in each system	Greenhouse: mid to late April; Field: early May
Phenological advantage in greenhouse	Plants start growing earlier under protection than outdoors	Roughly a three week advance in early development
Mirval F1 traits	Very early type, good adaptability and stable yield potential	Earlier fruit initiation, higher fruit number
Black Pearl F1 traits	Vigorous hybrid producing larger fruits, performs strongly in open field	Higher fruit mass, more robust vegetative growth
Expected hybrid differences	Anticipated variability in response to environmental conditions	Mirval favoured by field timing, Black Pearl enhanced in greenhouse

Source: authors' elaboration.

For ease of interpretation, the accompanying table groups the principal experimental factors and indicates how each was applied in practice, including brief notes from field observations. Organising the information in this manner makes the operational differences between the two cultivation systems somewhat clearer and suggests how the hybrids were expected to behave, though plants in real plots have a tendency of not following plans as neatly as theory would

sometimes like. Table 1 summarizes the principal elements of the experimental design, indicating how each factor was defined and applied across the two cultivation systems, showing how the hybrids could diverge in their behaviour and allowing the yield outcomes to be read against the broader agronomic tendencies that emerged, even if a section of year-to-year drift was, unavoidably, still present.

The greenhouse used in the trial was a straightforward, unheated tunnel covered with PE film, equipped with manually operated side vents, and occupying roughly 250 m². This area was sufficient for arranging all treatments and replications without forcing plants into an unnaturally tight spacing. The open-field plots assigned to the unprotected variant were situated only a short distance away, on the same well-drained cambic chernozem, ensuring that soil variability would not interfere with comparisons. Soil preparation followed the standard routine: autumn plowing, disking, and bed formation. Inside the tunnel the beds ended up somewhat wider, to make slightly better use of the protected surface, although planting density was kept the same in both systems, at least in theory; small deviations do slip in during fieldwork.

Plants were spaced 70 cm between rows and 40 cm on the row, a configuration equivalent to approximately 35,000 plants ha. Each experimental plot, corresponding to one A×B combination, contained four rows with ten plants per row, yielding forty plants over an effective surface of a little under 11 m².

The study employed a two-factor randomized block arrangement with three replications. Factor A, the cultivation environment could not be fully randomized, since each block necessarily included one greenhouse section and a corresponding open-field section positioned nearby. For this reason only the hybrid factor was randomized within each environment, while the environment itself functioned, in practice, as a fixed factor. Comparisons between the two systems were made across the three experimental years, with hybrid treatments replicated inside both environments.

This split-plot-type configuration was shaped largely by physical limitations, as greenhouse and field microplots cannot be shifted around like small pots. Nevertheless, the three-year repetition provides the design with strong comparability; each season acts as a temporal block that, in a way, tightens the reliability of the dataset, even if plants doesn't always cooperate perfectly.

Overall crop management

Crop management was maintained as closely as practicable between the two cultivation systems, since the intention was for any differences to arise from the experimental factors rather than from extra technological variability. Prior to planting, the soil received well-decomposed farmyard manure—about 30 t ha, incorporated in autumn to provide a reasonably uniform nutrient background. At transplanting, a small starter dose was placed directly in each planting hole, roughly 5 g of a 14-14-14 NPK formulation, a routine measure many growers use to help seedlings settle a bit quicker. Throughout the vegetation period, both systems followed the same top-dressing schedule. Ammonium nitrate was applied three weeks after transplanting at around 50 kg ha, followed by two monthly applications of a 20-20-20 fertilizer, close to 5 kg ha each time. These rates were adjusted in line with plant development, although in a few plots the timing slipped slightly, as field tasks rarely unfold with perfect precision.

Irrigation relied on drip lines one per row, in both the tunnel and the open field, all connected to the same water source so that no hidden discrepancies would creep in unnoticed. Under typical weather conditions watering occurred twice weekly; during hotter intervals it increased to three times, supplying roughly 25–30 mm per week, with open-field adjustments depending on rainfall. The greenhouse limited evaporation and saved some water, though under our temperate conditions the effect was noticeably milder than what is often reported for arid regions. To reduce water loss and suppress weeds, black polyethylene mulch was laid across the soil surface in both environments. It also maintained slightly higher soil temperatures at the beginning of the season, an advantage for

eggplant establishment, even if that benefit tends to fade as summer progresses and the soil warms on its own.

Disease and pest control

Disease and pest management was approached through a mix of preventive steps and direct interventions whenever the situation genuinely required it, following the general principles of Integrated Pest Management [3]. In the open field, the main pressure came from insect pests most notably the Colorado potato beetle (*Leptinotarsa decemlineata*), which has the habit of appearing almost abruptly in certain seasons. Populations were kept under control through targeted applications of biological products such as spinosad and, once the threshold of economic damage was passed, a few of the newer chemical options, though the use of these was held as low as practical. Inside the greenhouse the beetle rarely became an issue, the structure functioning as a partial barrier, but close supervision remained necessary to catch early aphid or whitefly outbreaks. Yellow sticky traps were used for monitoring, and treatments relied mainly on potassium soap or neem-based formulations, avoiding synthetic substances in the enclosed space whenever it was reasonably possible to do so.

One element that demanded more attention was pollination. Outdoors, pollination proceeded largely by itself through wind movement and insects; although eggplant flowers are self-fertile, they respond better when receive a mechanical vibration from pollinators. In the greenhouse, where natural pollinator activity is much more limited, two complementary measures were adopted. The tunnel was ventilated daily by opening side vents and doors during the warmer hours, allowing some insects to enter, and bumblebee hives (*Bombus terrestris*) were introduced close to the onset of flowering. These bumblebees provide the vibrational pollination essential for the crop, and published work reports yield increases of around 20–25% in protected systems when such hives are used [12].

Data recording and statistical analysis

Data were collected throughout the season, with observations entered whenever a developmental stage appeared, seedlings taking hold after transplanting, the onset of flowering, the first visible fruit set, and later the moment when fruits reached a marketable size. A marked difference in earliness emerged: plants inside the tunnel began flowering roughly 7–10 days ahead of those in the open field. Between the two hybrids, *Mirval F1* maintained its reputation for very early maturity, usually reaching the first harvest about 5 days before *Black Pearl F1*. This tendency was seen in both systems, although the exact calendar dates drifted slightly from one year to another.

Harvesting was done manually in successive rounds, once fruits showed the usual indicators of commercial maturity, glossy skin and the firmness typical for each hybrid. In most seasons the tunnel produced its first marketable fruits toward the end of June, whereas open-field plants reached their first picking only around mid-July, making the advantage of the protected environment fairly evident. Harvests continued until yields fell to negligible levels: in early October inside the tunnel, when night temperatures dropped below 10°C, and by mid-September outside, after the first light frosts stopped growth.

For each plot was recorded total yield in kilograms and converted it to a per-hectare basis. Fruit counts were also taken to estimate the mean number of fruits per plant. Average fruit weight was determined both from the ratio of total yield to fruit number and from a 20-fruit sample weighed at peak harvest, a procedure that helped smooth out the usual small irregularities in fruit size. Plant height was measured at the end of the cycle (September); both hybrids remained within roughly 70–90 cm, slightly taller in the tunnel, though these differences had no real effect on yield.

RESULTS AND DISCUSSIONS

The comparison between the two cultivation systems showed marked and fairly consistent differences in total yield per hectare across the three study years. Plants grown in the solar tunnel outperformed those in the open field in every season, and this held true for both

hybrids without any real exception. When the averages were considered together, the protected environment produced close to 60% higher yields than the outdoor plots, which, more or less, aligned with the expectations formed at the outset.

For *Mirval F1*, mean yield reached roughly 65.3 t ha in the tunnel, whereas the same hybrid produced around 45.1 t ha in open-field conditions. The contrast was sharper for *Black Pearl F1*, which recorded about 70.4 t ha under protection but only 40.2 t ha outside. Expressed in relative terms, *Black Pearl* gained nearly 75% over its open-field yield, while *Mirval* showed an increase of about 45%. The ANOVA confirmed the strong effect of the Environment factor ($p < 0.001$), underscoring how a moderated microclimate can, quite literally, reshape production levels.

These patterns echo findings reported elsewhere. A study from South Texas observed that organic eggplant grown in high tunnels achieved an 84% yield increase relative to outdoor plants, driven mostly by approximately 63% more fruits per plant and a smaller rise in average fruit weight of about 9% [17]. Comparable tendencies were visible in our dataset as well, though the specific components are examined in the next sections.

Table 2. Yield performance of eggplant hybrids

Hybrid	Greenhouse yield (t/ha)	Open-field Yield (t/ha)	Yield increase (%)
Mirval F1	65.3	45.1	45%
Black Pearl F1	70.4	40.2	75%
Mean (both hybrids)	67.85	42.65	59%

Source: Authors' statistical processing in SPSS (v.20)

The yield figures from the trial indicate the advantage of protected cultivation, with both hybrids performing better in the tunnel than in the open field. The extent of the gain did not follow the same pattern for each hybrid. *Mirval F1* increased from 45.1 t ha outdoors to roughly 65.3 t ha under protection, an improvement of about 45%. This is already considerable, yet *Black Pearl F1* responded even more strongly: its yield rose from 40.2 t ha to nearly 70.4 t ha, translating to roughly 75% improvement. The comparison suggests that Black Pearl depends more heavily on a steady microclimate and may cope less well with the small but persistent stresses that accumulate in open-field settings (Table 1 and Fig. 1).

Taken together, the two hybrids produced close to 60% higher yields in the protected environment than in the field plots. Similar tendencies have been reported elsewhere, where greenhouse systems often promote a greater fruit set and, in certain seasons, a slight increase in fruit size. The fact that this difference appeared yearly and for both hybrids, despite their distinct growth habit supports the idea that controlled structures offer a stable, almost dependable advantage for eggplant cultivation, even if field conditions, as growers know too well, seldom behave exactly the same from one year to another.

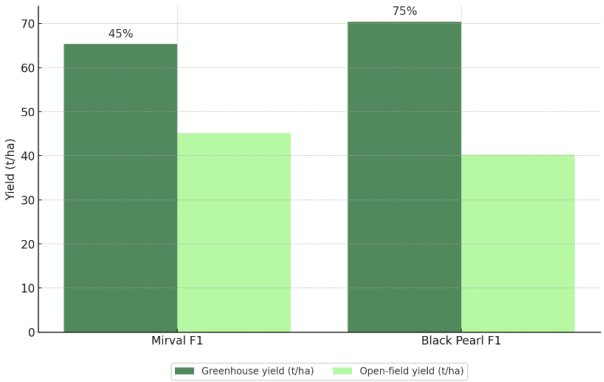

Fig. 1. Yield comparison of eggplant hybrids
Source: Own results.

The figure indicates that both hybrids performed better in the greenhouse than in the open field. *Mirval F1* showed an increase of about 45%, whereas *Black Pearl F1* displayed an even steeper rise, approaching 75%. Such a contrast suggests that *Mirval* does benefit from the moderated conditions of the protected system, though *Black Pearl* appears to depend more strongly on a stable microclimate to express its full yield potential. When the two patterns are considered side by side, the protected environment consistently surpassed the field plots, pointing to the capacity of controlled cultivation to raise eggplant productivity by a substantial margin, even if plant behaviour, as growers know, is never entirely smooth from one season to the next.

Number of fruits and average fruit weight

A closer examination of the yield components revealed distinct differences between the two cultivation systems, as well as between the hybrids themselves. Plants grown inside the greenhouse tended to carry more fruits per plant, and those fruits were, on average, marginally heavier than the ones obtained outdoors. Across years and hybrids, the protected environment produced roughly 30% more fruits per plant, a tendency that stayed surprisingly steady, even if the exact figures wandered a little from one season to the next.

For *Mirval F1*, the greenhouse conditions resulted in about 6.8 fruits/ plant, compared with roughly 5.0 in the open field. *Black Pearl F1* showed the same directional shift but with a sharper contrast: around 5.8 fruits plant in the tunnel and only 3.8 outdoors. This wider difference suggests that the shorter and more irregular field season likely restricted *Black Pearl* from forming a higher fruit load.

Despite these contrasts, *Mirval F1* remained the hybrid with the higher fruit number in both environments. Its advantage, about 1.2 fruits plant in the tunnel and outdoors alike fit its known morphology of short internodes and a notably strong fruit-setting ability, although in some plots the pattern appeared a bit less tidy than the numbers might imply.

Average fruit weight

The examination of average fruit weight revealed a pattern almost opposite to that observed for fruit number. *Black Pearl F1* consistently produced heavier fruits than *Mirval F1*, both in the tunnel and under field conditions. In the open field, Black Pearl averaged roughly 350 g, whereas Mirval remained closer to 280 g, a difference of about 25%. Under the steadier conditions of the greenhouse, both hybrids increased in weight: Black Pearl reached around 400 g, while Mirval settled near 320 g. The gap between them, usually in the 70–80 g range, stayed surprisingly constant, suggesting a strong genetic control over this trait. Black Pearl is bred as a large-fruited type, typically around 19 × 10 cm with an ovoid or slightly teardrop profile, while Mirval produces more elongated fruits of roughly 20 cm, most often falling in the 250–300 g interval in repeated observations. What emerges quite clearly is that the cultivation environment influenced fruit number far more than the weight of individual fruits. In proportional terms, average fruit weight increased by about 14% in the greenhouse, roughly 40 g for Mirval and about 50 g for Black Pearl. By contrast, fruit number rose by nearly 36% in Mirval and close to 53% in Black Pearl. This pattern indicates that the tunnel enhanced yield chiefly by extending the period during which plants could set fruits and by buffering late-season stress, rather than by making individual fruits substantially heavier.

Debates among growers often revolve around whether markets prefer many smaller fruits or fewer but larger ones; the answer depends on local demand. In this case, both systems produced sizes well within commercial expectations, and the greenhouse increased both weight and fruit number which is, from a practical standpoint, close to ideal.

The weight differences between the two hybrids mirror their breeding strategies. Mirval is selected for early maturity and a heavier fruit load, meaning assimilates are divided among more growing fruits, producing slightly smaller units. Black Pearl, in contrast, tends to bear fewer simultaneous fruits and reaches its production peak later, giving individual fruits more time and more resources to develop greater mass. This relationship is common across vegetable crops: genotypes with high fruit counts typically yield smaller fruits, while those with moderate fruit numbers often allocate more energy to size. From a management perspective the two approaches can reach similar total yields, though with different emphases heavy setters may need occasional fruit thinning, whereas large-fruited types demand more attentive nutrient supply to limit flower drop or alternating growth phases.

Earliness and harvest dynamics

Earliness and the general tempo of harvesting showed a few distinct tendencies, although these traits were not measured with exacting precision. Plants grown inside the tunnel entered production notably sooner, roughly two to three weeks ahead of those in the open field, an advance that carries real weight for growers, since early-season fruit usually

commands higher prices. Mirval F1, owing to its quicker maturity, reached its first marketable stage toward the end of June in the tunnel, at least in 2020 and 2021 when spring came somewhat warmer than expected. Black Pearl F1 followed only shortly after, with initial harvests appearing in the first days of July. In the open field the calendar shifted backwards: Mirval generally began around 10–15 July, while Black Pearl tended to reach usable maturity closer to the month's end, sometimes even a bit beyond, depending on the weather swings.

These contrasts in maturity rate shaped the seasonal distribution of yield as well. Mirval placed a larger share of its production in the early half of the harvest window, whereas Black Pearl maintained a steadier output and continued fruiting into the later weeks. The divergence was especially clear inside the greenhouse, where Black Pearl still produced reasonably well until late September, while Mirval had already shown a decline, most likely because it had pushed much of its growth and assimilates earlier in the cycle.

In practical terms, Mirval tended to "finish" its main period of productivity sooner, whereas Black Pearl stretched its output across a longer span. The choice between them, for most growers, depends on whether the premium of very early fruit matters more than having a more even and extended harvest, a decision that rarely stays the same from one farm, or season to another.

Environmental factors and sustainability

The higher yields obtained inside the tunnel appear closely tied to the set of environmental advantages that this type of structure more or less provides by itself. Temperature levels fluctuate far less avoiding those abrupt cold dips or unexpected heat surges that can unsettle field crops and humidity stays within a band that tends to favour both fruit formation and vegetative growth. The absence of rainfall is not trivial either, as strong drops may bruise flowers or trigger short disease incidents in outdoor plots. Pest pressure was generally lower as well. And although both systems relied on drip irrigation and black plastic mulch, the protected environment kept a steadier hydro-thermal balance around the root zone; with less evaporation and, at times, the possibility to reuse a portion of drainage water, each liter ended up being used somewhat more efficiently.

Evidence from other contexts illustrates the magnitude of such effects. For example, Fan et al. (2023), conducted a research under Egyptian semi-arid conditions, found that eggplants grown in greenhouses required almost 90% less water than those in open fields, while net profit rose by more than 80% [6]. The contrasts in our temperate setting are not nearly so large, yet the water needed per unit of harvested yield was still clearly lower inside the tunnel. This came mainly from the minimal direct evaporation and the tighter control over irrigation scheduling. During dry spells, this characteristic became especially valuable, allowing the crop to continue with rather modest water inputs and helping the farm navigate brief periods of scarcity.

A comparable pattern appeared with fertilizers. Nutrient uptake tends to be more efficient in protected structures, partly because rain cannot wash nutrients away and partly because the more even microclimate maintains a steadier uptake rhythm across the growth cycle, even when open-field conditions were, on paper, suitable.

Economic and quality aspects

Although the study centred primarily on the technical and biological aspects of cultivation, the economic implications are difficult to avoid, as the yield data repeatedly steers the interpretation in that direction. The additional production recorded in the tunnel, typically 15–25 t/ha above the field plots combined with the earlier harvest period, can lead to considerably higher earnings for growers. On local markets, early eggplants often reach prices two or even three times higher than those sold in mid-summer, so the first few tonnes harvested under protection may account for a disproportionately large share of a season's revenue.

Regarding costs, an unheated tunnel built from a light metal frame and PE film generally recovers its investment within two or three years, mainly through the larger yields and the premium obtained for early fruits. Findings from other regions, such as

the work by Fan and colleagues in arid climates, describe even sharper increases in net profit after switching to protected cultivation. In a temperate zone like Romania the gain is probably more moderate: somewhere near 30–50%, yet still too substantial to be dismissed. A complete economic evaluation should also consider the recurring expenses. Greenhouses entail extra outlays for the structure, ventilation components, mulching materials, and in some cases added labour related to pollination (including the purchase of bumblebee hives). Because the present experiment remained relatively small, a full cost accounting was not prepared; however, it was clear enough that the additional labour in the protected system was largely balanced, and sometimes exceeded, by the earlier and higher yields. From the standpoint of quality, no pronounced differences in flavour or visible traits emerged between the two environments. Even so, fruits from the tunnel appeared slightly more uniform, with fewer distortions or colour irregularities, likely because they were sheltered from abrupt weather events and the steadier pest pressure of the field. A portion of open-field fruits displayed minor scuffing caused by wind rubbing them against the mulch or neighbouring stems. This was less common in Black Pearl F1, whose first fruits are naturally positioned a bit higher above the soil, a trait that proved unexpectedly practical.
Fruits from the greenhouse also tended to show a glossier surface and a somewhat thinner skin, perhaps linked to gentler light levels and the absence of sharp humidity swings. Such features are usually appreciated by consumers, though they are not simple to quantify with precision. Nutritional attributes, dry matter, soluble sugars, phenolics, were not assessed here, but they merit further investigation, since subtle shifts in the growth environment can alter the phytochemical profile of solanaceous crops in ways that are not always visible at harvest.

CONCLUSIONS

The comparative assessment of eggplant grown in solar-tunnel structures and in open-field plots, using the hybrids Mirval F1 and Black Pearl F1, brought into view several aspects relevant for sustainable vegetable production. The unheated tunnels created a more buffered microclimate, and plants, almost predictably, responded with yields roughly 50–70% higher than those obtained outdoors. Most of this gain came from the increased fruit set, though individual fruits tended to weigh slightly more as well. In a few instances the presence of even a modest tunnel nearly doubled the harvest, which shows how strongly these simple constructions can alter productivity without relying on any advanced climate equipment.
A second advantage lay in the timing of harvest. Plants under protection entered production two to three weeks earlier, a difference that matters economically because early fruit usually commands better prices. Toward the end of the season, particularly with Black Pearl F1 fruiting continued well into late autumn, giving the protected crop both the earliest and, more or less, the final pickings of the year.
The hybrids themselves did not respond identically. Mirval F1, being a very early type, performed reliably even outdoors and maintained a stable number of medium-sized fruits despite the more erratic conditions. Black Pearl F1 expressed its potential far more fully in the extended, calmer tunnel environment, where it produced larger fruits and generally higher yields once the plants had enough time to progress through their cycle. These contrasts underline the need to align hybrid selection with the cultivation system, otherwise part of the genetic capacity remains, in practice, unused.
For growers, the results indicate that unheated tunnels represent a practical investment in temperate climates, increasing productivity while softening the impact of weather fluctuations. Even simple structures require attention, ventilation to prevent overheating and ensuring adequate pollination, at times with bumblebees, so fruit set does not suffer. Techniques such as drip irrigation and mulching, applied consistently in this study, ought to be seen as standard components rather than optional additions.

From a wider sustainability perspective, the move toward efficient protected systems advances ecological and economic aims simultaneously. Higher yields per area reduce pressure on land, water is used more sparingly since direct evaporation is minimal, and nutrients remain available instead of being washed away by rain. Although tunnels bring an initial cost, the steadier and higher returns typically balance this investment within a few seasons, strengthening longer-term resilience on the farm.

Stripped of the smaller details, the central point is that choosing the cultivation environment is not merely a technical adjustment but a strategic decision. A basic solar tunnel paired with a hybrid that fits its growth rhythm can lift production considerably without imposing notable ecological burdens. Further economic analysis or work on nutritional traits would refine the picture, though the core finding remains firm: protected cultivation offers a distinct advantage when managed according to the crop's requirements.

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ASSESSING POTATO YIELD PERFORMANCE UNDER CLIMATE CHANGE IN THE EAST OF THE CENTRAL DEVELOPMENT REGION OF ROMANIA

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Abstract

This study examined potato yield performance in the eastern part of Romania's Central Development Region, where climate change significantly affects agriculture. Potato yield data were obtained from the National Institute of Statistics, while air temperature and precipitation records came from the National Meteorological Administration for 1991–2020. Results demonstrated that monthly average temperature and precipitation during the growing season strongly influenced potato yield per hectare. Yields fluctuated from a low of 8,692 kg/ha in 1991 to a high of 27,072 kg/ha in 2017. Given the variability in thermal and hydrological resources, farmers should adapt potato cultivation practices to local climate conditions by implementing resilient varieties, precision irrigation systems, and sustainable soil management practices.

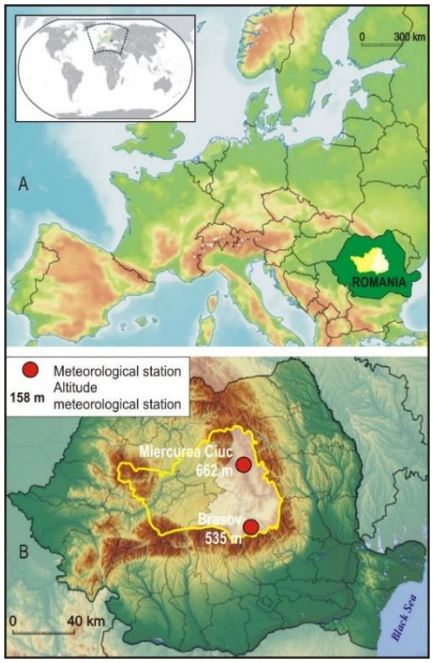
Key words**:** *air temperature, precipitation, potato, yields, Central Romania Development Region of Romania.*

INTRODUCTION

The potato is a staple food, holding a large share in the economy of many countries due to its high nutritional value and relatively high yield. Originally from the high-altitude tropical regions of the Andes in South America, its cultivation is widespread across the globe, with particular importance in temperate climate regions [7]. In Europe, the potato as a technical and food crop, became a major cultivated plant starting from the mid-20th century [9]. Potato cultivation in Romania has a long-standing tradition, with the earliest references dating back to the 18th century in Transylvania [4], currently representing a crop of national significance. In the current context of climate change, potato yields are affected by rising air and soil temperatures, but yields can increase if irrigated in temperate climates. In addition to the climatic context, economic factors, such as inadequate farm sizes or long distances to markets, affect current crop areas [8].

The analysis and evaluation of potato behavior in relation to climate, soil, water, fertilization and sanitary protection are of great importance, because all varieties cultivated in unfavorable conditions produce yields 40-60% lower than those obtained under normal cultivation conditions [14]. The purpose of this study is to analyze the impact of thermal and water resource variability on potato yields for the last climatological normal period 1991-2020. This period is used as a standard basis for assessing current

climate conditions [18]. The analysis is carried out for the eastern part of the Central Development Region of Romania, administratively represented by the counties of Brasov, Covasna and Harghita, considered a highly favorable to favorable area for potato cultivation (Map 1).



Map 1. The location of the study area (the territory highlighted in white – Brasov, Covasna and Harghita Counties) and of the meteorological stations analyzed. Source: own processing from GIS open sources.

The study area is characterized by the intra- and extra-mountain depressions of the Romanian Carpathians and by the hilly area of the Transylvanian Hill Depression. Also, the soils are well aerated with a balanced thermal and hydrological regime. The correct exploitation of ecological conditions is an efficient way to achieve profitable production and save material and energy resources [14].

MATERIALS AND METHODS

The study of the variability of agricultural yields for potato cultivation was based on the average values of production obtained per hectare, provided by the National Institute of Statistics (NIS), for the period 1991-2020. The analysis was correlated with the agroclimatic particularities specific to the study area. To assess the variability and identify the changes in the thermal and pluviometric regime, data sets from two meteorological stations (MS) under the coordination of the National Meteorological Administration (NMA) were used.

These stations were selected due to their geographical positioning in the study area and the altitude of the meteorological platforms, thus being considered representative (Map 1). The climate data used in the study include monthly average values of air temperature (°C), surface soil temperature (°C) and precipitation (mm), for the period 1991-2020. Agricultural and climate data were processed using statistical-mathematical methods and digital mapping techniques.

RESULTS AND DISCUSSIONS

Potatoes exhibit a strong ecological plasticity, but prefer a temperate and humid climate. Potato varieties are extra-early, early, mid-early, mid-late and late, with growing periods between 90 and over 130 days [11]. The analysis was carried out for potato crops regardless of varieties, so the growing period was considered to be the monthly interval from April to October [15].

Potato yields

Europe currently accounts for a quarter of global potato production, which is declining due to the constant reduction in cultivated areas, while yields have increased modestly [16]. Romania is a medium producer in the European Union [6] with a high potential, but dependent on the import of certified planting material. The study area, represented by Brasov, Covasna and Harghita counties, constitutes an area of strong tradition in potato cultivation, with high average yields per hectare due to the favorable climate and a better technological level compared to other regions in the country. Potato yields for the analyzed period are shown in Figures 1 and 2 both for the entire study region and for the counties that make up the region. The average production per hectare for the entire analyzed period was 17,451 kg/ha with higher or lower yield values over the years. The lowest average yields per hectare were recorded in the years: 1991 (8,692 kg/ha), 2005 (12,230 kg/ha) and 2012 (10,065 kg/ha) (Fig. 1).

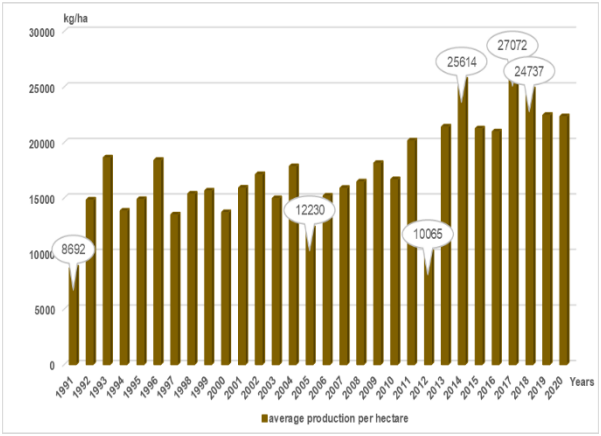


Fig. 1. The average potato yield per hectare (kg/ha) in the study area (1991–2020).
Source: processed data from NIS, 2025 [12].

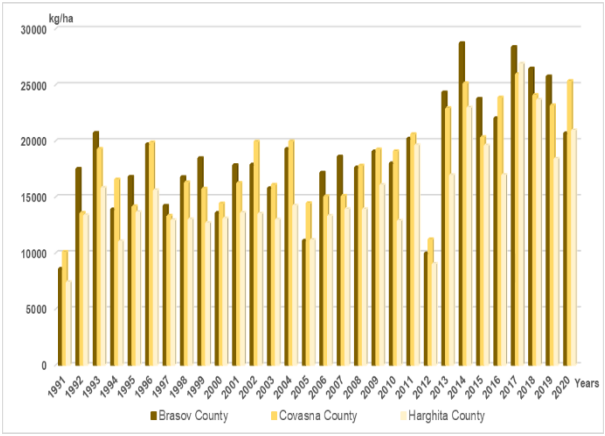


Fig. 2. The average potato yield per hectare (kg/ha) in the analyzed counties (1991–2020).
Source: processed data from NIS, 2025 [12].

In the last decade of the analyzed period, the highest potato yields of 25,614 kg/ha (2014), 27,072 kg/ha (2017) and 24,737 kg/ha (2018) were recorded (Fig. 1). In terms of yields in the component counties of the study area, it was observed that the highest average productions per hectare were recorded either in Brasov County or in Covasna County (Fig. 2). It was also observed that in the years with the lowest yields, Covasna County recorded higher productions compared to Brasov and Harghita Counties (Fig. 2). In the years with the highest yields, Brasov County ranked first (Fig. 2). Harghita County in most years registers average yields per hectare below those registered in the other two counties (Fig. 2). Spatial differences in potato yield result from the combined influence of pedoclimatic, technological and structural factors. Although the entire study area is suitable for potato cultivation, local contrasts in temperature and precipitation regimes, soil types, and water availability generate distinct yield responses.

Potato requirements for climatic factors

The potato is considered a plant of temperate climates, which differs from the conditions in its area of origin. It requires relatively large amounts of water, nutrients and pesticides due to both its relatively weak and superficial root system and its vulnerability to diseases and pests [10; 13]. The heat requirement varies throughout the growing season, so that the average air temperature favorable for the entire growing season is 17-20°C. In terms of water requirements, the potato is one of the plants that requires a continuous supply of water. The amount of precipitation of 250-550 mm, over the entire growing season, is sufficient provided that there are water reserves in the soil at the beginning of the growing season. The amount of precipitation must be distributed monthly in amounts of 90-130 mm for the period May-August [14]. These monthly amounts of precipitation represent another condition for the success of potato cultivation.

The meteograms show the climatic characteristics of the study area for the period 1991-2020 at the two meteorological stations: Brasov and Miercurea Ciuc (Fig. 3).

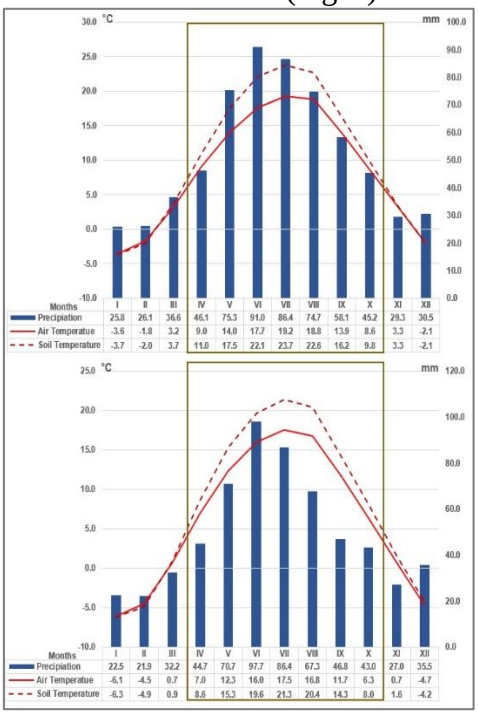


Fig. 3. Metograms of the meteorological stations analyzed for the period 1991-2020: Brasov (above) and Miercurea Ciuc (below). Note: the brown border highlights the growing season of the potato crop.
Source: processed data according to NMA, 2025.

For the analyzed period, it was observed that in Brasov M.S. the average monthly air temperature, during the potato vegetation period, oscillates between 8.6°C in October and 19.2°C in July (Fig. 3 above).

The soil surface temperature recorded values between 9.8°C (October) and 23.7°C (July), and the monthly amount of precipitation records the optimal precipitation requirement only for the month of June (91.0 mm) (Fig. 3 above). The average values of the main climatic factors of influence for the potato growing season (April-October) 1991-2020 in Brasov M.S. are: 14.4°C air temperature (below optimal requirement), 17.5°C surface soil temperature and 476.8 mm precipitation (meets optimal requirement).

For Miercurea Ciuc M.S. the air temperature recorded monthly values between 6.3°C (October) and 17.5°C (July), the surface soil temperature ranged between 8.0°C (October) and 21.3°C (July) and the monthly precipitation amounts exceeded the optimal requirement of 90.0 mm in June for the vegetation period from 1991-2020 (Fig. 4 below). The average values of the entire vegetation period (1991-2020) are: 12.5°C air temperature (below the optimal requirement), 15.4°C surface soil temperature and 456.5 mm precipitation meeting the optimal requirement. The decadal average values shown in Table 1 highlight the variability of climatic factors from one decade to another, which is reflected in the variability of crop yields.

Table 1. Decadal average variation of air temperature, surface soil temperature and precipitation amounts at the meteorological stations analyzed for the period 1991-2020.

Climate parameter	Decade	Brasov M.S.	Miercurea Ciuc M.S.
air temperatue (°C)	1990s	7.7	5.5
	2000s	8.2	6.1
	2010s	9.1	6.8
	1991-2020	8.3	6.1
soil temperature (°C)	1990s	9.2	7.4
	2000s	10.3	7.9
	2010s	11.0	8.4
	1991-2020	10.2	7.9
precipitation (mm)	1990s	593.6	555.5
	2000s	648.9	648.9
	2010s	632.7	582.4
	1991-2020	625.1	595.6

Source: processed data according to NMA, 2025.

Over the three decades of the 1991-2020 period, an increase in both air temperature and surface soil temperature is observed at both meteorological stations analyzed, each decade being warmer than the previous one (Table 1). From a pluviometric point of view, the same climatic signal is not observed, the last decade being with higher amounts than the first decade, and the decade 2001-2010 is the wettest in the period 1991-2020 (Table 1). This decennial regional analysis is in line with what is happening at the national scale [3]. Against the background of this variability and climate change, there are oscillations in crop yields ranging from 8,692 kg/ha (1991), representing 50% of the average production for the entire period analyzed, to 27,072 kg/ha (2017), representing 155% of the average production of 17,451 kg/ha (1991-2020). These potato productions are the result of the variability of the main thermal and pluviometric parameters of each year and their analysis is a mandatory condition for efficient crop management [5]. The year 1991 was an extremely rainy year [2], and excess water, similarly to drought, has negative effects on both plant growth and the level and quality of potato production [14]. The year 2017, from a climatic point of view, was a warm and rainy year [1]. The study area is characterized climatically by colder winters and milder and rainier summers, but in dry years irrigation is needed. Potato is much more sensitive to water stress than most field crops in Romania, so the possibility of irrigation is particularly important.

In Romania, depending on the potato variety, yields of 15,000-25,000 kg/ha are recorded for mid-early varieties, and for mid-late and late varieties yields of 25,000-50,000 kg/ha [11] when optimal requirements for climatic factors are met. In the study area, a water deficit of about 160-260 mm is recorded in some years, which limits potato production. It was found that for every 10 mm of water deficit achieved during the potato growing season, production decreases on average by 500-700 kg/ha for the study area [17].

CONCLUSIONS

Climate variability and climate change in recent decades are reflected in the variability of potato yields, especially in areas with a temperate continental climate, such as the study area. Potatoes have good plasticity, but are very sensitive to deviations from the optimal temperature and precipitation regime. The increase in air temperature and soil temperature at the surface, the variability of precipitation without a clear trend of increase or decrease are climatic signals for reducing potato yields. The eastern part of the Central Romania Development Region is part of the highly favorable and favorable area for potato cultivation in Romania, and the component counties of Brasov, Covasna and Harghita are among the top five growing counties. This favorability is given by the climatic characteristics of the area where air temperatures are moderate, without exceeding 25°C and with average temperatures during the vegetation period of 18-20°C. Annual precipitation amounts usually exceed 650 mm, being well distributed across vegetation phases, with a monthly minimum between 80-100 mm for the months of June, July and August. However, there are years when this thermal and pluviometric optimum is not reached and irrigation is necessary to compensate for the water deficit and moderate the soil temperature.

From the perspective of adaptation, climate variability and climate change require the reconfiguration of technology such as choosing varieties more tolerant to thermal and water stress, punctual irrigation, soil protection, etc. to reduce climatic pressure. In the absence of these measures, climatic variability turns into increased variability in yields and, implicitly, into economic volatility for potato cultivation.

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ENERGY TRANSITION AND ITS STRUCTURAL IMPLICATIONS FOR THE DEVELOPMENT OF AGRICULTURE IN THE REPUBLIC OF MOLDOVA

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Abstract

The article analyzes the energy transition as a highly important process for the Republic of Moldova, one that directly influences the development of agriculture, a sector essential for the country's economy and food security. The paper examines how changes in the energy sector, such as the wider use of renewable energy sources, improved energy efficiency, and reduced dependence on imported energy, affect the competitiveness, productivity, and resilience of agriculture in the face of crises. The analysis is based on statistical data for the period 2015–2025, drawn from national and international sources, including the National Bureau of Statistics of the Republic of Moldova and Eurostat. Descriptive and comparative analytical methods are used to highlight the main effects of the energy transition on the agricultural sector. The article focuses on several important areas: energy costs for agricultural producers, modernization of rural infrastructure, electrification of agricultural processes, and the introduction of green technologies into the agri-food chain. It also highlights the role of public policies, investments in locally based renewable energy sources, and financial support mechanisms that can help farmers transition more easily to sustainable practices. In essence, the analysis shows that the energy transition is not only a response to climate and geopolitical challenges, but also a factor that can fundamentally transform agriculture. The main conclusion is that this transition has a dual effect: in the short term, it can lead to higher costs and greater pressure on farmers, but in the medium and long term, it can help increase the competitiveness and resilience of the agricultural sector, provided that well-targeted investments are made and new technologies are adopted more rapidly in practice.

Key words**:** *energy transition, sustainable development, agri-food sector, renewable energy, economic resilience.*

INTRODUCTION

The Republic of Moldova is undergoing a broad process of energy transition, in line with global trends toward decarbonization and the expansion of renewable energy sources. This transition involves, on the one hand, reducing greenhouse gas emissions and promoting green energy, and on the other hand, ensuring energy security at affordable costs. Over the past decade (2015–2025), the energy transition has gained particular relevance for Moldova, a country traditionally dependent on fossil fuel imports, which account for approximately 80% of total energy consumption, primarily supplied by the Russian Federation.

Agriculture, a sector that contributes around 7–10% to national GDP and accounts for approximately 45% of total exports (Gandrabura, 2025) [11], is directly affected by developments in the energy sector through fuel, electricity and fertilizer prices. In addition, it is indirectly influenced by decarbonization policies that increasingly target sustainable agricultural practices.

The period 2015–2025 was marked by significant increases in energy prices, especially in its second half, culminating in the regional energy crisis triggered by the conflict in Ukraine in 2022. The energy crisis exposed Moldova's structural vulnerabilities, including its high dependence on imported energy, limited diversification of supply and weak resilience of key economic sectors. These systemic weaknesses were highlighted by policy analyses emphasizing the socio-economic impact of the crisis and the urgent need for energy system reform (Ioniță, 2025) [13]. Moldova, already vulnerable due to its high level of energy dependence, experienced a sharp increase in electricity and natural gas

prices during 2022–2023 (CNED, 2025) [4]. These developments generated cascading effects on agricultural production costs, as the sector relies heavily on energy inputs for mechanization such as diesel fuel for machinery and electricity for irrigation and storage facilities as well as on energy-intensive inputs, including nitrogen-based fertilizers whose production depends on natural gas.

As a result, energy price shocks exerted substantial pressure on farmers through rising expenditures on fuel, electricity and agricultural inputs. These challenges were further intensified by additional adverse factors, including severe droughts during 2020–2022 and disruptions in supply chains, which together amplified the vulnerability of the agricultural sector (Agerpres.ro, 2022) [1].

At the same time, the decarbonization commitments undertaken by the Republic of Moldova and European countries such as reducing greenhouse gas emissions by 70% compared to 1990 levels by 2030 and achieving climate neutrality by 2050 have increasingly shaped national policy frameworks. Moldova's decarbonization objectives are anchored in its Updated Nationally Determined Contribution (NDC), which frames climate action across all economic sectors, including agriculture (Ministry of Environment of the Republic of Moldova, 2020) [17]. These commitments are reflected in updated energy strategies aimed at increasing the share of renewable energy in total energy consumption, with a target of 30% renewable energy by 2030, as well as in the implementation of energy efficiency measures across all sectors, including agriculture.

Sustainable agriculture has consequently become a strategic priority, supported by initiatives that promote the use of biomass energy through the valorization of agricultural residues, the installation of solar panels and biogas facilities on farms, and the adoption of climate-smart agricultural practices [25]. These measures are designed to reduce both dependence on fossil energy sources and the carbon footprint of the agricultural sector, while simultaneously enhancing long-term resilience and environmental sustainability.

In this context, the present article aims to analyze the impact of the energy transition on agriculture in the Republic of Moldova, focusing on the period 2015–2025 and developing possible projections and implications up to 2035.

The analysis addresses four main dimensions: (a) the evolution of energy prices and their effects on agricultural production costs; (b) the structural adaptation of agriculture in terms of productivity and investment under the pressure of rising energy prices and decarbonization policies; (c) the extent to which renewable energy sources and energy efficiency measures are being adopted within the agricultural sector; and (d) a comparative perspective, with particular emphasis on Romania, in order to contextualize Moldova's developments within the regional landscape.

The results integrate official statistical data, relevant economic formulas such as elasticities, and energy intensity indices and analytical models, supported by graphs and tables presenting key indicators from the agricultural and energy sectors. This integrated approach provides a rigorous and comprehensive assessment of the phenomena under investigation.

MATERIALS AND METHODS

The study is based on a combination of secondary statistical data and comparative quantitative analysis methods. Time series data covering the period 2015–2025 were collected from governmental sources and international databases, including the National Bureau of Statistics of the Republic of Moldova (NBS) [21] such as the national energy balance and annual agricultural indicators, as well as reports issued by relevant ministries, namely the Ministry of Energy and the Ministry of Agriculture and Food Industry.

In addition, data from Eurostat and FAOSTAT [9, 10] were used to support international comparisons regarding agricultural production, energy consumption in agriculture and productivity indicators.

Information from the International Energy Agency (IEA) [15] and the International Renewable Energy Agency (IRENA) [16] was also incorporated, particularly with respect to decarbonization targets and energy transition objectives.

Furthermore, recent reports and analytical studies published between 2022 and 2025 by research organizations and think tanks including the Energy Policy Group, the OECD and the World Bank were employed to calibrate specific parameters, such as price–consumption elasticities, and to incorporate projections and scenarios related to future developments.

The methodology consists of the following components:

- Descriptive trend analysis – temporal developments in prices for different forms of energy (electricity, natural gas and fuels) and key agricultural indicators (physical output, yields and production costs) were examined over the period 2015–2025, with the aim ofidentifying major changes and critical turning points;

- Structural and comparative analysis – energy intensity in agriculture was assessed, defined as the amount of energy consumed per unit of agricultural value added, and compared both across economic sectors and with selected countries in the region, with particular emphasis on Romania. In addition, energy productivity measured as the value added generated per unit of energy used was analyzed as an aggregate indicator of economic efficiency. For example, energy intensity (EI) can be formally defined as the ratio between the energy usedand the gross domestic product generated. Energy intensity (EI) is formally defined as the ratio between energy consumption and GDP, expressed in megajoules per 1,000 USD:

$$EI = \frac{Energy\ consumption}{\text{GDP}} \quad \text{.....(1)}$$

A decline in this indicator reflects improved energy efficiency, whereas an increase indicates a higher degree of energy dependence in order to generate the same level of output (NBS, 2023) [21].

A simplified economic modeling approach was employed, using elasticity-based formulas to quantify the sensitivity of demand to variations in energy prices. The price elasticity of demand, generally is defined as:

$$\epsilon = \frac{\%\Delta\text{Demand}}{\%\Delta\text{Price}} \text{.....(2)}$$

It was drawn from the relevant literature in order to estimate the impact of energy price increases on consumption in sectors such as agriculture.

The relatively low absolute value of this elasticity (below 1) reflects limited substitution possibilities, as consumers including farms are unable to significantly reduce energy consumption in the short term, even when prices increase, due to the absence of viable alternatives (OECD, 2018) [23].

Projections toward the year 2035 were developed using a qualitative approach, based on scenarios derived from official strategic documents, such as the Energy Strategy 2050 of the Republic of Moldova, the Nationally Determined Contribution (NDC 3.0) under the Paris Agreement [8], and the Integrated National Energy and Climate Plan 2025–2030 [14]. Although no advanced econometric simulations were conducted within this framework, the analysis relies on relationships identified during the observed period and on prevailing policy directions in order to extrapolate trends and to identify structural challenges and opportunities for agriculture over the 2030–2035 horizon.

The methodology combines the examination of empirical data with relevant economic formulas and simplified modeling approaches, allowing for a rigorous interpretation of phenomena at the energy–agriculture nexus. The following section presents the results obtained and the associated discussion, structured around key themes: the impact of rising energy prices, the adaptation of the agricultural sector to the energy transition particularly in terms of productivity and cost dynamics investment and innovation processes, including the adoption of renewable energy in agriculture, and an international comparative perspective.

RESULTS AND DISCUSSIONS

In recent years, energy price increases in the Republic of Moldova have generated immediate effects on agricultural production costs. Natural gas prices essential both for electricity generation and for the production of chemical fertilizers—rose sharply during 2021–2022 amid the regional energy crisis. As a result, electricity tariffs for consumers, including farms connected to the grid, were increased by approximately 44–49% in 2022 (NAER, 2022) [20].

In practice, Moldova was forced to purchase energy at significantly higher prices on the regional market, costs that were partially transferred to end-user tariffs despite the temporary compensation mechanisms applied during the state of emergency. Fuel prices followed a similar trajectory: diesel prices, which are critical for agricultural operations, increased on average by more than 20% in 2022 compared to the previous year (Agerpres.ro, 2022) [1].

Overall, agriculture was subject to substantial additional cost pressures, given its strong dependence on diesel fuel for ploughing, sowing, harvesting and transport—and on electricity for irrigation, silo ventilation and primary processing of agricultural output.

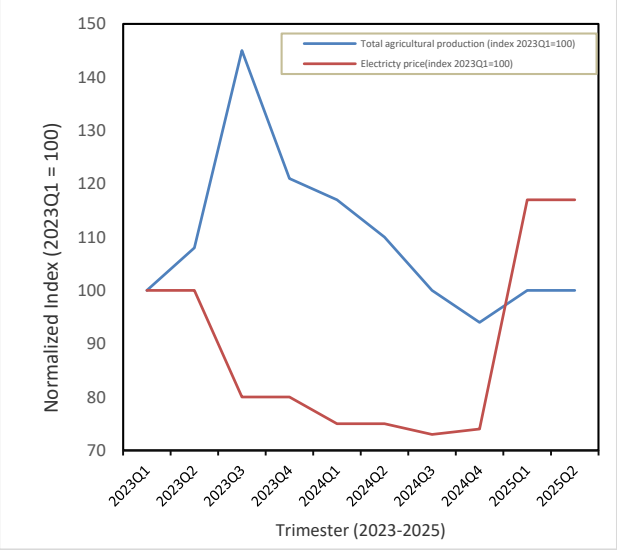

Fig. 1. Relationship between energy prices and total agricultural output
Source: elaborated by the authors based on data from the National Bureau of Statistics of the Republic of Moldova and Invest Moldova [21].

Figure 1 shows that when energy prices decline, agricultural output tends to increase, whereas rising energy costs are associated with a contraction in production.

Although the relationship is not perfectly linear, the overall trend highlights the strong dependence of agricultural performance on energy costs.

A particularly illustrative example is the sharp increase in mineral fertilizer prices, which was closely linked to the surge in natural gas prices. The dramatic increase in fertilizer prices and the continuous revision of price forecasts during 2022 confirm the high exposure of Moldovan agriculture to energy market shocks (Crivoi, 2022) [6]. Nitrogen-based fertilizers, such as urea and ammonium nitrate, which rely on ammonia produced from natural gas, experienced price increases of four to five times during the winter of 2021–2022 (Mold-Street.com, 2022) [19]. (Fig. 2).

Consequently, in 2022 the Republic of Moldova recorded the highest fertilizer prices observed over the past decades.

This extreme price volatility demonstrates how strongly energy shocks can affect the agricultural sector. Faced with prohibitively high costs, many farmers reduced fertilizer application rates, thereby increasing the risk of lower yields.

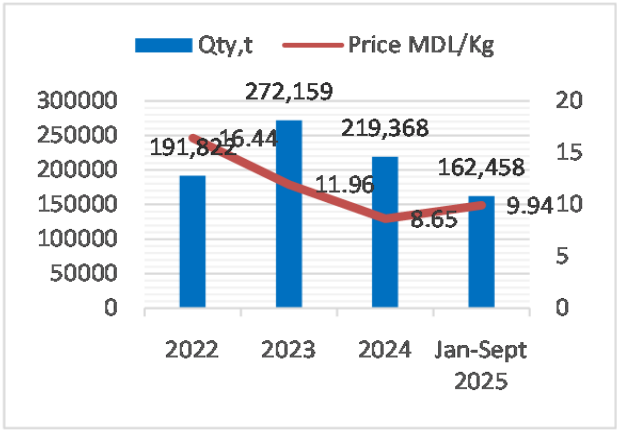

Fig. 2. Imports of mineral fertilizers
Source: elaborated by the authors based on data from Moldova in Progress (2025) [18].

By contrast, the decline in fertilizer prices during 2024–2025 allowed producers to resume input procurement, enabling a partial recovery of output without a proportional

collapse in crop production (Moldova in Progress, 2025) [18].

The phenomenon was felt at the regional level. In Romania, the cost of nitrogen-based fertilizers increased more than fourfold, from approximately 900 lei per ton in 2020 to over 4,000 lei per ton in 2021, driven by the European gas crisis. At the same time, natural gas prices increased by around 40%, electricity prices by approximately 19%, and diesel prices by about 21%, values comparable in magnitude to those observed in the Republic of Moldova. These similar figures confirm that the energy shock was regional and global in nature rather than purely local, and that farmers in both countries faced the same challenge of sharply rising input costs.

The major difference lay in the capacity to respond. As a member of the European Union, Romania benefited from support packages and financial instruments, including the National Strategic Plan 2023–2027, aimed at mitigating the impact of the crisis. These measures included subsidies for agricultural diesel, state aid for farmers affected by drought and high input prices, and other targeted support mechanisms (Agerpres.ro, 2022) [1]. In Moldova, the government implemented emergency measures such as partial compensation for energy tariff increases affecting food-sector enterprises and, through AIPA, introduced temporary reimbursement schemes covering part of the electricity costs used in agriculture, for example for irrigation or on-farm processing.

Nevertheless, the financial burden on Moldovan farmers remained substantial, with many producers forced to resort to credit financing or to postpone investments due to working capital constraints caused by elevated energy bills.

An indicator of this development is energy intensity in agriculture, defined as the amount of energy used to produce one unit of agricultural value added. According to a national energy profile, the energy intensity of the agricultural sector in the Republic of Moldova increased significantly, by approximately 139% in recent years, indicating that agriculture has come to consume substantially more energy per unit of output (Odyssee-Mure.eu, 2025) [22]. In other words, the energy cost per unit of agricultural value added has risen, either because energy prices increased more rapidly than the value of agricultural production, or because farmers were forced to use larger quantities of energy such as additional pumping and irrigation during drought years to obtain comparable harvests.This phenomenon may signal either a decline in efficiency or an adaptation to more challenging operating conditions. It should be noted, however, that at the macroeconomic level the Republic of Moldova has gradually improved its overall energy intensity, decreasing from approximately 4.4 MJ per GDP (1,000 USD) in 2015 to about 2.7 MJ per GDP in 2022, indicating that the economy as a whole has become more energy efficient (NBS, 2023) [21]. The divergence between the agricultural sector characterized by a rising energy intensity and the national trend marked by declining energy intensity highlights a sector-specific challenge in keeping pace with the energy transition. Primary agriculture remains less efficient and more vulnerable to price shocks, which underscores the need for targeted interventions aimed at improving efficiency and reducing dependence on conventional energy sources.

Rising energy prices have translated into substantially higher import costs for fuels, electricity and fertilizers, while simultaneously compressing producers' profit margins. This erosion of profitability directly affects the international competitiveness of Moldovan agri-food products, confirming earlier findings that efficiency and cost structures are decisive determinants of trade performance (Coreţchi, et al., 2014) [5]. Farmers tried to adapt in the short term by reducing energy consumption wherever possible. However, energy demand in agriculture is not easy to cut, which shows that the possibilities for rapid adaptation are limited (OECD, 2018). At the same time, the energy transition does not mean only higher prices for fossil fuels, but also the need to switch to renewable energy sources and more sustainable practices, including in the

agricultural sector. In recent years, concrete examples have also started to appear in the Republic of Moldova, showing that agriculture is gradually turning toward green energy, both to better cope with difficulties and to reduce costs. A good example in this regard is agrophotovoltaics, also called agrivoltaics. This involves using the same land both for agriculture and for the production of solar energy.

At the end of 2025, the Ministry of Energy of the Republic of Moldova published the first national guide on agrivoltaic systems, which shows that this field is beginning to be taken more seriously at the level of public policy as well (Hituc, 2024) [12]. More specifically, these systems involve installing photovoltaic panels above crops or pastures at a height that still allows the land to be used for agricultural activities. According to the information presented in the guide, one hectare of land can be used for the installation of panels capable of producing enough electricity to supply dozens of households, while at the same time the land underneath can remain productive. For example, shade-tolerant crops can be grown there, melliferous plants can be sown, or the land can be used for grazing (Hituc, 2024) [12]. Compatibility of major agricultural systems with agrivoltaic systems is shown in Table 1.

Table 1. Compatibility of major agricultural systems with agrivoltaic systems

Crop / system	Compatibility with shading	Why it is suitable for agrivoltaics
Vineyards (grapevines)	Very high	Reduces water and heat stress; provides protection against sunburn and hail
Orchards (apples, plums, etc.)	High (with appropriate system design)	Replaces anti-hail nets and supplies energy for cooling and post-harvest processing
Shade-tolerant vegetables (lettuce, spinach, cabbage, etc.)	High	Reduced wilting, improved soil moisture, extended growing season
Pasture with sheep (solar grazing)	Very high	Natural maintenance, livestock shade, improved drought resilience

Source: elaborated by the authors based on Barron-Gafford et al. (2019) [3].

Another important advantage is that these panels not only produce energy, but also help agricultural crops. They can reduce water evaporation from the soil and provide some protection against extreme weather conditions, such as hail or excessive solar radiation. In this way, a more favorable microclimate can be created for certain crops. At the same time, farmers gain an additional source of income from electricity generation, increasing their energy autonomy and offsetting electricity-related costs. Given that approximately 75% of the territory of the Republic of Moldova is used for agricultural purposes, agrivoltaics offer a balanced solution for the expansion of solar energy capacity, avoiding the exclusive occupation of productive land with photovoltaic installations (Hituc, 2024) [12].

For example, one hectare of agricultural land equipped with agrivoltaic systems can generate approximately 400 MWh of electricity per year, equivalent to the annual consumption of around 150–200 households.

At current tariff levels, this energy output may generate revenues exceeding 1.3 million lei annually, while maintaining or even improving agricultural production.

Through self-consumption, the electricity produced significantly reduces costs related to irrigation, refrigeration, processing and storage, directly lowering the unit cost of agricultural production. In this way, agrivoltaics transform land into a dual-productivity asset, generating both food and energy. This enhances farmers' financial stability, improves the competitiveness of agricultural products and increases the sector's resilience to drought and energy price volatility.

Such models have already been tested in the European Union and the United States, and their adaptation in Moldova supported by development partners suggests a strong potential for structural transformation of rural areas, where future farms may simultaneously function as producers of both food and energy (Photo 1).

Such systems can reduce soil water evaporation and protect crops, while simultaneously generating electricity for self-consumption or for delivery to the grid. Beyond solar energy, Moldovan agriculture is also exploring other renewable energy

sources, notably biomass and biogas. As a predominantly agrarian economy, the Republic of Moldova has substantial quantities of plant residues such as straw, corn stalks and by-products from winemaking that can be valorized for energy purposes. The International Energy Agency has highlighted Moldova's significant potential for biomass energy development, given the agricultural structure of its economy.

Photo 1. Agrivoltaic system with elevated structures over rows of fruit trees
Source: elaborated by the authors based on Hituc, L. (2024) [12].

Several livestock farms have already begun to implement biogas installations, converting manure and other organic waste into methane that can be used as fuel for heating or electricity generation. This approach not only provides a local and renewable energy source, but also contributes to improved waste management and the reduction of uncontrolled methane emissions from agriculture, given that methane is a highly potent greenhouse gas when released directly into the atmosphere. In parallel, many farmers have switched to biomass boilers using pellets derived from agricultural residues or sustainably sourced wood to heat greenhouses and farm facilities during winter, thereby reducing reliance on natural gas or fuel oil.

Energy efficiency measures have also started to gain traction, including the use of heat pumps for cold storage facilities and the modernization of irrigation systems through higher-efficiency pumps and drip irrigation technologies, which reduce both water and energy consumption. These developments have been encouraged primarily through international financing programmes (Efremov et al., 2025) [7].

Grants and subsidies targeted at green energy investments have played a key role in accelerating this transition. In 2023, amid the peak of the energy crisis, projects supported by UNDP, the Austrian Development Agency and the Government of Japan were launched to assist agricultural producers in improving energy efficiency and adopting renewable energy solutions.

A dedicated programme focused on women entrepreneurs in rural areas provided grants of up to USD 6,000 for agricultural microenterprises and up to USD 18,000 for women-led agricultural SMEs, subject to a 20% co-financing requirement. Eligible investments included photovoltaic panels, biogas equipment, heat pumps and biomass boilers, as well as other energy efficiency measures implemented on farms. The stated objective of these initiatives was to enhance the energy autonomy of agricultural holdings and to reduce their vulnerability to energy price shocks (AgroExpert.ro, 2023) [2]. It is also worth noting the emerging fiscal incentive framework that the Republic of Moldova is beginning to develop in order to stimulate green investments in rural areas. In several European Union countries, fiscal incentives are already in place; for example, France offers specific "agro-voltaic" tax incentives, including tax exemptions, for farmers who combine solar energy production with agricultural activities. Similar recommendations appear in policy-oriented studies for Moldova, such as reducing value-added tax on renewable energy equipment (solar panels, turbines, batteries) or granting land tax exemptions for farmers who install photovoltaic systems on their agricultural land. Such measures could enhance the economic attractiveness of these investments by shortening payback periods and lowering upfront costs.

At the practical level, the effects of decarbonization in agriculture are also reflected in a growing orientation toward farming practices with a lower carbon footprint. The concept of Climate-Smart

Agriculture, promoted by organizations such as the FAO and the World Bank, is gradually gaining visibility in Moldova. This approach involves techniques such as cover cropping and minimum tillage aimed at maintaining carbon stocks in soils and reducing fuel consumption associated with repeated ploughing optimized crop rotations that can decrease dependence on chemical fertilizers, improved livestock waste management to reduce methane emissions (potentially through capture in biogas installations), and soil carbon sequestration through organic matter management and conservation agriculture practices.

Recent studies indicate that agricultural soils in the Republic of Moldova have the potential to sequester up to 27% of the country's carbon emissions if sustainable land management practices are widely adopted. At present, this potential is only partially exploited; however, as environmental policies introduce new incentives such as payments for ecosystem services or voluntary agricultural carbon market mechanisms farmers could benefit financially from soil regeneration and emission reductions, in addition to the broader gains associated with improved soil fertility and climate resilience.

To fully integrate agriculture into the objective of climate neutrality by 2050, a key challenge will be the electrification and efficiency improvement of agricultural mechanization. Although electric tractors and harvesters are currently at pilot or experimental stages at the global level, technological progress over the coming decades may lead to the adoption of electric or hybrid machinery in commercial farming. Such technologies would significantly reduce diesel consumption and could be powered by locally generated renewable energy, for example from agrivoltaic systems, thereby closing the sustainability loop. In the interim, transitional solutions include the use of biofuels (such as vegetable oil or biodiesel) in existing machinery and logistical optimization measures, including the reduction of unnecessary transport and increased cooperation among farmers for the shared use of energy-efficient equipment.

Overall, the energy transition offers Moldovan agriculture an opportunity for positive structural transformation: reducing dependence on imported fossil fuels, lowering vulnerability to volatile energy prices, and creating alternative income streams through renewable energy production or savings. The steps taken to date from the initial deployment of solar installations on farms, to subsidy schemes supporting energy efficiency, and the gradual integration of agriculture into climate policy frameworks represent a foundation upon which future development can be built.

A critical issue concerns the extent to which the energy transition both through rising energy prices and through the broader processes of modernization and decarbonization has effectively influenced the productivity of the agricultural sector in the Republic of Moldova over the past decade. Agricultural productivity can be assessed from multiple perspectives: through partial productivity measures, such as physical yields expressed in tons per hectare or the efficiency of specific inputs (for example, energy efficiency measured as value added per unit of energy consumed), or through total factor productivity (TFP), which provides an aggregated measure of the contribution of all production factors.

Economic modeling indicates that, under conditions of low electricity demand elasticity ($\varepsilon = -0.11$), a 44% increase in energy tariffs leads to only a marginal reduction in consumption (approximately −4.8%), while total energy expenditure rises by around 37%. Given that energy accounts for roughly 20% of total agricultural costs, this translates into an increase in overall production costs of approximately 7–9% (Table 2).

Economic modeling of the impact of energy price increases on agriculture imposed to calculate the indicators mentioned below.

(1)Price elasticity of energy demand:

$$\varepsilon = (\%\Delta Q_e)/(\%\Delta P_e) \quad \text{.....(3)}$$

These results in:

$$\%\Delta Q_e = \varepsilon * \%\Delta P_e$$

$$\%\Delta Q_e = -0.11\text{x}\,44\% \approx 4.8\%$$

(2) Total energy expenditure:

$C_e = P_e \times Q_e$ ... ... (4)

After the price increase:

$$C_e = 1.44 \times 0.95 \approx 1.37$$

⇒increase ≈ +37%

(3) Impact on total agricultural costs:

$\%\Delta C_{tot} \approx s_e \times \%\Delta C_e$..... (5)

$\%\Delta C_{tot} \approx 0.20 \times 37\% \approx 7.4\%$

Table 2. Economic modeling of the impact of energy price increases on agriculture in the Republic of Moldova (2022)

Indicator	Symbol	Value
Price elasticity of electricity demand	E	−0.11
Increase in electricity tariffs	$\%\Delta P_e$	+44%
Estimated reduction in energy consumption	$\%\Delta Q_e$	−4.8%
Estimated increase in energy expenditures	$\%\Delta C_e$	+37%
Share of energy in agricultural costs	s_e	20%
Estimated increase in total agricultural costs	$\%\Delta C_{tot}$	+7–9%

Source: elaborated by the authors based on Šikl et al. (2025) [24].

Such an increase significantly reduces farm profitability, particularly for small and medium-sized holdings, confirming that energy price shocks are largely transmitted into the cost structure of agricultural production.In the short term, the surge in energy prices had a predominantly negative effect on agricultural performance, not so much through an immediate decline in output volumes which were more strongly influenced by drought and other natural factors but through the erosion of farm profitability and a reduction in investment activity. In 2022, despite elevated production costs, Moldova nevertheless achieved relatively good agricultural output levels for certain crops. However, farmers' margins were substantially compressed, as cereal selling prices did not increase proportionally to input costs, resulting in lower net incomes. This weakened farm capitalization and led producers to adopt a more cautious approach in 2023. For example, some farmers reduced the areas planted with input-intensive crops, such as maize or greenhouse vegetables, or shifted toward more resilient and sustainable crops, including nitrogen-fixing crops like soybeans to reduce fertilizer requirements, or oilseed crops that require fewer treatments.

Overall, although physical productivity measured in tons per hectare did not collapse following the energy price increases, yields of wheat and sunflower were weak due to drought conditions, while maize production was particularly affected, falling to less than half of its 2021 level. As a result, disentangling the impact of energy prices from that of adverse weather conditions remains challenging. In 2023, a more favorable agricultural year, high production levels were once again achieved, supported in part by improved access to lower-cost inputs, including fertilizers at reduced prices.

An important complementary indicator is energy productivity. According to the National Bureau of Statistics, the energy productivity of the Moldovan economy measured as GDP in thousand USD per tonne of oil equivalent of energy consumed increased from 9.6 in 2015 to 15.8 in 2022 (NBS, 2023) [21]. This trend reflects overall progress, indicating that more economic value is being generated per unit of energy consumed, largely driven by non-agricultural sectors such as light industry and services, which have achieved higher efficiency gains than agriculture. Agriculture did not contribute to this overall increase; on the contrary, as previously noted, its energy efficiency has deteriorated. This situation indicates that Moldovan agriculture still possesses substantial potential for productivity growth through technological modernization and the adoption of more energy-efficient practices. For example, average yields per hectare in the Republic of Moldova remain lower than those recorded in Romania or across the European Union for many basic crops, including cereals and legumes. This gap is partly explained by lower investment levels, limited irrigation infrastructure and the continued use of outdated technologies.

In this context, the energy transition may act as a catalyst for modernization. On the one hand, high energy costs compel farmers to seek new solutions for instance, investing in drip irrigation systems powered by solar panels, which in the long run reduce diesel consumption and increase yields per hectare. On the other hand, policy support for green technologies provides access to funding that translates into new equipment and technical know-how, such as the installation of heat pumps for grain drying, which consume up to three times less energy than older gas-based drying systems.

In the long term, the sustainability of agriculture will depend on the extent to which it succeeds in decoupling production growth from increases in energy and resource consumption. The concept of energy efficiency thus becomes an integral component of productivity. While farmers have traditionally focused primarily on physical yields (maximizing output), in the future the indicator of energy performance output per unit of energy consumed will gain increasing importance, particularly if emission costs (such as carbon taxes) or schemes rewarding energy savings are introduced.

A practical example is the transition to smart irrigation systems equipped with soil moisture sensors and powered by solar panels which can increase crop productivity by 20–30% while simultaneously reducing water and energy consumption by comparable proportions, relative to traditional flood irrigation methods that are energy-intensive and inefficient. Such efficiency gains contribute to improvements in total factor productivity (TFP), which in agriculture has stagnated or increased only slowly over recent decades. The ultimate objective is an agriculture that is economically competitive producing more with fewer resources and ecologically resilient, avoiding the degradation of resources needed by future generations.

A comparison with Romania reveals similar patterns. Romanian agriculture has also been strongly affected by recurrent droughts and rising input prices; however, long-term productivity has increased moderately due to integration into EU markets and access to modernization funds, including newer machinery, improved seed hybrids and more balanced fertilization practices. Like Moldova, Romania has significant untapped potential in rural renewable energy. Following the sharp rise in electricity prices after 2022, many large Romanian farms began installing their own photovoltaic systems to secure energy independence. In both Romania and the Republic of Moldova, greater attention has been given in recent years to the rehabilitation of irrigation systems. Although these investments lead to higher energy consumption in agriculture, they are very important for maintaining and increasing agricultural production in a context where drought is becoming more and more frequent. The main issue is that these systems must be efficient not only from a technical point of view, but also in terms of energy use and environmental impact. That is why new technologies, such as solar-powered pumps and sensor-controlled micro-irrigation systems, are becoming increasingly important. Without such solutions, there is a risk that the problem of drought will be replaced by another one, namely dependence on expensive energy for pumping water.

In the short term, the energy transition has brought serious financial pressure and, in some cases, even production declines, especially for farmers who do not have enough resources to cope with higher costs. In the medium and long term, however, this process can also bring positive effects, because it pushes farmers to use new technologies and become more efficient. In this way, agriculture can become more resilient to crises, less dependent on external factors, and better adapted to environmental requirements.

Everything depends, however, on how well this change is managed, both by state institutions and by agricultural producers. Investments in modern technologies, the use of more sustainable practices, and the proper use of support measures are all very important, so that today’s problems can be turned into opportunities for the future. To better understand the position of the Republic

of Moldova in this process, it is useful to look at other countries as well. Romania is a close example, because it has similar natural and agricultural conditions, but also better access to financial resources and support mechanisms, as a member state of the European Union. Agriculture there has also been strongly affected by rising energy prices. The Romanian state intervened through direct drought compensation, amounting to approximately 365 million lei for affected farmers, as well as through other support measures, such as the temporary capping of electricity tariffs and exemptions from excise duties on diesel used in agriculture.

Although Moldova also provided certain compensation measures, its fiscal capacity was significantly more limited, meaning that Moldovan farmers bore a relatively greater share of the impact using their own resources. In Romania, the Common Agricultural Policy (CAP) played a stabilizing role: direct payments to farmers ensured a minimum income even under rising costs, while rural development measures enabled access to funding for energy-efficient equipment, such as support for installing photovoltaic panels on farms through the National Rural Development Programme. By contrast, the Republic of Moldova relied primarily on its national budget and external assistance, which helps explain why positive initiatives, including green grants, were implemented on a smaller scale.

Another important difference lies in the structure of agricultural holdings. Romania, similar to Moldova, has a dual agricultural sector consisting of several thousand large, highly mechanized commercial farms alongside over one million subsistence or semi-subsistence farms. In both countries, large farms demonstrated a stronger capacity to absorb the energy shock, benefiting from better bargaining power, financial reserves and economies of scale. Small farms were the most exposed. In Moldova, small vegetable and dairy producers were directly affected by higher electricity tariffs, as a substantial share of their output requires refrigeration and on-farm processing. In Romania, protective measures were introduced, including reduced VAT rates on electricity and natural gas for agricultural users and tax exemptions under income-norm regimes for farms using protected cultivation systems supplied by renewable energy. These efforts were aimed at preventing the bankruptcy of small producers.

Compared to the EU average, both countries remain at lower levels of energy efficiency and renewable energy penetration in agriculture; however, the overall trend points toward convergence. The European Union increasingly promotes the “Farm to Fork” strategy, which incorporates targets related to energy sustainability, including emission reductions in agriculture, renewable energy use on farms and circular economy principles. In this context, Romania and the Republic of Moldova particularly as Moldova became an EU candidate country in 2022 and began aligning with the acquis are expected to implement increasingly similar standards. One example is the requirement for energy audits in medium and large agri-food units, already applied in the EU and likely to be extended to Moldova, thereby accelerating the modernization of inefficient equipment. In parallel, EU discussions on concrete targets for reducing methane emissions from agriculture are expected to encourage farms in both Romania and Moldova to invest in anaerobic digestion (biogas) and improved livestock nutrition in order to lower emissions.

Within the broader energy transition, diversifying energy sources and reducing dependence on fossil fuels represent strategic priorities for agricultural economies. Romania has increasingly capitalized on its wind and solar potential, particularly in the Dobrogea region, which hosts one of Europe’s largest wind farms. Over the long term, this process contributes to more stable and potentially cheaper energy, benefiting not only the overall economy but also agri-food value chains by reducing energy costs associated with processing and storage.

Although on a smaller scale, the Republic of Moldova is undergoing a similar process of structural transformation. Accelerated investment in renewable energy sources and

the synchronization of the national power system with the European ENTSO-E network have strengthened energy security and enabled a gradual departure from dependence on vulnerable traditional sources. The Cernavodă-Isaccea-Chișinău interconnection holds particular strategic significance, as it marks Moldova's transition from an isolated energy system to an integrated and more resilient one. In the short term, energy diversification has involved increases in electricity tariffs, which have been reflected in higher agricultural production costs. In the medium and long term, if farmers have access to safer and cheaper energy, they will be able to use more modern technologies, improve their irrigation systems, storage and processing facilities, and reduce post-harvest losses.

Energy interconnection does not mean only transmission lines and infrastructure, but also broader changes at the level of institutions and the market. It can contribute to greater transparency, clearer rules, and more stability. For agriculture, all of this matters because it reduces uncertainty, makes rural investment more attractive, and can open access to European funding programmes for more energy-efficient technologies, such as electric irrigation systems, modern cold-storage facilities, biogas installations, or anaerobic digestion systems.

Viewed as a whole, the Cernavodă–Isaccea–Chișinău interconnection is not just a technical project, but also a real opportunity for the modernization of agriculture in the Republic of Moldova. It can help reduce farmers' dependence on energy crises, increase the competitiveness of the agri-food sector, and guide it toward a more sustainable and energy-efficient production model.

At the same time, the European Union is moving more and more toward policies focused on reducing carbon emissions. The expansion of the ETS system and the possible application of the CBAM mechanism could mean that, in the future, imports will also be taxed according to how polluting their production was. For the Republic of Moldova, which exports agri-food products to the European Union market, this is very important. It means that reducing emissions will no longer be only an environmental issue, but also a matter of market access.

In other words, if agricultural products are obtained through methods that consume a lot of energy and generate high emissions, they could be disadvantaged on the European market. For this reason, aligning with the European Union's green standards is not only a good choice, but also an economic necessity. Romania is a relevant example in this respect, because as part of the European Union it already applies stricter environmental rules in agriculture and invests in lower-emission production models.

Moldova will need to pursue a form of "leapfrogging" development, and current signals indicate that this direction is politically endorsed. At COP27 and COP28, Moldovan officials reiterated the target of reducing emissions by 70% by 2030 and called for international support to achieve this goal, emphasizing that energy security and the green transition are mutually reinforcing.

Regional perspectives confirm that the energy transition is an inevitable and ongoing process in agriculture. Although the Republic of Moldova starts from a position of relative disadvantage, it also benefits from unique opportunities, including external support, the ability to incorporate lessons learned elsewhere, and significant potential for renewable energy in rural areas. Close cooperation with Romania and other EU partners can accelerate the adoption of green technologies in agriculture and support the development of an integrated agro-energy system at the regional level, generating mutual benefits for example through interconnected grids enabling renewable energy exchange or joint agricultural research programmes focused on climate adaptation.

Looking toward the 2030–2035 horizon, Moldovan agriculture will be positioned at the intersection of several critical trends: developments in global energy markets, climate change with the potential to fundamentally alter production conditions, and progressive integration into the European Union. Based on the data and policy

directions analyzed, a number of key expectations and challenges can be identified:

Stabilization of energy prices and efficiency improvements

Following the shock experienced during 2021–2024, scenarios developed by international agencies such as the International Energy Agency (IEA) in the World Energy Outlook anticipate a medium-term stabilization of fossil fuel prices, with a potential downward trend as the transition toward renewable energy sources reduces demand for hydrocarbons. For the Republic of Moldova, this would imply that the years of sharp price increases may be followed by a period of greater predictability in energy costs. Nevertheless, price volatility cannot be fully excluded, particularly in an unpredictable geopolitical context.

The most effective safeguard against future energy shocks will be improved energy efficiency. If by 2035 Moldovan agriculture succeeds in halving its energy intensity through technological upgrades and more efficient practices, the impact of any future energy price increases would be substantially mitigated. An indicative target would be for agricultural energy intensity to return to its 2015 level or below, effectively reversing the approximately 139% increase recorded over the previous decade. Achieving this objective requires sustained investment in modern, energy-efficient machinery, logistics optimization, and the reduction of energy losses at farm level.

Diversification of the agricultural energy mix

A significant share of commercial farms in the Republic of Moldova is expected to become energy prosumers, producing part of their own energy requirements. Whether through small photovoltaic installations of several kilowatts mounted on storage facilities, small-scale wind turbines in areas with favorable wind conditions, or biogas generators on livestock farms, such sources could supply a substantial proportion of the sector's energy consumption estimated at 20–30% or more. Government policies already support this transition, and as the costs of green technologies continue to decline, the threshold for economic viability will become increasingly accessible for agricultural producers.

Adaptation to climate change

The coming decade is likely to bring increasingly extreme climatic events, such as droughts and heatwaves, which will intensify the demand for agricultural inputs particularly water for irrigation and, in some cases, additional fertilization to compensate for stress-affected crops. If current practices are maintained, this may result in higher energy consumption in agriculture. The key challenge will therefore be to achieve "more with less" by combining climate-smart agriculture with clean energy solutions. For instance, if irrigated areas expand, newly developed systems should ideally be electrified and powered by renewable energy sources rather than by diesel pumps, as was common in the past. In this way, even if the volume of pumped water increases, the fossil energy footprint can remain low. New technologies, such as solar-powered pumps and, where needed, desalination solutions for the intensive use of surface water or groundwater, could become increasingly important for this region.

Technological innovations

Some solutions that today still seem new or even experimental could become, in the coming years, something common and accessible for farmers. One example is the emergence of autonomous electric tractors. There are already companies testing electric agricultural robots, including some powered by solar energy, for tasks such as mechanical weeding or vegetable harvesting. If such technologies become cheaper and are used on a large scale, they could significantly change the cost structure in agriculture. In other words, instead of purchased diesel, electricity generated directly on the farm could become the main source of power.

Another example is the development of smart rural microgrids. This means that villages or several farms in the same area could connect to a local energy network, where they would share renewable energy production and energy stored in batteries. Through this kind of organization, local demand could be covered more easily, and dependence on the

centralized grid could decrease. Such a solution would be especially useful for more isolated agricultural communities, because it would provide them with greater energy security. For the Republic of Moldova to benefit from such innovations, cooperation with external partners, participation in pilot projects, and access to research and innovation funding will be important.

Policies and financing

If by 2035 the Republic of Moldova joins the European Union, its agriculture could benefit from the support provided through the Common Agricultural Policy. This would mean access to larger direct payments and to funds for rural development. In addition, since 2023, the Common Agricultural Policy has placed increasing emphasis on environmental protection, and an important part of its budget is linked to climate-related measures. EU accession would therefore provide significant financial resources to support the green transition in agriculture, including investments in renewable energy, nutrient management and agroecological forestry practices.

Agricultural emissions and the economics of emissions

In the future, farmers may increasingly be rewarded for reducing emissions, for example through voluntary carbon markets where they can sell carbon credits generated by sequestration practices, afforestation and agroforestry systems, or by reducing methane emissions through anaerobic digestion. By 2035, if such mechanisms are further developed, a Moldovan farmer could obtain an additional source of income by operating a digester that reduces emissions by a given amount of CO_2, subsequently selling these emission savings to companies seeking to offset their carbon footprint.

Overall, a picture emerges of a Moldovan agricultural sector in transition: more technologically advanced, more closely interconnected with the energy sector and, ideally, more financially and climatically resilient. Uncertainties will nevertheless persist, such as fluctuations in global carbon credit prices which could indirectly increase fertilizer costs if producers are required to pay for emissions or the introduction of new regulatory frameworks, for instance carbon-related charges on transport that would also affect the distribution of agricultural products. In this context, it is essential for policymakers and the agricultural community to remain proactive and to anticipate these developments.

Although the Republic of Moldova starts from the position of a small economy, it benefits from greater agility, allowing it to adopt measures more rapidly than larger countries and to implement pilot-scale solutions more efficiently. The political commitment demonstrated toward the energy transition represents a strong catalytic factor. If this commitment is sustained and translated into concrete projects for agriculture as outlined in strategic policy documents by 2035 Moldova could achieve a modern, competitive and sustainable agricultural sector, one that does not merely withstand the energy transition but thrives as a result of it.

CONCLUSIONS

Over the past ten years, the energy transition has had a strong impact on agriculture in the Republic of Moldova and has clearly shown that energy security and food security are closely connected. In short, the main conclusions of the analysis are the following:

Rising energy prices exerted unprecedented pressure on agricultural production costs. The energy shock eroded farm profitability, particularly among small-scale producers, and exposed the structural vulnerabilities of Moldovan agriculture, including high energy intensity and strong dependence on imported inputs such as natural gas, fertilizers and fuels. In the absence of support mechanisms, the impact would have been even more severe, forcing farmers to adapt by reducing consumption and improving operational efficiency wherever possible.

The transition toward renewable energy sources and improved energy efficiency has begun to take shape as both a response to recent shocks and a strategic solution. Agriculture is taking its first steps toward integrating solar energy such as agrivoltaic

systems bioenergy and energy-efficient technologies, a process encouraged by emerging policies and grant schemes.

This trend needs to be accelerated, as in the long term only through a degree of energy autonomy based on farms acting as energy prosumers and reduced dependence on fossil fuels can agriculture enhance its resilience. Investments implemented to date, including photovoltaic installations, biogas facilities and irrigation modernization, confirm both the technical feasibility and the economic benefits of the green transition at farm level.

Agricultural productivity and sustainability are affected by the energy transition in a dual manner: negatively, through cost shocks that can reduce input use and threaten output levels; and positively, by creating incentives to innovate and adopt more energy-intelligent practices that lead to higher efficiency in the long term. The data indicate that agricultural energy efficiency has declined in recent years, signaling the need for corrective action. The large-scale implementation of climate-smart agriculture and precision technologies will be essential to decouple production growth from increasing energy consumption and to achieve sustainability objectives.

The Republic of Moldova faces challenges similar to those encountered by other countries in the region, such as Romania, in the fields of energy and agriculture, but with more limited internal resources to manage them. Alignment with European Union policies and funding instruments particularly the Common Agricultural Policy and the European Green Deal represents a major opportunity to provide financial support for the green transition of agriculture in the coming years. Experience from other countries suggests that an optimal policy mix should include targeted subsidies for critical inputs during periods of crisis, substantial investments in infrastructure such as energy-efficient irrigation systems and modern rural electricity networks fiscal incentives for renewable energy adoption, and a stable regulatory framework that encourages private initiative in on-farm green energy development.

2030–2035 Prospects

Moldovan agriculture has the potential to become more resilient and competitive if the energy transition is managed proactively. Scenario analyses point to an increasing share of renewable energy in rural areas, a gradual reduction in energy intensity as efficient technologies penetrate the market, and deeper integration with European markets for both agricultural products and energy. The future of agriculture is closely intertwined with the future of energy, and in the case of the Republic of Moldova this implies a structural shift toward a low-emission, digitalized agri-food sector that is increasingly interconnected with smart energy networks.

The structural implications of the energy transition for Moldovan agriculture are reflected in a transformation of the way food is produced, encompassing input use, technological processes and farm business models. Adapting to these changes is not optional but essential for the sustainable development of agriculture and for ensuring both food and energy security at the national level. Although the Republic of Moldova is a small economy, it has the potential to become a regional example of energy-smart agriculture, provided that it continues on a path of innovation and cooperation, effectively leveraging both internal resources human and agricultural and the support offered by its international partners.

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APPLICATION OF DIGITAL MARKETING IN BULGARIAN SMALL AND MEDIUM-SIZED WINERIES

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Abstract

The aim of the study was to evaluate the applicability of digital marketing for Bulgarian small and medium-sized wineries, with emphasis on online visibility, competencies, and sustainable growth. In 2024, a survey was conducted among 13 wineries from Northwestern and Central Northern Bulgaria. The results showed that the most frequently used channels were social media platforms Facebook and Instagram, while video marketing was only marginally represented. The data clearly identified a need for training in digital marketing and for regionally targeted strategies for the national market. Accordingly, it was necessary to develop training programs and practically oriented tools for digital channels that could enhance return on investment.

Key words**:** *digital marketing, winemakers, social networks, training, wine tourism*

INTRODUCTION

The evolution of the Internet since the 1990s, driven by digitalization and platforms, has transformed marketing through social media and differentiated online from offline markets (Alves et al., 2016) [1]. In the contemporary environment, owning a website and actively implementing digital tools are critical conditions for customer access, company sustainability and brand recognition (Kannan & Li 2017; Verhoef et al., 2021) [12, 18].

Marketing is evolving from analog to digital, utilizing new tools to enter a brand new technological environment. Its primary object is to reach, research and deliver to digital consumers what they are looking for. Online trading platforms and social networks played a major role in this process (Alves et al., 2016) [1]. These platforms have not only changed the way purchasing behaviour, but have also established new standards for delivery speed, supported by innovations in logistics. (Krastev, 2017; Mastroberardino et al., 2022) [14, 15]. In this context, new marketing opportunities have opened up for the wine sector and wine tourism, using direct online stores, social channels for advertising, reservation and logistics networks to reach the end consumer. (Bonarou et al., 2017) [3]. At the heart of this new marketing landscape is the concept of the *Attention Economy*, a term first proposed by Simon (1971) [16]. It postulates that in a world saturated with information, the primary scarce resource is human attention (Simon, 1971) [16]. The attention economy, which evolved from the idea that attention itself is a commodity, plays a key role in shaping economic value and popularity in digital media formats (Törhönen et al., 2018) [17]. In the contemporary digital ecosystem, consumer attention is perceived as the currency with which they pay for content. (Huberman, 2013) [8]. This compels brands, including in specific niches such as wine tourism, to fight for every second of engagement, turning visual aesthetics and personal brand into key strategic assets. (Dziagacz, 2024) [7].

In a study by Iațișin (2025) [10] concludes that the integration of modern technologies is the key to the recovery of the wine sector in R. Moldova, and the introduction of innovations will facilitate to the sector's restoration, which in turn will improve working conditions, reduce the environmental footprint and significantly increase profitability. In Bulgaria, in 2022, 358 wineries were

registered, reached 365 by 2025(Koev, 2026) [13]. In a study by Chorbadzhijski (2024) [4], cited by Dimitrov & Dimitrova (2025) [5], the majority of them are small in terms of production volume, which indicates that they are mainly family-owned, with limited financial and managerial resources, oriented towards the domestic market. These constraints affect their competitiveness and market sustainability, primarily leading to savings in resources and effort at the expense of marketing and advertising. Nevertheless, a significant number of them have oriented themselves toward digital channels and tools for advertising and customer acquisition (Dimitrov et al., 2025) [6].

It is precisely digitalization in the wine sector that will be key in positioning and reaching customers, especially younger ones, who interact much more widely and naturally with brands in a digital environment. For them, an online presence is not merely a convenience, but a key factor in building trust and loyalty to the product. Moreover, digital technologies do not "spoil" the image of traditional products, but on the contrary – they are the only way for these products to remain competitive and visible in the modern world (Jelea & Brumă. 2024) [11]. For this reason, enhancing the digital competence of management in small and medium-sized enterprises is strategically important for the successful implementation of digital marketing and for ensuring the competitiveness of the business.

The aim of the study is to evaluate the applicability of digital marketing by small and medium-sized Bulgarian wineries, with an emphasis on online visibility, competencies and sustainable growth.

MATERIALS AND METHODS

The research based on a primary survey conducted during the "*Time for Wine*" *festival* in Pleven, Bulgaria (August 29 – September 1, 2024).

The object of the research is the digital marketing and online presence of 13 wineries from North-West and North-Central Bulgaria, all active members of the *Association of the* Danube Winemakers (https://danubewinemakers.bg) [2]. Managers of enterprises classified as small and medium-sized enterprises (SMEs) were surveyed, in accordance with the respondent profile established in a previous stage of comprehensive research. Nine of them are micro- and small enterprises with the following production volumes: five wineries produce between 75 and 150 hl; two wineries – from 150 to 375 hl; and two – from 375 to 750 hl. Four enterprises are classified as medium-sized with an average production volume above 750 hl (Dimitrov & Dimitrova, 2025) [5].

The subject of the research was on the specific forms of virtual communication, digital tools and strategies that managers use to promote their products and wine tourism. The selection of these specific subjects allows for an integrated analysis of the relationship between their production capacity and their digital presence strategies.

Research instrument: Data were collected using a structured questionnaire entitled: "*Research on digital marketing in the wine sector*". The questionnaire consists of 16 questions, designed mainly as closed-ended. In order to ensure comprehensive data collection, several questions allowed for multiple-choice responses, which allows for in-depth understanding of the digital tools used by the enterprises.

Data processing and analysis: The collected data were processed using MS Excel, utilizing univariate frequency distributions for both qualitative (non-metric) and quantitative (metric) variables (Goev et al., 2019) [9]. The interpretation is followed by an analytical approach to identify the strengths and weaknesses in the digital communication strategies used by winery managements to effectively reach their target audiences.

The analysis is structured around four research questions (Research Questions - RQ), which address the following:

1. Infrastructure provision (RQ1): What proportion of the enterprises have their own website and do they maintain up-to-date information for users?
2. Communication channels (RQ2): Which social networks and video channels (YouTube

and TikTok) dominate the marketing mix, and what is their visibility?
3. Barriers and tools (RQ3): What are the main obstacles (budget, time, knowledge) facing wineries and which digital tools are used most effectively?
4. Budgeting and results (RQ4): What share of the budget is invested in digital activities, and how does this affect managers' ability to evaluate return of investment (ROI)?

RESULTS AND DISCUSSIONS

The first group questions pertains to website availability, the frequency of information updates, and market positioning – specifically, the markets toward which the wineries are oriented.
The first question was: "*Do the wineries have their own website?*". When processing the responses, nine wineries *have a website*, one *does not*, and three (at the time of the survey) are *in the process of being developed*. This indicate that most wineries already have their own page and have the opportunity to advertise. Regarding the winery that *does not have* one – it has been on the market for a relatively short time (founded after 2022), despite the lack of such an option in the responses, the manager noted that they currently advertise only through one social network – *Facebook*.
The purpose of the second question is to check "*How often they update the information on their website?"*. The reason for this is to reveal the frequency of content and information upodating. It is linked to conducting regular advertising and promotional campaigns. Nine of the respondents *update their content regularly*, one updates it *infrequently*, while none rely solely on *general information*; the remaining three *do not yet have* a website (Fig. 1).
The results indicate that most wineries strive to update their information and offer up-to-date proposals more frequently. Furthermore, they have the opportunity to monitor click-through rates and identify the most searched-for content, allowing them to better direct their marketing policies.

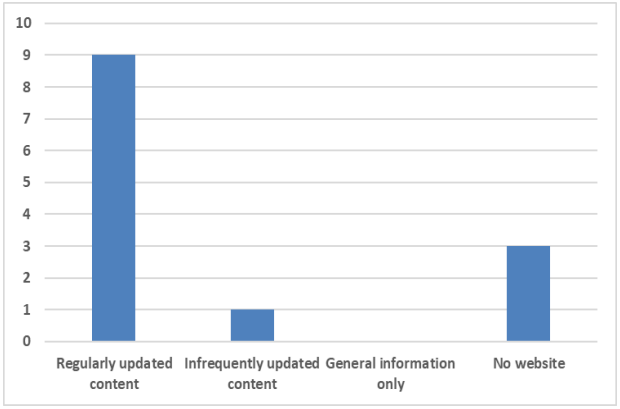

Fig. 1. Website Content Management (n=13)
Source: own calculation based on the survey.

The third question was: "*What is your primary target market in the digital space?*". Based on the data (Fig. 2), the responses are distributed as follows: The response options were as follows:

a) National – 9 mentions (60%);
b) Regional – 2 mentions (13%);
c) International – 0 mentions (0%);
d) National and International – 4 mentions (27%).

The total number of responses is 15 exceeds the number of participants – 13. Although the option to select more than one answer was not provided, representatives from two of the wineries indicated both *national and regional* markets. We assume that their response is driven by the fact that the majority of their production is sold on the local market, with a smaller portion reaching international markets. The primary focus for the wineries is the *national market* (60%), followed by those targeting both *national and international* markets (27%). For the latter group, digital capabilities must be tailored to the specific characteristics of the respective international markets to which they export, taking into account the tastes and traditions of the local population, as well as the potential channels and social networks required to reach their target groups. Additionally, representatives from two of the wineries indicated a focus on both national and regional markets.
There is a clear need for a more integrated digital approach that balances local traditions with global digital trends, ensuring that wineries not only reach, but also resonate with diverse consumer groups across different geographic boundaries.

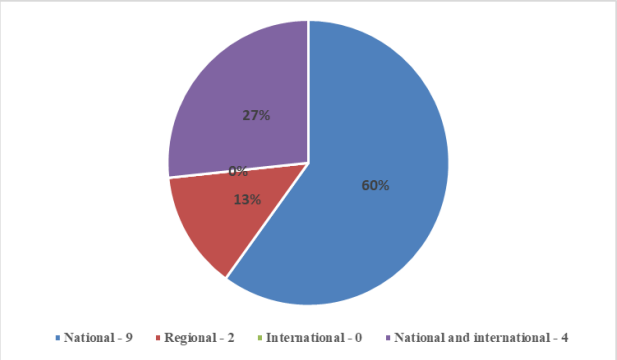

Fig. 2. Target market in the digital space
Note: The total number of mentions (n=15) exceeds the number of respondents (n=13) because some participants provided more than one answer.
Source: own calculation based on the survey.

The next set of questions are related to Research Question - 2 (RQ2): Which communication channels do wineries use, and what marketing mix do they employ to enhance their visibility in the digital space.
Regarding the question: "*Do you use social media for marketing your products?*", the managers responded as follows:

a) Yes, we actively use several social media networks – 9 responses;

b) Yes, but we focus on only one social media network – 3 responses;

c) We use social media, but not actively – 1 response;

d) We do not use social media – 0 responses.

The results indicate that all surveyed wineries utilize at least one social media platform. The majority of them maintain an active presence, which demonstrates that their digital marketing is primarily focused on social media advertising. This appears to be the most critical segment of their overall digital marketing strategy.
It is noteworthy that while some wineries do not yet have a fully functional website, all of them, without exception, are present on social networks. This confirms the role of social platforms as an "entry point" for the digital presence of newer or smaller producers.
This high intensity of use of social networks is probably due to the possibility of direct communication with the end consumer, the relatively low advertising costs and the tools for precise targeting of interest groups (e.g. wine lovers, wine and culinary tourism enthusiasts, etc.).

The next question aims to specify: "*Which are the most frequently used social media networks by the enterprises?*". Since some enterprises utilize more than one platform, managers were given the opportunity to select multiple answers. During the data processing, the total number of selections reached 25. Among them, *Facebook* is the most widely used platform, with 12 out of 13 wineries maintaining a presence there. This is followed by *Instagram*, which is used by 9 of the respondents. Only three wineries utilize video platforms such as *YouTube* and *TikTok*, while the "Others" category (e.g., *LinkedIn*, *X*) was selected by only one respondent (Fig. 3).
The responses unequivocally demonstrate that within the most widely used digital marketing channel - social media - owners have focused primarily on *Facebook* and, to a lesser extent, *Instagram*.

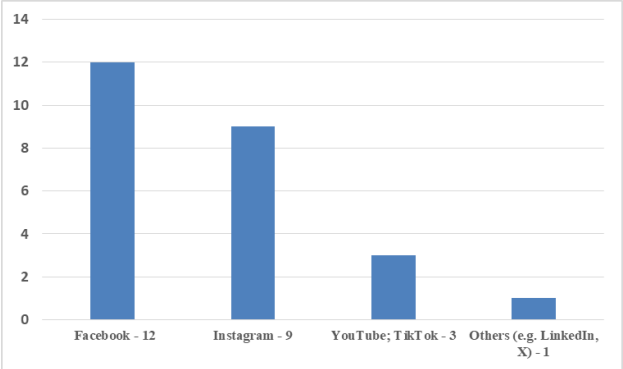

Fig. 3. Social media and digital channels used by wine cellars
Note: Total mentions (n=25) exceed the number of respondents (n=13) due to the multiple-choice format of the question.
Source: own calculation based on the survey.

Only a few wineries (3) utilize video channels, despite their high potential for better positioning and increased visibility of the wineries' offerings. This suggests that wineries should redirect their advertising policies toward these platforms. Furthermore, only one respondent reported advertising on other social media, highlighting another untapped opportunity, such as the business-oriented platform *LinkedIn*. Wineries offering wine tourism, particularly those with accommodation facilities, could also successfully leverage global reservation networks such as *Booking.com* and

TripAdvisor. Short video messages are frequently used by companies offering wine tourism. For this reason, we examined the adoption of this marketing tool through the question: "*Do you use video channels to promote your products?*". The responses indicate that video content is currently overlooked as a powerful advertising opportunity (Table 1). Only one respondent reported *posting videos regularly*, while five others *do so rarely*. On a positive note, five managers *plan to start* using video content more frequently. Only two respondents stated that they *have no plans* to use video channels for now, which suggests they may become less visible in the future compared to those who embrace this format..

Table 1. Using video channels for advertising (n=13)

Response category	**Number of respondents**
Yes, we post videos regularly	1
Yes, but we rarely post videos	5
No, but we plan to start	5
No / Not planned	2
Total	**13**

Source: own calculation based on the survey.

The results reveal a significant deficit in the use of video content, despite its proven role in achieving high visibility and engagement. The data shows that over 84% of the surveyed managers do not use video channels regularly, which limits their competitiveness in the digital environment.

Regarding one of the key questions in this study: "*What types of digital marketing do you employ?*", managers were allowed to select multiple answers.

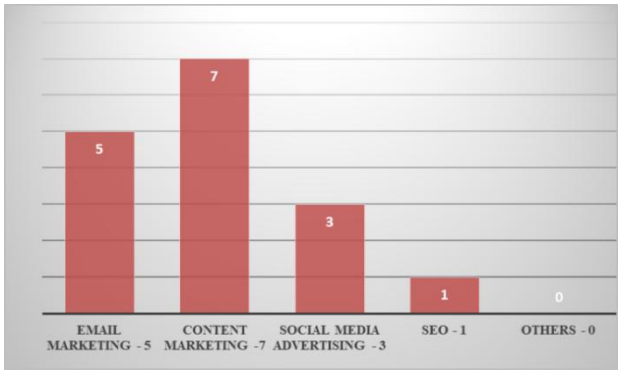

Fig. 4. Distribution of digital marketing instruments applied by wine enterprises (n=12)
Source: own calculation based on the survey.

Of all participants, only one (the winery without a website) did not respond. For the remaining 12 respondents, the total number of mentions reached 16 (Fig. 4).

The most widely applied method is *Content Marketing* (7 mentions), followed by *Email Marketing* (5 mentions), *Social Media Advertising* (3 mentions), and *SEO* (1 mention). Two respondents selected two options, while only one winery utilizes a combination of *Email Marketing*, *Content Marketing*, and *Paid Advertising*. The results clearly indicate that wine enterprises do not sufficiently utilize the full range of digital instruments to position themselves in the market. This is primarily due to their heavy reliance on social media, which provides flexibility in content updates (mainly for promoting products and upcoming events) but relies significantly less on paid advertising. One of the most effective tools – SEO is utilized by only one manager.

The analysis reveals a weak adoption of digital instruments. We can assume this is driven by several factors: limited budgets; lack of familiarity with digital marketing tools; lack of experience or specialized knowledge; absence of qualified personnel; time constraints; or the fact that digital marketing is not currently a strategic priority.

A well-developed advertising campaign is a vital component of a company's development and promotion, often requiring a substantial budget. Consequently, this study examined "*Whether and how regularly wine enterprises use paid advertisements on platforms (such as Google, Facebook, and others)*?". The response options are detailed in Table 2.

The results show that only three wineries use paid advertising *regularly*, while five do so *rarely*. Additionally, two respondents are *considering starting*, whereas three *have no plans to use* paid advertising. Based on these findings, two hypotheses can be proposed: first, that wineries operate with limited budgets for paid promotion; and second, that there is a lack of market familiarity regarding the opportunities for online investment. This suggests a potential concern among managers regarding the return on investment (ROI) and

the overall effectiveness of digital advertising funds.

Table 2. Use of paid advertising in digital platforms by wine enterprises (n=13)

Response category	Number of respondents
Yes, regularly	3
Yes, but rarely	5
No, but considering starting	2
No, and no plan to use	3
Total	**13**

Source: own calculation based on the survey.

The following set of questions focuses on the managers self-assessment of their familiarity with digital tools, their level of preparedness, and their potential need for additional qualification and training. In response to the first question in this series: "*Rate the knowledge and expertise of your team regarding digital marketing*", the results are presented in Table 3.

One participant did not provide an answer. The majority of respondents (7) stated that they possess a "Good enough" level of knowledge, followed by those with "Very good"(2) and "Basic" knowledge"(2). Only one respondent indicated a "lack of sufficient digital expertise".

Table 3. Assessment of digital marketing knowledge and expertise (n=13)

Evaluation	Respondents
Very good	2
Good enough	7
Basic knowledge	2
Lack of digital expertise	1
Did not answer	1
Total	**13**

Source: own calculation based on the survey.

The results from this question clearly show that the majority of managers (nearly 70% of those who answered) feel confident in their digital knowledge, defining it as *Good enough* or *Very good*. However, this subjective optimism contrasts with the actual operational use of digital tools described in previous sections. There is a clear digital skills gap. When managers rate their knowledge as "sufficient", yet previous findings show low utilization of instruments such as SEO or paid advertising, it indicates either an over-optimistic self-assessment or a lack of understanding regarding the full potential of digital marketing.

With the question: "*What are the biggest challenges you face in digital marketing?*", our goal was to identify the specific barriers and constraints that managers encounter in their digital marketing efforts. Respondents were given the opportunity to select more than one answer (Table 4).

Table 4. Challenges in digital marketing (n=12)

Challenge Type	Respondents (Counts)	Share of respondents (%)*
Limited time to support campaigns	5	41.7%
Insufficient knowledge and skills	4	33.3%
Lack of budget	3	25.0%
Competition with bigger brands	3	25.0%
Other (please specify)	0	0.0%
Total Responses	**15**	125.0%

*Note: The survey allowed for multiple responses. The percentages are calculated based on the total number of participating respondents (n=12). One respondent did not provide an answer.

Source: own calculation based on the survey.

The total number of responses reached 15 because three of the winery representatives selected two options each. Two of them identified both *insufficient skills* and *limited time*, while the third respondent highlighted a *lack of budget* and *limited time* as concurrent challenges.

The results clearly show that the *limited time* required to conduct, monitor, evaluate, and maintain digital campaigns is a resource that many managers lack. Given that the majority of the surveyed entities are small-scale production wineries with fewer employees, the primary difficulty lies in allocating time for marketing amidst their other operational responsibilities. *Insufficient knowledge and skills* is the second most frequently cited challenge, which confirms our hypothesis that the personnel of certain wine producers require additional training and professional qualification. Three respondents indicated that they face difficulties in advertising and promoting their brand because there is *competition with bigger brands*. In reality, it

is quite difficult to allocate the time and budget that larger enterprises undoubtedly possess. Large wine producers have their own marketing departments and/or hire advertising agencies, which small firms cannot afford. Three respondents stated that they have a *lack of budget* for marketing campaigns, which puts their future competitiveness at risk compared to brands that advertise and seek customers in the digital space. The analysis emphasizes the importance and necessity of training that small wine producers may require to cope with the challenges of digital marketing. Providing support through training will be key to their successful adaptation and market competitiveness. The conclusion is that investing in training can help wine producers adopt new strategies and tools that will make their marketing more effective.

In response to the question: "*Do you use tools to analyze and track the effectiveness of your marketing campaigns?*", the managers' answers are presented in the diagram in Figure 5.

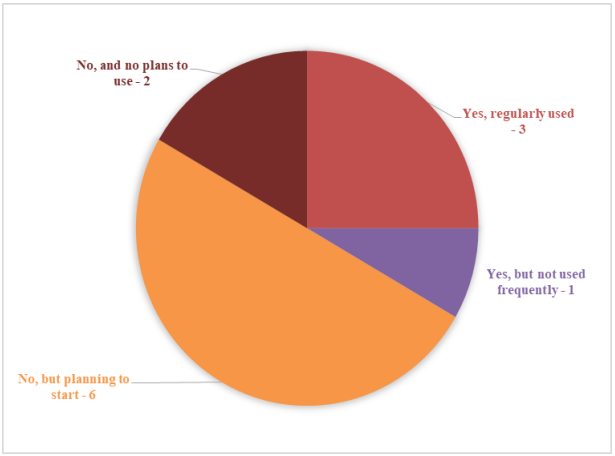

Fig. 5. Usage of marketing analytics and performance tracking tools (n=13)
Source: own calculation based on the survey.

The results indicate that the first group, consisting of three managers, *regularly uses* tracking tools. One respondent utilizes such tools, though *not frequently*. A positive trend is observed in the largest group of six respondents, who have not used them so far but *plan to start*. Only two respondents stated they have *no plans to use* analytical tools, which may signal a need for educational initiatives. Focusing on training and awareness could lead to a broader adoption of analytical tools and, ultimately, to more successful marketing campaigns. Overall, there is a positive outlook toward using analysis tools; however, the two managers who do not plan to use them should be encouraged through increased information and necessary training.

In response to the question: "*What kind of training and additional knowledge do you need?*", the possibility for multiple answers was provided, resulting in a total of 18 selections. Four of the respondents indicated a need for more than one of the suggested options (Figure 6).

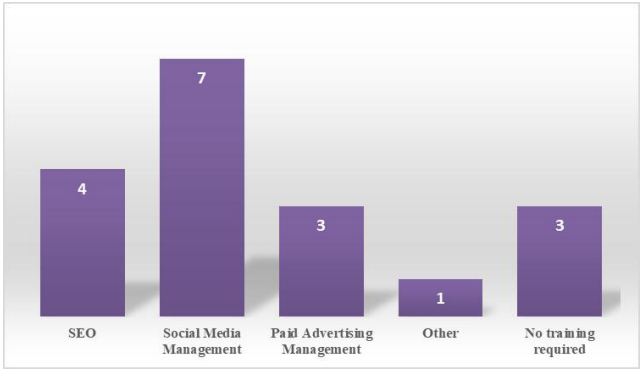

Fig. 6. Identified digital marketing training needs
Note: Number of respondents (n=13) were allowed to select more than one option.Total number of responses is 18.
Source: own calculation based on the survey.

Most commonly, managers prefer training related to *Social Media Management*. This is expected, considering their previous responses indicating that their digital tools are primarily concentrated in social media. In second place is the need for *SEO optimization*. This is also the most frequently desired profile by 4 managers, along with training in social media management. Only three of the respondents stated that they have *no need for training*. However, two indicated a need for training related to *Paid Advertising*. We also provided an opportunity to specify other training needs. One respondent replied in this field, stating: "*Combining knowledge of wine with digital marketing skills and expertise*". This indicates that training sessions related to digital marketing could be organized in the near future in response to the needs of the business. Based on the question: "*How effective are*

your digital marketing efforts?", the distribution of responses presented in Figure 7, clearly indicates a trend toward a moderate assessment of digital efforts. The highest bar in the chart corresponds to the category *sufficiently effective* (7 responses), which serves as an indicator of a basic level of proficiency with digital tools. At the same time, the significant number of managers (5 responses) who evaluate their efforts as *not so effective* underscores the presence of serious difficulties in achieving optimal results. The fact that only one respondent falls into the category "very effective" categorically confirms our hypothesis regarding the need for specialized training.

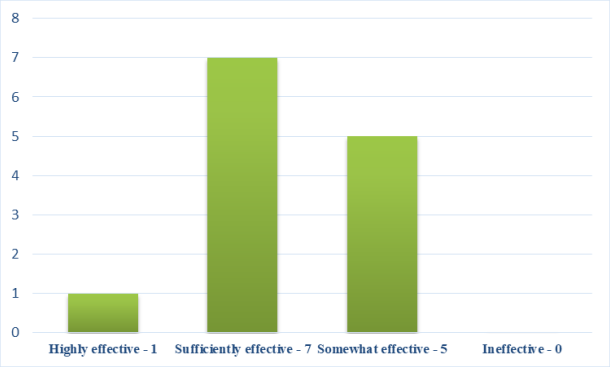

Fig. 7. Managers' self-assessment of digital marketing effectiveness (n=13)
Source: own calculation based on the survey.

Based on the question: "*What percentage of the marketing budget is allocated to digital marketing?*", it is understood to what extent wine producers have directed their efforts toward online markets. The number of respondents is 12. The data regarding the distribution of the marketing budget (Figure 8) indicates a clear trend toward low levels of investment in the digital environment. The results can be differentiated into three main categories:

-Minimal investment (under 10%): This is the most prevalent model, followed by eight respondents. This high proportion indicates a strong reliance on traditional marketing channels and an underestimation of the online space.

-Moderate investment (up to 30%): Two of the managers allocate up to one-third of their budget, which indicates a transitional stage where digital marketing is not yet the primary focus.

-Strategic investment (30% – 50%): Only two respondents invest a significant portion of their funds in digital activities, demonstrating a high level of recognition of the importance of an online presence.

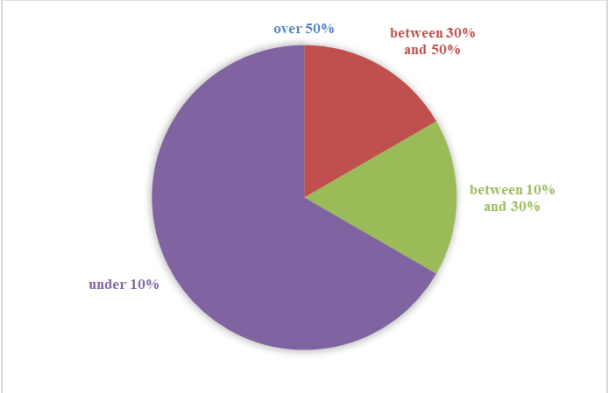

Fig. 8. Share of digital marketing in total marketing budget (n=12)
Source: own calculation based on the survey.

The results show that nearly 70% of the respondents do not invest adequately in digital marketing. This passive strategy threatens the long-term competitiveness, particularly of small wineries. There is a need for active promotion of awareness regarding the benefits of digital advertising within this sector.

In response to the question: "*How do you evaluate the return on investment (ROI) from your digital marketing campaigns?*", 11 out of 13 managers provided an answer. The respondents' answers are noted in Table 5. Two respondents evaluated it as *very good*. This group consists of respondents who allocated a larger budget, as identified in the preceding question. As a result, we can assume that with higher expenditures, there is a sufficiently good profit, which indicates the positive impact of implementing digital marketing on the business. For two respondents, the ROI is sufficient – *satisfactory*. For three of the surveyed, the return is *insufficient*, and those who cannot *unable to determine* are four. Given the small investments allocated by most of them – under 10% (the previous question), it indicates a low or zero return. Here, training related to analytical tools could be helpful. The group that cannot *unable to determine*

(4), along with those *without a response* (2), demonstrates a necessity for improving the methods for measuring and analyzing ROI to ensure a better awareness of the effectiveness of investments.

Table 5. Managers' assessment of Return on Investment (ROI) from digital marketing (n=11)

ROI Assessment Category	**Response count**	**Percentage share (%)**
Very good	2	18,2
Satisfactory	2	18,2
Insufficient	3	27,3
Unable to determine	4	36,3
Total respondents	**11**	**100**

Note: Two of the respondents opted not to answer this question.
Source: own calculation based on the survey.

The importance of investment in digital marketing and how their levels influences return is clearly outlined. It also highlights a need for training and awareness regarding ROI measurement is noted, in order to improve business results and encourage producers toward a broader adoption of digital strategies. In our view, this information is valuable for developing approaches that help wine producers maximize their investments and achieve better results.
With the final 16th question of our survey, we aimed to determine: "*Do you intend to increase your presence in digital channels?*" The responses are shown in figure 9. To the options provided, the participants responded as follows:
a) Yes, significantly – 3;
b) Yes, but on a limited scale – 7;
c) No, we will remain at the same level – 2;
d) No, we plan to reduce our digital activity – 1.
Overall, the majority of respondents (10 out of 13) express a willingness to expand their digital footprint, albeit with varying degrees of intensity. The group that responded they will *significantly* increase their presence (3) provides a positive sign for strategic development through online markets.The largest group of respondents (7) plan to expand their presence, but *on a limited scale*. This may be a sign of a cautious approach or limited resources. The group that stated they will remain at the *same level* (2) shows that they are perhaps satisfied with their current presence and do not see a need for expansion, or they face very limited budgets, lack of time, and insufficient competencies. Only one respondent stated they are considering *reducing their digital activity*, possibly due to a low return on investment (ROI).

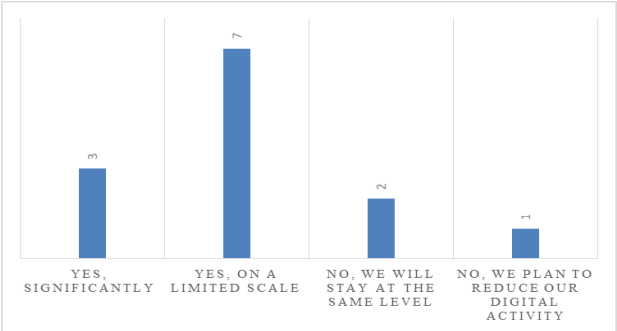

Fig. 9. Future intentions for digital presence expansion over the next 3 years (n=13)
Source: own calculation based on the survey.

Today's marketing, much like winemaking, requires both intuition and technological precision. The transition from a limited scale to effective digital growth is possible through the implementation of monitoring and analysis tools. Focusing on increasing digital literacy is the best first step, ensuring that every invested resource will bring maximum added value to the winery.

CONCLUSIONS

The small and medium-sized wineries surveyed members by *Association of the "Danube Winemakers"* are at a turning point of "digital awakening", as the majority of managers now recognize the need for a more permanent digital presence. However, due to constraints in time, budget, or specific know-how, they require accessible training and simplified, automated reports rather than complex software platforms to directly link marketing expenditures with the number of wine cases sold or winery visitors. Analysis from the survey manages to provide answers to the previously set questions:
1. Digital infrastructure and presence (RQ1) - current status shows that most wineries have a basic online identity (website), but it is often static.
Conclusion: The results indicate the existence of a solid fundamental digital base (over 70%

of the wineries have a web presence); however, a deficit in interactivity and dynamic content management is still observed. Digital infrastructure is perceived more as a 'business card' rather than an active tool for sales and consumer engagement.

2. Communication Channels and Video Marketing (RQ2) – Widespread use of Facebook/Instagram and the neglect of video platforms and short-form videos.

Conclusion: There is a pronounced reliance on traditional social networks (Facebook and Instagram), which creates a risk of saturation and high competitive density. The critical underestimation of video platforms (YouTube, TikTok) reveals a missed opportunity, particularly for attracting younger audiences and for a deeper emotional presentation of wine tourism through visual storytelling.

3. Regarding barriers and resource deficit (RQ3) – the limiting factors are lack of time and knowledge.

Conclusion: Regarding barriers and resource deficit (RQ3) – the limiting factors are lack of time and knowledge. The identified 'digital deficit' in the surveyed wineries is not so much financial as it is structural and cognitive, where the lack of time and specific expertise hinders the transition from intuitive to strategic marketing. This highlights a significant "digital skills gap", as the widespread use of content marketing is not accompanied by technical competence in complex areas such as SEO and Video marketing. Consequently, training programs must shift from general digital literacy toward providing practical experience in analytical tools and performance measurement, as without such specialized support, small wineries will find it difficult to achieve sustainable online visibility.

4. *Regarding Investment and Return (RQ4)* – the managers' responses clearly indicated the allocation of low budgets and an inability to measure ROI.

Conclusion: The study demonstrates a direct correlation between the size of digital investment and the ability to evaluate its effectiveness. The widespread allocation of less than 10% of the marketing budget to digital activities leads to an inability to measure ROI. This creates a persistent barrier of low investment and poor results, which can only be broken through specialized training in analytical tools and the reallocation of funds toward high-performance digital channels.

Firstly, the study demonstrates the necessity of conducting specialized training to enhance the digital literacy of management teams. The identified *Digital Skills Gap* in the areas of SEO, Video marketing, and ROI tracking tools is a major obstacle to effective positioning and budget expenditure. Training programs should be practically oriented, guiding winemakers to transition from intuitive social media posting to strategic decision-making based on data-driven marketing.

Secondly, as a strategic solution to overcome the chronic lack of time and limited financial resources, we propose the implementation of a model for shared (common) digital marketing under the auspices of *Association of the "Danube Winemakers"*. Cooperation would enable wineries (especially for micro and small) to pool their budgets for hiring external specialists, building common regional digital platforms, and joint advertising campaigns for the region's wines and wine tourism. This approach would enhance the online visibility of the entire region and ensure a professional presence on video channels, which are currently underutilized by individual small producers.

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CHARACTERISTICS OF THE BULGARIAN WINE GRAPE MARKET

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Abstract

The paper examined the structural characteristics of the Bulgarian wine grape market. The organization of the wine supply chain was studied, and the key determinant of wine grape demand and supply were identified. Tendencies in harvested areas of wine grapevine varieties, as well as wine grape production and processing over the period 2007-2024, were assessed. Particular attention was paid to the dynamics and variability of producer prices, which were compared with price levels observed in selected European countries. Profitability in wine grape production in 2025 was assessed based on data on production activity and output obtained from the cultivation of the wine grapevine varieties Rubin, Misket kailashky and Muscat Ottonel at the Institute of Viticulture and Enology. The long-term decline in wine grape and wine production in Bulgaria revealed challenges across the supply chain. Stable farm profitability emerged as a critical condition for maintaining the supply of quality grapes and required improvements in contractual arrangements between grape growers and wineries, supported by appropriate financial and institutional measures.

Key words**:** *wine grapes, market, price, value chain, profitability*

INTRODUCTION

The wine grape market is an important element of the overall structure of the functioning and development of the viticulture and wine sector. The report of the Comité Européen des Entreprises Vins (CEEV, 2024) [5] highlighted the complex mechanism of interrelationships along the wine value chain, encompassing different economic sectors – viti-viniculture (agriculture), winemaking (industry), and commercialization (services). Wine grape production stands at the beginning of the value chain and determines the possibilities for ensuring a stable supply of high-quality and differentiated products. For this reason, profitability in farms cultivating wine grapevine varieties has been a key issue, which over the years has shaped the framework of financial support in the sector under the Common Agricultural Policy (CAP), given its significant socio-economic importance for many rural areas in the European Union (Pappalardo et al., 2012; Pappalardo et al., 2012a; Šajn, 2023; High-Level Group on Wine Policy, 2024) [23, 24, 27, 13].

The production of quality wine with Protected Designation of Origin (PDO) or Protected Geographical Indication (PGI) has been at the core of the strategic positioning of EU wines on the international market, as geographical indications function as a mechanism for product differentiation, reputation building, and price premium generation (Agostino and Trivieri, 2014; EU Wine Market Observatory, 2024) [1, 10]. The structure of wine production in the EU in 2022 showed a dominant share of PDO wines – 75.6 million hl, followed by PGI wines – 33.9 million hl, varietal wines – 10.6 million hl, and other wines – 38.9 million hl (CEEV, 2024) [5]. The use of geographical indications has also served as a mechanism for protecting production in traditional wine-growing regions within the Union (Martínez-Arnáiz et al., 2022; Todorova, 2025) [15, 28]. In the context of ensuring a stable supply of wine grapes with the required quality parameters for PDO and PGI wine production, European countries with well-developed viticulture and

wine sectors have relied to a large extent on vertical integration along the supply chain. This type of organization has created conditions for improved profitability of wine grape producers, particularly for smaller farms, depending on vineyard size and economic scale (Montaigne and Coelho, 2012; Castriota, 2020; Corsi et al., 2023; Pacifico et al., 2025) [20, 4, 6, 22].

Viticulture in Bulgaria can be defined as a highly competitive sector, due to the large number of economic entities, with a predominant share of small-scale farms (Borisov et al., 2023) [2]. In the context of negative trends associated with the continuous decline in harvested vineyard areas, as well as the decrease in grape and wine production, the question has arisen regarding the position of wine grape producers within the overall organization of the wine supply chain and their bargaining power. In this regard, the analysis of the wine grape market provides insight into the key relationships, interdependencies, and challenges faced by one of the crucial segments of the value chain – wine grape producers.

The aim of this study was to examine the main characteristics of the Bulgarian wine grape market, while identifying the opportunities for maintaining the stability of production.

MATERIALS AND METHODS

This study focused on the role and position of wine grape production within the overall organization of the wine supply chain in Bulgaria. A framework of interrelationships across the different segments of the chain has been developed based on induction and deduction methods, literature review, and interviews with vineyard and winery managers.

The main characteristics of the wine grape market have been analyzed from the perspective of supply and demand. Trends in harvested vineyard areas (ha) and wine grape production (tons) have been identified. The structure of farms cultivating wine grapevine varieties has been examined according to their legal status, based on data from the Agricultural Census 2020. The information has been grouped according to the intended use of the produced wine grapes – for wines with Protected Designation of Origin (PDO), for wines with Protected Geographical Indication (PGI), and for other wines (without PDO and PGI). The following indicators have been used: number of holdings; vineyards area within holdings (ha); and average physical size of holdings (ha per farm).

From the demand-side perspective of the wine grape market, the dynamics of processed quantities (tons) have been examined, both in industrial and non-industrial conditions, as well as the volume of wine produced (hl).

Producer price dynamics (EUR/kg) have been analyzed as a key determinant of farm profitability in wine grape production, and a comparative analysis with neighbouring countries, namely Greece and Romania, has been conducted.

The study period was 2007-2024. The methods of comparative, index and graphical analysis, descriptive statistics, analysis of variance, correlation analysis and regression analysis were applied (Boshnakov, 2009; Goev et al., 2019) [3, 12]. The estimation of producer price fluctuations was based on the values of the coefficient of variation (CV, %), calculated as the ratio between the standard deviation of the prices and the average price for the studied period, using the following formula:

$$CV(\%) = \frac{SD}{\bar{P}} * 100 = \frac{\sqrt{\frac{\sum_{i=1}^{n}(P-\bar{P})^2}{n}}}{\bar{P}} * 100 \quad \ldots(1)$$

where:

SD – standard deviation,

$\bar{P}$- average producer price of wine grapes for the studied period.

Sources of primary data were Eurostat [11], the Ministry of Agriculture and Food (MAF) [16, 17, 18, 19], the Agrostatistics Department, the National Statistical Institute (NSI) [29].

The level of profitability in wine grape production is an indicator of the sector's attractiveness and a partial measure of future expectations. For the purposes of the analysis, data from an experiment conducted in 2025 have been used. The experiment was carried

out in an experimental vineyard planted with the red wine grapevine variety Rubin and the white wine grapevine varieties Misket kailashky and Muscat Ottonel, located at the Experimental Base of the Institute of Viticulture and Enology – Pleven. The method of economic evaluation has been applied, including the following indicators:

- average yield (kg/ha) - The average theoretical yield per unit area for the different grapevine varieties was calculated based on the average yield per vine in 2025, taking into account the vine density per unit area, i.e. 3,130 vines per hectare;
- gross output (EUR/ha) - The gross output was determined by valuing the obtained output at the average producer price, based on data from the National Statistical Institute (NSI) for the third quarter of 2025 (0.61 EUR/kg);
- production costs (EUR/ha) - The total production costs, including material and labor costs, were calculated based on average market prices and hourly wage rates for the period under study. The standard labor and material costs were calculated based on data from the Institute of Viticulture and Enology – Pleven. Depreciation costs for the vineyard were also included in the total direct production costs (excluding costs related to organization, management, and other overhead activities);
- net income (EUR/ha) – The indicator was calculated as the difference between gross output and direct production costs;
-prime cost (EUR/kg) – The indicator was calculated as the ratio between production costs and average yield;
-profitability rate (%) – The indicator was calculated as the ratio between net income and production costs.

RESULTS AND DISCUSSIONS

Wine grapes production accounted for a major share of total grape production in Bulgaria (92.2% of total output in 2024). The long-term trend indicated a continuous decline, with production amounting to 341,818 tons in 2007 and decreasing to 124,161 tons in 2024 (Figure 1). The reduction was substantial – 63.7%, mainly resulting from the decrease in harvested vineyard areas within farms. A comparative analysis showed that the total area of vineyards planted with wine grapevine varieties decreased by 44,770 ha in 2024 compared to 2007, indicating limited entrepreneurial interest in the sector. The dynamics of average yields showed a certain degree of stability, with the average level for the period 2013–2019 (5,840 kg/ha) exceeding that for 2007–2012 (4,701 kg/ha). A large share of the depreciated and inefficiently managed vineyard areas was abandoned, but the data indicated the need for investments in vineyard renewal. The problem was particularly pronounced under conditions of climate change, as prolonged periods of drought and irregular precipitation negatively affected production stability. The lower levels of average yields from vineyards with wine grapevine varieties in 2023 (5,165 kg/ha), and especially in 2024 (4,843 kg/ha), reflected the negative impact of high temperatures and severe drought. The introduction of new grapevine varieties resistant to stress factors, as well as the use of varieties adapted to local conditions, represents one of the possible approaches for improving the economic performance of farms in terms of average yields, grape production, and wine output (Popescu, 2019) [25].

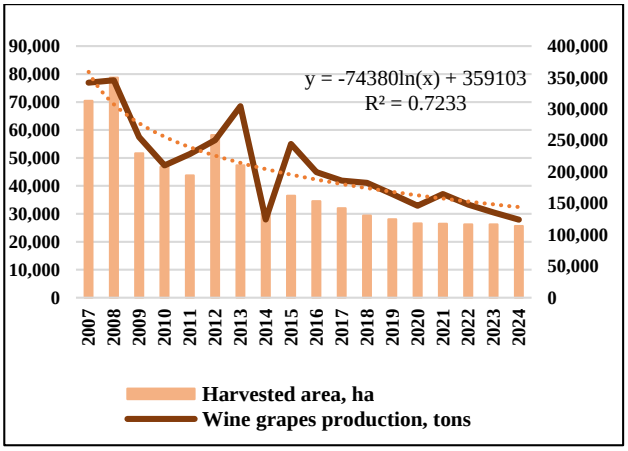

Fig. 1. Dynamics of vineyards with wine grapevine varieties and wine grapes production during the period 2007-2024
Source: Ministry of Agriculture and Food (2025), Ministry of Agriculture and Food (2025a) [18, 19].

In addition to the challenges associated with climate change, wine grape and wine

production in the country developed under conditions of market changes driven by changes in the global wine market. The observed persistent decline in global consumption of red wines over the past fifteen years (OIV, 2023) [21] has raised concerns regarding the sustainable functioning of the Bulgarian viticulture and wine sector. Red wine grapevine varieties traditionally dominate the varietal structure of vineyards for wine grape production, which is determined by the favorable soil and climatic conditions in the country, particularly in the wine-growing regions of Southern Bulgaria (Roychev, 2012) [26]. In 2024, their share in the total harvested vineyard area amounted to 60.4% (15,493 ha), compared to 39.6% (10,145 ha) for white wine grapevine varieties.

Vineyards represent a long-term asset with a long productive lifespan, which constitutes a limiting factor with regard to the adaptive capacity of viticultural holdings. At the same time, wine producers have been required to respond adequately to market changes in order to limit potential losses of markets and market niches. As a result, the share of white wine production in total wine output has gradually increased, reaching 59.2% in 2024 (375,612 hl), compared to 40.8% (259,038 hl) for red wines (MAF, Agricultural Report, 2025) [16].

It is unfavorable that the overall trend in wine production in the country has indicated a significant decline, which has been much more pronounced in red wines – by 63.7% in 2024 compared to 2007. The decrease in white wine production over the same period has amounted to 40.0%. The negative dynamics in wine production have been directly associated with the decline in exports, while the reasons for the loss of market positions in the international wine market have been complex and have largely stemmed from strong competition, wine quality, product assortment, branding, and product positioning (Dimitrova and Dimitrov, 2025) [8].

Wine market conditions determine the interactions between grape producers and wine producers with regard to the supply and processing of wine grapes within the overall framework of the wine supply chain (Figure 2).

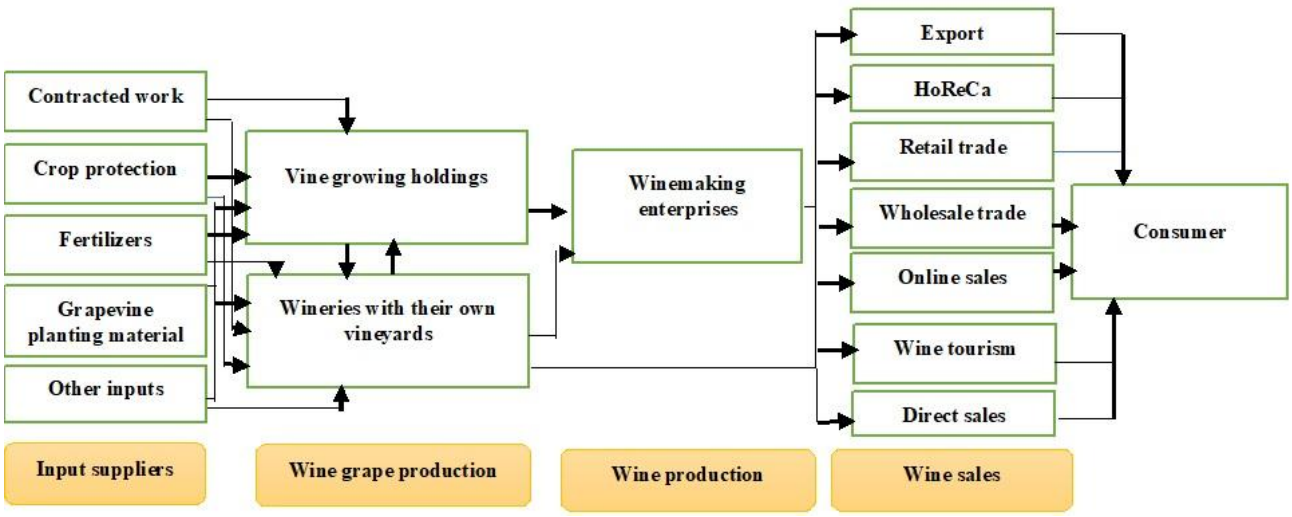

Fig. 2. Mapping the wine supply chain in Bulgaria
Source: Created by authors.

Grape production constitutes the initial stage of the wine supply chain. A large number of economic entities produced grapes without possessing processing facilities. On the other hand, most wineries have relied on their own vineyard areas for the main part of their production activities. Official data showed that in 2020, a total of 13,869 holdings cultivating vineyards with wine grapevine varieties operated in the country (MAF, 2023) [17]. A significant differentiation in the structure of viticultural holdings was observed, both in terms of their legal status

and with regard to their size and specialization in wine grape production. Natural persons dominated the total number of economic entities, accounting for 93%, but they managed a relatively small share of vineyard areas – 10,267 ha (32.5%) (Table 1). The majority of these producers cultivated grapes intended for processing into wines without geographical indication, which indicated a lower degree of specialization and market orientation.

At the opposite end were commercial companies, which managed the largest share of the total vineyard area planted with wine grapevine varieties (51.9%). They played a key role in the production of raw material for processing into PGI wines (7,914 ha) and PDO wines (1,483 ha), with a large proportion of them possessing established processing facilities. It is evident that these entities are primarily oriented towards the production of wines with higher added value. It should be noted that within the overall structure of viticultural holdings, vineyard areas intended for the production of grapes for PDO wines (2,317 ha) and PGI wines (10,466 ha) accounted for 40.5% of the total vineyard area within holdings, which partly explained the difficulties in maintaining stable market positions of the wine sector.

Table 1. Number of holdings and areas of vineyards by legal status and direction of wine grapes production in 2020

Legal status of the farm	Vineyards for wine grapes production							
	Total		of which for wines with protected designation of origin (PDO)		of which for wines with protected geographical indication (PGI)		of which for other wines (without PDO/PGI)	
	Holdings (number)	Area (ha)	Holdings (number)	Area (ha)	Holdings (number)	Area (ha)	Holdings (number)	Area (ha)
Total	13,869	31,599	446	2,317	409	10,466	13,129	18,815
Natural persons	12,899	10,267	359	341	172	1,032	12,408	8,894
Sole traders	137	2,741	9	175	29	1,044	112	1,521
Co-operatives	65	2,002	4	c	5	c	58	1,227
Companies	750	16,392	73	1,483	201	7,914	535	6,995
Civil associations and others	18	197	1	c*	2	c	16	178

*c – confidential information

Source: Ministry of Agriculture and Food (2023) [17].

Sole traders and cooperatives accounted for a significantly smaller share, both in terms of number and vineyard area. In both types of organizational structures, the majority of vineyard areas were allocated to the production of grapes for wines without geographical indications – 1,227 ha (61.3%) in cooperatives and 1,521 ha (55.5%) in sole trader holdings.

Data on the average physical size of holdings confirmed the significant concentration of vineyard areas in larger organizational structures (Table 2). The average size of vineyards planted with wine grapevine varieties per holding was 2.28 ha, indicating the predominance of small-scale farms. Among natural persons, the average size was only 0.80 ha, clearly illustrating the small-scale nature of this group of wine grape producers.

Significantly larger average vineyard sizes were observed in cooperatives, commercial companies, and sole traders, amounting to 30.80 ha, 21.86 ha, and 20.00 ha, respectively. When analyzed by production orientation, the highest degree of land consolidation was observed in vineyard areas intended for the production of grapes for PGI wines, amounting to 39.37 ha in commercial companies and 36.00 ha in sole trader holdings, as well as for PDO wines, amounting to 20.32 ha in commercial companies and 19.44 ha in sole trader holdings. This suggested a tendency towards better integration into the market for quality wines among these types of organizational structures. A proportion of sole traders consisted of family-run holdings that invested in product differentiation (primarily in terms of grapevine varieties) and in the production of high value-added products as a means of achieving economic viability.

Table 2. Average area under vines (ha per holding)

Legal status of the farm	Total	for wines with protected designation of origin (PDO)	for wines with protected geographical indication (PGI)	for other wines (without PDO/PGI)
Total	2.28	5.20	25.59	1.43
Natural persons	0.80	0.95	6.00	0.72
Sole traders	20.00	19.44	36.00	13.58
Co-operatives	30.80	c	c	21.16
Companies	21.86	20.32	39.37	13.07
Civil associations and others	10.94	c*	c	11.13

*c – confidential information
Source: Ministry of Agriculture and Food (2023) and own calculations [17].

From the perspectives of market structure, it can be concluded that the supply of wine grapes in Bulgaria was characterized by a high degree of fragmentation, with a significant share of production being provided by a large number of small-scale farms with limited economic capacity and, consequently, weak bargaining power in the market. In this context, Borisov et al. (2023) [2] identified commercial intermediaries as a key link facilitating the relationship between grape producers and processing enterprises. In recent years, however, a trend towards a declining role of intermediary structures has been observed. This process has been driven both by the significant reduction in the number of vineyard holdings managed by natural persons largely as a result of unfavorable demographic processes in rural areas and by changes in market conditions in the wine sector. Under conditions of strong competition in the wine market, a number of small and medium-sized wineries have increasingly relied on product differentiation and diversification of their product range, which has required better control over the quality and origin of raw materials (Dimitrov and Dimitrova, 2025) [7]. This has often been achieved through direct contracting of wine grape supplies between producers and wineries, which has gradually reduced the importance of intermediaries.

Another important structural characteristic of the wine grape market is the number and concentration of buyers. Data presented in the accompanying document entitled "The Viticulture and Wine Sector in Bulgaria in the Period 2015–2020," attached to the draft "Strategy for the Development of the Viticulture and Wine Sector in Bulgaria for the Period 2022–2027," discussed in 2022, showed that as of 31 August 2021, a total of 327 wine producers were registered in the country. Of these, 138 operated their own vineyard holdings, 125 maintained contractual relationships or were affiliated with grape producers, and 65 purchased raw materials annually without prior contractual arrangements. According to official data from the Executive Agency on Vine and Wine (EAVW) [9], the number of registered wineries in 2025 amounted to 362, however, no information was available regarding the channels of raw material procurement. Given the significantly smaller number of wine producers compared to the number of vineyard holdings, it can be concluded that the wine grape market was characterized by relatively stronger bargaining power on the side of buyers. This, in turn, determined their substantial influence on market conditions and price formation in the wine grape market.

A limitation to conducting an in-depth empirical analysis was the lack of detailed information on the quantities of wine grapes purchased by wineries. This deficiency of statistical data hindered the precise assessment of the volume and structure of raw material trade, as well as the degree of market concentration in the buying grapes segment. Nevertheless, the assessment of product flow movements along the "raw material production–processing" chain allowed the main characteristics of the market situation to be outlined.

The dynamics of wine grapes production and processing over the period 2007–2024 outlined significant transformations, particularly with regard to the scale of the raw material base, which may have affected the functioning of the wine grape market. The analysis of the ratio between produced quantities and their subsequent processing provided some insight into market structure and the interaction between producers and processors. During the period 2007–2012, the average annual production of wine grapes

amounted to 272,018 tons, with approximately 66.4% of the produced output being directed towards industrial processing (Table 3). Processing under non-industrial conditions accounted for a relatively significant share – 19.6%, while 14.0% of the raw material was used for the production of other products. The relatively high share of non-industrial processing could be interpreted as an indicator of weaker integration of a segment of wine grape producers into the market supply chain.

During the subsequent period 2013–2018, the average quantity of produced raw material decreased by 23.9%, while the decline in quantities processed under industrial conditions was relatively modest – 4.1%. The share of industrial processing in total wine grape production reached 83.8%, while the share of non-industrial processing declined to 13.3%. This dynamic could be interpreted as an indicator of a gradual strengthening of vertical integration, as well as the increasing role of organized channels for the marketing of raw materials.

During the six-year period from 2019 to 2024, wine grape production continued to decline, with the impact of climate change becoming increasingly evident. The average quantity of produced output for the period under review amounted to 54.1% of the average level for 2007–2012. At the same time, a more pronounced decline was observed in industrially vinified grapes, which decreased by 34.5% compared to the average level for the previous six-year period. In contrast, processing under non-industrial conditions increased by 14.2%, while its share of total wine grape production reached an average of 21.4%.

Table 3. Dynamics of wine grapes production, processed quantities and wine produced during the period 2007-2024

Years/Periods	Produced wine grapes (tons)	Industrial vinification (tons)	Non-industrial vinification (tons)	Produced wine – industrial (hl)	Produced wine – non-industrial (hl)	Total produced wine (hl)
2007	341,818	200,823	123,316	1,339,536	415,412	1,754,948
2008	345,650	203,447	46,444	1,378,937	227,436	1,606,373
2009	255,257	181,926	42,352	1,215,803	181,593	1,397,396
2010	210,398	148,454	50,643	992,821	194,471	1,187,292
2011	228,451	157,945	33,136	1,049,797	138,674	1,188,471
2012	250,533	191,923	23,825	1,271,711	104,788	1,376,499
Average 2007-2012	***272,018***	***180,753***	***53,286***	***1,208,101***	***210,396***	***1,418,479***
2013	304,452	249,637	34,272	1,724,469	158,937	1,883,406
2014	124,216	103,521	10,808	746,951	48,078	795,029
2015	244,357	195,860	42,176	1,310,149	200,748	1,510,897
2016	199,547	173,503	26,765	1,207,785	126,196	1,333,981
2017	186,131	165,818	24,327	1,079,896	113,195	1,193,091
2018	182,569	151,938	27,029	1,040,650	129,536	1,170,186
Average 2013-2018	***206,879***	***173,380***	***27,563***	***1,184,983***	***129,448***	***1,314,432***
2019	164,878	129,311	30,558	857,375	147,497	1,004,872
2020	146,221	114,336	29,542	756,225	135,792	892,017
2021	164,784	127,446	34,448	837,467	157,447	994,914
2022	147,948	114,946	30,839	746,683	141,837	888,520
2023	135,409	100,803	35,112	675,740	168,695	844,435
2024	124,161	94,685	28,360	634,649	128,661	763,310
Average 2019-2024	***147,234***	***113,588***	***31,477***	***751,357***	***146,655***	***898,011***
2013-18/2007-12 (%)	76.1	95.9	51.7	98.1	61.5	92.7
2019-24/2013-18 (%)	71.2	65.5	114.2	63.4	113.3	68.3
2019-24/2007-12 (%)	54.1	62.8	59.1	62.2	69.7	63.3

Source: Ministry of Agriculture and Food (2008-2025) and own calculations [16].

The data indicated a deterioration in market conditions for wine grape producers in terms of demand and producer price levels. Changes in the wine market, and in particular the difficulties in selling of red wines, affected the demand for raw materials and led to a contraction in production in wineries, which, in turn, resulted in an increase in wine

production under non-industrial conditions. On the other hand, the decline in wine grape production may have led to increased competition among wine producers for securing raw materials, which in certain years could have improved market conditions for vineyard owners. Nevertheless, due to the fragmented nature of production and the limited market coordination among producers, the bargaining power of grape growers remained relatively weak.

Producer price levels represented another important characteristic of the wine grape market. The data presented in Figure 3 illustrated the movement of price levels over the period 2007–2024.

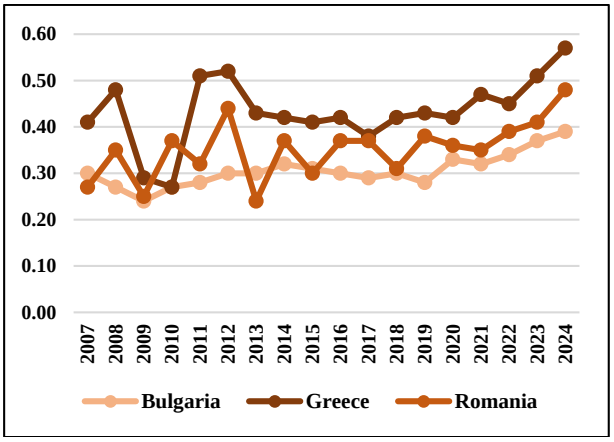

Fig. 3. Dynamics of producer prices during the period 2007-2024, EUR/kg

Source: Eurostat, https://ec.europa.eu/eurostat/databrowser/view/apri_ap_crpouta/default/table?lang=en [11].

The observed dynamics showed that until 2019, Bulgarian prices remained relatively stable, within the range of 0.24 EUR/kg to 0.32 EUR/kg. After 2020, an upward trend in price levels emerged, driven by inflationary processes, rising fuel prices, and increasing input costs, which led to higher production costs in farms.

The dynamics of producer prices for wine grapes in Bulgaria, Romania, and Greece showed similar fluctuation patterns, driven both by changes in raw material production and by the specific characteristics of market conditions. A very small share of wine grapes produced in the country was subject to international trade, with exported quantities typically ranging between 130 and 180 tons, and imported quantities between 500 and 1,200 tons.

According to the results of the descriptive statistics (Table 4), the average levels of producer prices for wine grapes were lowest in Bulgaria, ranging between 0.24 EUR/kg and 0.39 EUR/kg, with a mean value of 0.31 EUR/kg. In Romania, the price range was wider – between 0.24 EUR/kg and 0.48 EUR/kg, with an average value of 0.35 EUR/kg, while in Greece the highest price levels were observed – between 0.27 EUR/kg and 0.57 EUR/kg, with an average level of 0.43 EUR/kg.

Table 4. Analysis of the variation of producer prices of wine grapes during the period 2007-2024

Indicator	n	R	Pmin	Pmax	$\bar{P}$	SD	CV (%)
Producer price (Bulgaria), EUR/kg	18	0.15	0.24	0.39	0.31	0.036	11.8
Producer price (Romania), EUR/kg	18	0.24	0.24	0.48	0.35	0.062	17.8
Producer price (Greece), EUR/kg	18	0.30	0.27	0.57	0.43	0.074	17.1

Source: own calculations with MS Excel

R – range of variance, Pmin – minimum price, Pmax – maximum price.

The values of the coefficient of variation indicated a low degree of fluctuation in all three countries, with the lowest price variability observed in Bulgaria (11.8%). The price dynamics in the country showed that prices were formed under a stronger influence of the processing sector and under more limited market competition among buyers. In order to assess the extent to which supply influenced changes in Bulgarian wine grape prices, correlation and regression analysis methods were applied.

The results of the correlation analysis examining the relationship between producer price and the quantity of wine grapes produced indicated the presence of a moderately strong negative relationship (Table 5). An increase in wine grape production was associated with a tendency for producer prices to decline, which was consistent with the classical principles of market equilibrium between supply and demand. The relatively high value of the

correlation coefficient (r = –0.594) indicated that production volume was an important factor in the formation of producer prices.

Table 5. Correlation between the quantity of production and the level of producer price

	Production, thousand tons	**Producer price, BGN/kg**
Production (thousand tons)	1	
Producer price (BGN/kg)	-0.59426	1

Source: own calculations with MS Excel.

The presence of an inverse relationship between the two variables was also confirmed by the results of the conducted linear regression analysis (r = 0.594) (Table 7).

Table 6. Assessment of the adequacy of the linear regression model

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Regression	0.0078	1	0.0078	8.735	0.0093
Residual	0.0142	16	0.0009		
Total	0.0220	17			

Source: own calculations with MS Excel.

The regression model was statistically significant (sig = 0.0093 < 0.05 = α), indicating that the independent variable wine grape production had a statistically significant effect on the formation of producer prices, although it did not fully explain their dynamics (Table 6).

Table 7**.** Values of measures of dependence

R	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
0.594	0.353	0.313	0.029

Note: The independent variable is production, thousand tons.
Source: own calculations with MS Excel.

The value of the coefficient of determination (R^2 = 0.353) indicated that approximately 35.3% of the variation in producer prices could be explained by changes in production volume. This implied that, although production was a significant factor in price formation, a substantial part of price fluctuations was determined by other economic and market factors, such as demand from wine producers, harvest quality, climatic conditions, and overall market conditions in the wine sector.

An important aspect in the context of long-term negative trends in grape and wine production was the assessment of profitability from production activities, determined based on the average producer price. The results of the economic evaluation were obtained from a case study involving the cultivation of vineyard plantation of the red wine grapevine variety Rubin and the white wine grapevine varieties Muscat Ottonel and Misket kailashky. The main technological operations vine pruning and harvesting were performed manually. The data presented in Table 8 showed low levels of net income (ranging between 370 EUR/ha and 1,130 EUR/ha), respectively low profitability rates across all three levels of average yield determined by varietal characteristics between 9.3% and 27.3%.

Table 8**.** Economic results of wine grape production from the wine grapevine varieties Rubin, Muscat Ottonel and Misket kailashky in 2025

Indicators	Rubin variety	Muscat Ottonel	Misket kailashky
Average yield, kg/ha	7105	7806	8634
Gross output, EUR/ha	4334	4761	5267
Production costs, EUR/ha	3964	4058	4137
Net income, EUR/ha	370	703	1130
Prime cost, EUR/kg	0.56	0.52	0.48
Profitability rate, %	9.3	17.3	27.3

Source: own calculations based on data from a field experiment.

Under these price conditions, it was likely that many wine grape producers, particularly small-scale farms, were under strong pressure to maintain low production costs, which in some cases led to a deterioration in both the quantitative and qualitative parameters of the obtained output. For the sake of analytical accuracy, it should be noted that these data referred to the official statistical information on the average national price level for the period July–September, when the harvest of the three varieties was carried out under the conditions of the Pleven region, located in Northern Bulgaria.

Price levels often varied across different regions of the country depending on supply volumes, the ripening period of grapes, and

demand from wineries. A specific feature of the Bulgarian grape market in recent years has been the stronger demand for grapes from white wine grapevine varieties, which has determined their higher producer prices. In particular, in 2025, unfavorable climatic conditions—sharp weather fluctuations during the spring months, including a critical cold spell between 7 and 10 April, and prolonged periods of drought (EAVW, 2026) [9] negatively affected harvest volumes, which led to a more pronounced increase in producer prices. In Northern Bulgaria, at the beginning of the harvesting campaign, producer prices for white wine grapes reached up to 1.00 EUR/kg. Unfortunately, official statistics did not provide information on the differentiation of producer prices according to varietal characteristics. Nevertheless, the data presented in Table 8 demonstrated the stronger position of wineries in determining price conditions, which for a proportion of grape producers were unfavorable and led to an increase in the quantity of grapes processed under non-industrial conditions, as well as to the withdrawal from economic activity. The obtained results were consistent with the findings of Kirechev (2024) [14], according to which net income without subsidies in farms specialized in grape production during the period 2007–2022 was highly variable and even negative in certain years. According to the author, farm performance was strongly dependent on the level of public support.

According to Castriota (2020) [4], producers who chose to sell grapes as raw material had to accept lower remuneration. The same study indicated that small-scale producers were highly dependent on wineries. Vertical integration of grape producers along the value chain represented an opportunity to improve their market position and farm profitability. Corsi et al. (2023) [6] noted that this was a preferred option among producers of quality wines, as it allowed for greater control over both the individual stages of wine grape production and the subsequent stages of winemaking. The authors emphasized the significant share of cooperatives in leading European wine-producing countries, noting that in Italy approximately half of total grape production was processed in cooperative wineries, in France – 37%, in Spain – 60%, and in Germany – 33%. Despite the proven advantages of the cooperative model in countries with well-developed viticulture and wine sectors, this type of vertical integration had limited application in Bulgaria. The reasons could be explained by a combination of historical, institutional, and economic factors. The characteristics of the wine grape market in the country clearly defined the unfavorable position of grape growers, which required the identification of an appropriate and effective model, adapted to national specificities, to improve the overall functioning of the wine supply chain.

CONCLUSIONS

The results of the conducted analysis indicated a long-term downward trend in wine grape production in Bulgaria, leading to a contraction of the raw material base and creating significant challenges for the sustainable development of the sector. This dynamic was driven both by the reduction in harvested vineyard areas and by the impact of climate change and changes in the market environment.

The structure of production was characterized by a high degree of fragmentation and a dominant share of small-scale farms, which limited their market power and their ability to negotiate favorable price conditions. At the same time, larger organizational structures, primarily commercial companies, concentrated a significant share of vineyard areas and were more strongly oriented towards the production of higher value-added wines (PDO and PGI).

The analysis of the supply chain showed that vertical integration between grape producers and wine producers remained limited. Due to the smaller number of wineries compared to vineyard holdings, a stronger bargaining position was formed on the side of buyers, which exerted a significant influence on market conditions and price levels.

Industrial processing remained the main channel for the utilization of wine grapes, however, in recent years, a relative increase in

quantities processed under non-industrial conditions was observed. This was associated with difficulties in selling grapes and a weakening of demand from wine producers in the context of changes in the wine market.

Producer price levels in Bulgaria were lower compared to those in neighboring countries. The dynamics of prices indicated relatively low variability, influenced by the stronger bargaining power of buyers. Annual fluctuations in production volumes explained 35.3% of the variation in price levels, while a number of other factors also exerted influence, including demand from wine producers, harvest quality, and overall market conditions in the wine sector.

The relatively low levels of profitability in the sector placed wine grape producers under pressure to reduce production costs, often at the expense of both the quantity and quality of output.

Maintaining a stable production of high-quality wine grapes required improvements in contractual relationships, the development of vertical integration, and the implementation of appropriate financial and institutional measures tailored to the specific characteristics of the national sector.

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AN APPROACH FOR DETERMINING AND ANALYZING THE PRICE DYNAMICS OF DESSERT GRAPES AND WINE GRAPES

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Abstract

This article presents an approach for determining and analyzing the price dynamics of dessert grapes and wine grapes in Bulgaria for the period 2018-2024. Information concerning the two types of grapes is searched from the built relational database. The number of the agricultural products stored in the database is 41.The extracted sets of elements related to the listed two types of grapes are processed and analyzed. For this purpose, the respective set of variables must be calculated. This study also uses hierarchical cluster analysis for the indicated data. The results show that the pace of growth in the price per ton of the dessert grapes is significantly faster in 2019-2021. The increase in the indicator is 25.47% for the first of the examined year, 20.64% for the second and 16.31% for the third, respectively. Moreover, the growth pace of the mentioned indicator is relatively slower for this product in the time segment 2022-2024.During 2019, compared to 2018, the price per ton of wine grapes decreased by 8.32%.A similar case is observed in 2021, where the decline is about 3.07%.But, the values of the researched indicator for the mentioned product increase in the time segment 2022-2024, as well as in 2020.Grouping the years with relation to the values of the examined indicator (price per ton) led to the formation of three clusters for dessert grapesand two clusters for wine grapes. This approach could also be used when studying data in areas such as finance, agriculture, ecology, etc.

***Key words*:** *approach, analysis, database, dessert grapes, wine grapes*

INTRODUCTION

In modern society, it is particularly importantfor both managers and farmers to make adequate and timely decisions [6, 18] regarding the successful management and functioning of the respective business [21, 1]. Information technologies provide powerful tools [20, 3] for processing of data from various fields [17, 2, 22]. According to Holloway and and Mengersen [7] “There are many approaches to analyzing time series data” [7]. The study of Sevilla et al. [16] notes also that “Due to the increasing use of data analytics, information visualization is getting more and more important” [16]. Some of these issues are considered in this study.

The data related to prices per ton of some agricultural products are extracted from the website of the National Statistical Institute (NSI)of Bulgaria [11], [12]. The information about the indicated objects is presented in xlsx files. The examined elements from these files are organized and saved into a built relational database. The quoted database contains the following tables:

- Continent (Id_1, name);
- Country(Id_2, country, Id_1);
- Elements(Id_3, element, Id_2);
- Values(Id, years, prices (BGN), unit, Id_3).

The Continent table is related to the Countrytable.TheElements table is related to the Valuestable.TheCountry table is related to the Elementstable. The created relationships between the listed tables are of type one-to-many.Information concerning two of the products(dessert grapes and wine grapes)stored in the database is the subject of research in this work.

It should be pointed out that one of the activities, that is of great importance [15, 9] for some countries is wine production [15, 14]. Miteva and Kanchev (2017) [10] indicate that “the existing forms of organization of wine production and trade have a direct impact on the development of the rural areas in which they are located” [10]. In addition, the price variation [4] of grapes is to some

extent also related to the purchasing power of individual consumers.

The aim of this article is to present an approach for determining and analyzing the price dynamics of dessert grapes and wine grapes in Bulgaria for the time interval from 2018 to 2024.

MATERIALS AND METHODS

Approach description: The presented database contains information concerning forty-one agricultural products.It should be pointed out here that the Elements table contains the names of the respective products. The Country table includes the name of the studied country, and the Values table stores the price per ton of each product over the examined seven-year period. This work studies and analyzes the price per ton of two of the mentioned products. In this case, these are dessert grapes and wine grapes (Fig.1).

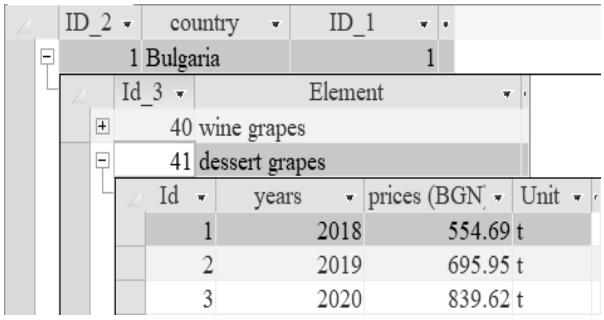

Fig. 1 Information about the two examined products organized in database tables
Source: Data fromNSI [11, 12]

The information for the two listedobjects is searched from the four tables of the database. Users can track the individual values of the researched indicator (price per ton) for dessert grapesduringthe indicated interval 2018-2024 (Fig. 1). In a similar way,the data for the other examined object - wine grapes can be visualized from the related tables Country, Elements and Values.Furthermore, users can also use different queries. As a result, the values of the indicator (price per ton) for the two studied grape types are visualized for a selected year of the time segment.

In order to determine and analyze the dynamics of the studied indicator for the two types of grapes, the following variables must be calculated:

- $N_{q+1} = p_{q+1} * 100. \frac{1}{p_q} - 100$

where: N_{q+1} - percentage change in the price per tonof dessert grapes for the current year towards the previous year,

p_{q+1} and p_q -price per tonof dessert grapes for $q+1$ and q year, $1 <= q <= 6$;

- $j_{q+1} = w_{q+1} * 100. \frac{1}{w_q} - 100$

where: j_{q+1} - percentage change in the price per ton of wine grapes for the present year towards the preceding year,

w_{q+1} and w_q -price per ton of wine grapes for $q+1$ and q year;

- The difference- F_{q+1}

$F_{q+1} = p_{q+1} - p_q$,

- The difference- Z_{q+1}

$Z_{q+1} = w_{q+1} - w_q$;

- $B_q = 100. p_q . \frac{1}{w_q} - 100$

where: B_q - percentage change in the price per ton of dessert grapes towards the wine grapes for a given year, $1 <= q <= 7$.

This work also uses hierarchical cluster analysis [13], [19], [8]. As a result, the grouping [5] of the examined years depending on the values of the considered indicator (price per ton) for each of the products (dessert grapes and wine grapes)is shown.

RESULTS AND DISCUSSIONS

The presented comparative analysis shows that the price per ton of the first product (dessert grapes) continuously increases in each year of the time segment. The situation for the second agricultural product (wine grapes) is different.In two years of the period (2019 and 2021), a decline in the indicator values is observed, as can be seen from the diagram presented in Fig. 2.Summarizing the results related to the variable N_{q+1}, two subintervals can be considered.

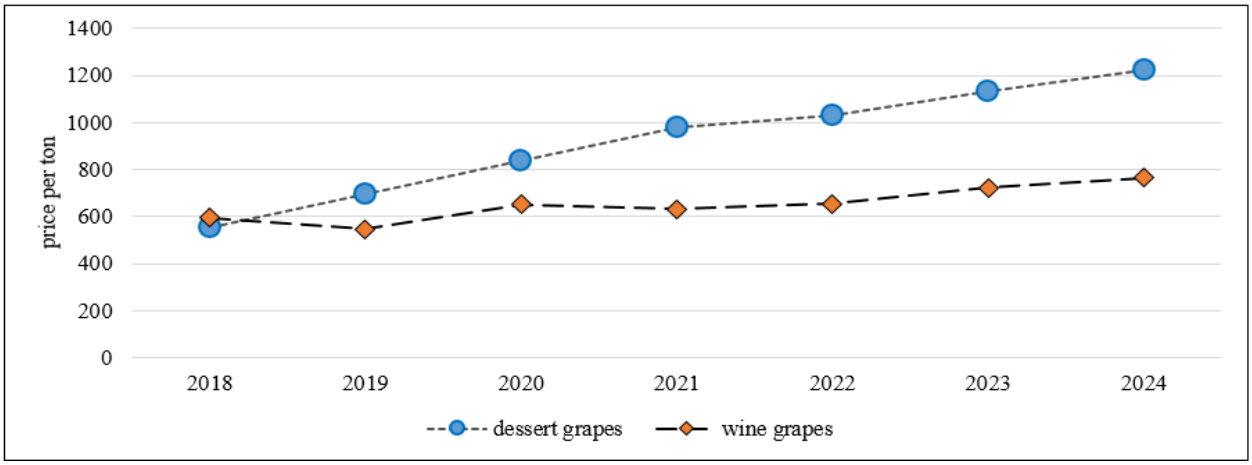

Fig. 2. The dynamics of the studied prices per ton for the two products during the considered interval
Source: Data from NSI [11, 12].

The first of them includes the years 2019-2021. Here, the pace of growth in the price per ton of the studied product dessert grapes is significantly faster (Fig. 3). In the first of the listed years, the increase in the indicator is 25.47%, for the second 20.64% and for the third 16.31%, respectively. The second subinterval contains the next three years 2022-2024. In the indicated segment, the growth pace is relatively slower.The calculations show that the price per ton of dessert grapes goes up by 5.49%, 9.79% and 8.23%, respectively for each of the listed years.The second surveyed variable j_{q+1} has negative values in 2019 and 2021. Therefore, for the first of the mentioned years 2019, compared to 2018, the price per ton of wine grapes decreased by 8.32%.The case is similar in 2021, but here the decline in the indicator is about 3.07%.For the other years from the time segment, the values of j_{q+1} are positive. The price per ton of the second product (wine grapes) increased by 19.48% in 2020 compared to 2019.In addition, an increase in the studied indicator is also observed over the last three years of the examined time period.It is 3.77% in 2022, 10.12% in 2023, and 6.02% in 2024, as shown in Fig. 3.Analyzing the obtained values of the variable F_{q+1} for dessert grapes, it is found that in the last three years of the time segment they are much lower than these values in the other studied years.

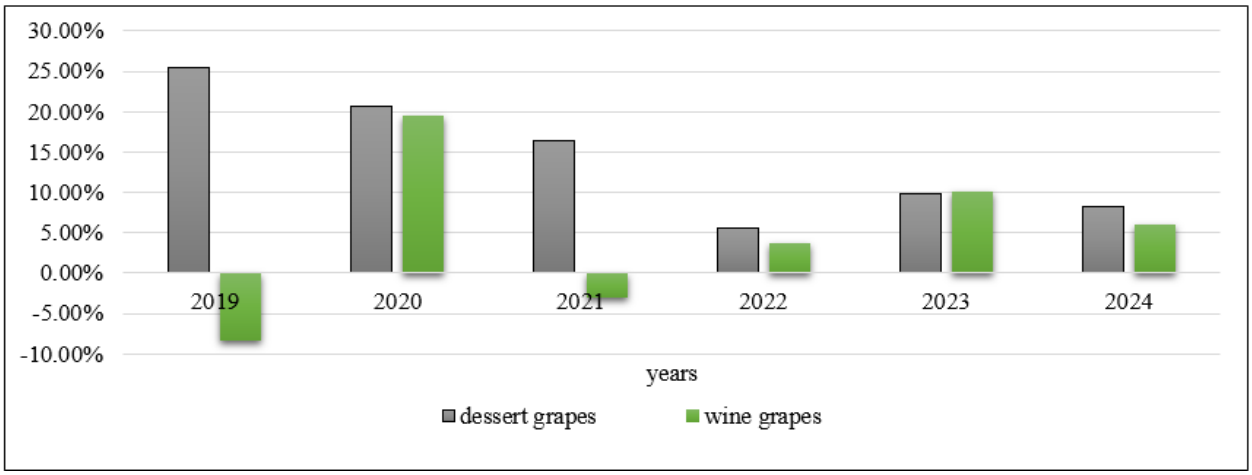

Fig. 3. The obtained results about the examined variables N_{q+1} and j_{q+1} related to the examined products
Source: Own calculations on the basis of data from NSI [11, 12].

The mentioned values vary in the range from approximately 144 BGN to 53 BGN. It should be pointed out that the variable Z_{q+1} for the

other examined product (wine grapes) has the highest value in 2020. It is around 106 BGN. The lowest value was calculated during 2019.The present work calculates the percentage change (B_q) in the price per ton of dessert grapes towardsthe wine grapes for each year of the considered time interval. Only in 2018 the indicator value for dessert grapes is 6.72% lower than that for wine grapes.Over the next two years, 2019 and 2020,the calculations show that the price per ton of dessert grapes is 27.66% and 28.92% higher, respectively, than the price per ton of wine grapes.The period 2021-2024 is characterized by much higher values of the studied indicator for dessert grapes.For each of the four listed years, the price per ton of dessert grapes is over 54% higher than that for wine grapes, as can be seen from Fig.4.

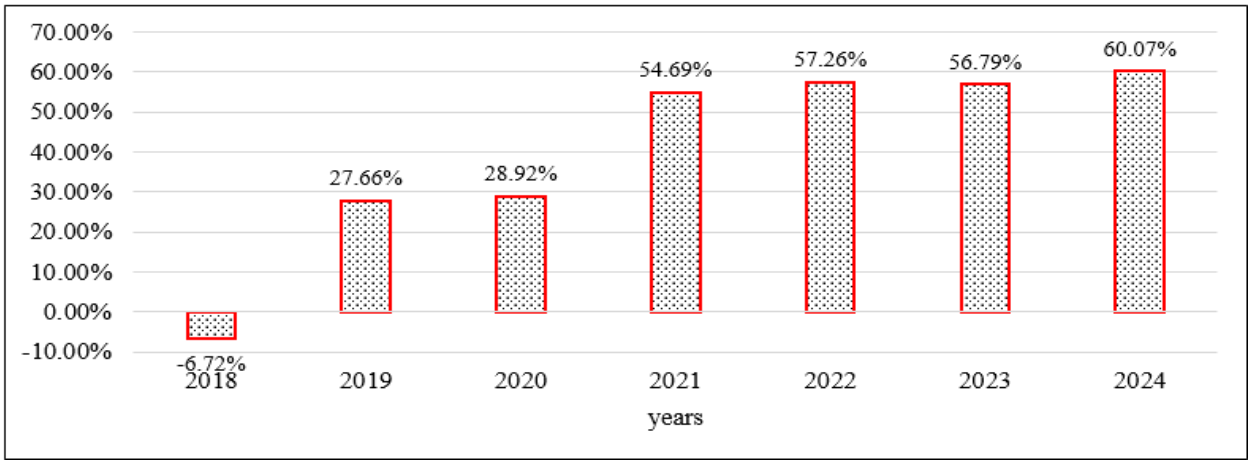

Fig. 4. Percentage change of the investigated variable B_q in the time period2018-2024

Source: Own calculations on the basis of data from NSI [11, 12].

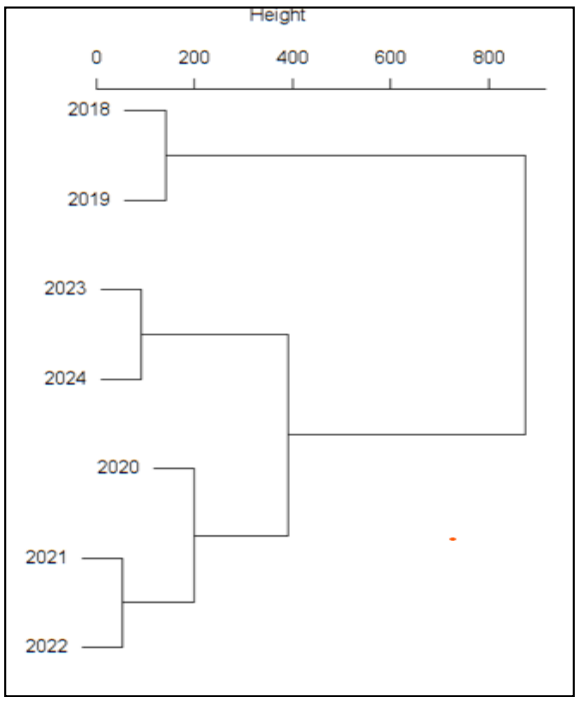

Fig. 5. Grouping the years depending on the indicator values for dessert grapes

Source: Own calculations on the basis of data from NSI [11, 12].

This study also uses hierarchical cluster analysis for the mentioned data related to these two considered products.Grouping the years based on the values of the surveyed indicator (price per ton) for dessert grapes presented the following three clusters (Fig. 5):

- Two of the studied years - 2018 and 2019 are included in one cluster. Here, the values of the examined indicator are the lowest throughout the considered interval:
- Two other years, in this case 2021 as well as 2022, form a separate cluster. The year 2020 also joins to it;
- The years 2023 and 2024 are presented in one cluster. This time segment is characterized by the highest values of the considered indicator for dessert grapes.

Grouping of years based on the values of the mentioned indicator (price per ton) of the other examined product (wine grapes) is presented in the dendrogram in Fig. 6. As a result of data processing, the following two clusters are formed:

- A separate cluster is formed by the years 2023 and 2024;
- The next cluster contains two sub clusters. The first of them includes 2020 as well as 2022.Subsequently, the year 2021 also joins to it. The second sub cluster includes two consecutive years, in this case 2018 and 2019. Here, the values of the examined indicator for wine grapes are relatively lower.

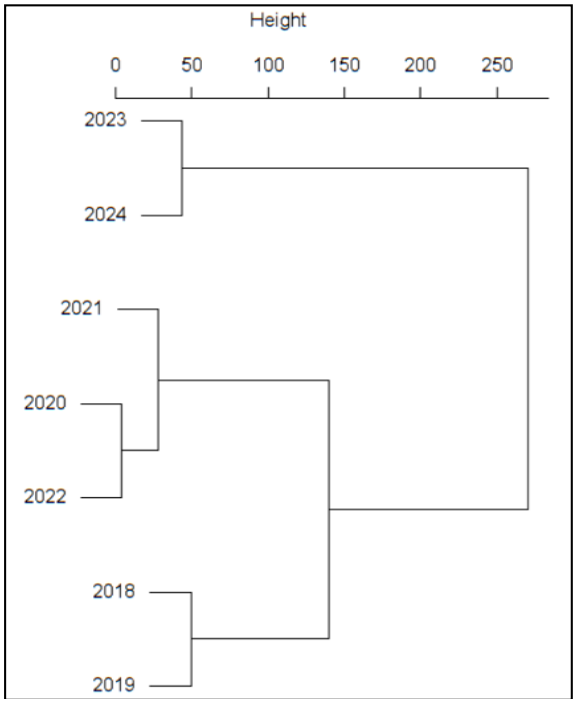

Fig. 6. Grouping the years depending on the indicator valuesforwine grapes
Source: Own calculations on the basis of data fromNSI [11, 12].

CONCLUSIONS

The current paper presents an approach for determining and analyzing the price dynamics of dessert grapes and wine grapes in Bulgaria for the time period 2018-2024. Information concerning these two examined objects is searched from the built relational database.The number of the agricultural products stored in the database is 41. The extracted subsets of objectsrelated to the listed two types of grapes are processed and analyzed. For this purpose, the respective set of variables must be calculated. This study also uses hierarchical cluster analysis for the considered data. In this regard, the grouping of the surveyed years depending on the values of the considered indicator (price per ton) for each of the products (dessert grapes and wine grapes) is presented.

The performed comparative analysis shows that the price per ton of the first studied product (dessert grapes) continuously rises in the studied time interval, while a decline in the indicator values for the second product (wine grapes) is observed for two non-consecutive years. The pace of growth in the price per ton of the dessert grapes is significantly faster in the interval 2019-2021. The increase in the indicator is 25.47% for the first of the listed year, 20.64% for the second and 16.31%for the third, respectively. In addition,the growth pace of the mentioned indicator is relatively slower for this product in the time period 2022-2024. During 2019, compared to 2018, the price per ton of wine grapes decreased by 8.32%. A similar case is observed in 2021, where the decline is about 3.07%. But, the values of the researched indicator rise for the indicated type of grapes in the time segment 2022-2024 as well as 2020.

As a result of the performed hierarchical cluster analysis of the data concerning the two types of the studied products, the following conclusions can be drawn:

- Grouping the years based on the values of the surveyed indicator (price per ton) for dessert grapes presented three clusters;
- Grouping the years depending on the values of the price per ton of wine grapes formed two clusters.

This approach could also be used when studying data in areas such as finance, agriculture, ecology, etc.

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THE IMPACT OF AGRICULTURAL POLICY ON INCREASING PRODUCTIVITY IN WHEAT CULTIVATION

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Abstract

Agricultural policies have an important role in increasing wheat productivity, influencing both farmers' decisions and the overall performance of the agricultural sector. The study analyses the impact of agricultural policies on increasing wheat productivity. The main public policy instruments analysed are subsidies, financial support schemes, pricing policies, investment incentives, and environmental regulations. The research highlights how public interventions influence the adoption of modern technologies, the efficiency of input use, and agricultural management practices. The results show that correctly implemented agricultural policies contribute to increasing wheat production yields, thus reducing economic and environmental risks. At the same time, the study also emphasizes the fact that inconsistent implementation of agricultural policies and limited institutional support can restrict the potential for increasing wheat productivity. The effects of agricultural policies on the sustainability of production and the stability of farmers' incomes are analysed. In conclusion, the study highlights the importance of an integrated agricultural strategy, combining financial support with innovation and professional training, to ensure sustainable development of the wheat growing sector.

Key words**:** *wheat, production, agricultural policies, SE Region, Romania, EU*

INTRODUCTION

Studying how different climatic factors interact and influence wheat production is essential when making decisions on how to adapt to the effects of climate change (Godfray et al., 2010) [11]. Strategies adopted to improve cereal crop productivity must be correlated with the type of crop used. In this sense, a change in temperature implies the adoption of a different strategy than a change in precipitation (Asseng et al., 2015) [3]. The behaviour of the wheat crop under temperature is particularly important for assessing the impact of climate change on wheat production, because the greatest uncertainty in the simulated impact on yield comes from increasing temperatures (Asseng et al., 2013) [2]. Cereals are important staple foods globally, directly contributing over 50% of total human calorie intake (Erenstein et al. 2022; Hawkesford, 2014; Senapati et al. 2022) [8, 14, 20]. Cereal production must continue to grow as demand increases, and both improved yields and sustainability are major challenges facing agriculture today. Nitrogen is an absolute requirement for plant growth, and crop yields and quality depend on substantial nitrogen inputs.

Chemical nitrogen fertilizers were first used in agriculture in the 19th century. Today, more than half of chemically fixed nitrogen is used in agriculture, representing over 80 Mt per year, worldwide (Hawkesford, 2014) [14].

Various wheat varieties are being studied for their resistance to drought, high temperatures, and diseases.

Production technologies are being improved, which allows for high wheat yields. As productivity per unit of cultivated area increases, wheat production increases (Gąsiorowski, 2004) [10]. Wheat production uses various material and energy inputs, including fertilizers and fuel (Vinci et al., 2022) [22]. The large number of agrochemicals and fuels associated with global wheat production has had serious environmental implications since the Industrial Revolution and, more recently, the Green Revolution (Acevedo et al., 2018;

Kheiralipour et al., 2024) [1, 15]. Changing climatic conditions, such as rising temperatures and fluctuations in the amount and distribution of precipitation, as well as unpredictable events such as war, are making it increasingly difficult to meet the growing demand for wheat (Lobell et al. 2011; Dadrasi et al. 2023) [16, 5].

Durum wheat can also be grown in semi-arid environments due to its very good adaptation to adverse weather conditions, such as high temperature and drought (Grosse-Heilmann et al. 2024) [13]. In warmer, drier regions, such as the Mediterranean basin, it is grown as a winter wheat, while in northern regions, characterized by cold and long winters, sowing is usually carried out in spring and harvesting in early autumn. (Sieber et al., 2014) [21]. The increase in average temperature in recent decades has already generated adverse effects on wheat yields worldwide (De Vita & Taranto, 2019) [6] and is expected to intensify in the coming years. The frequency and intensity of extreme heat waves, heavy rainfall, ecological and agricultural droughts in some regions will increase, according to the Intergovernmental Panel on Climate Change (IPCC), significantly reducing agricultural production (D'Odorico et al., 2018) [7]. At the same time, the world population is expected to grow in the coming decades, which will lead to increased demand for food and pressure on agricultural production (Goicoechea et al., 2016; Rulli et al., 2013) [1, 18].

Durum wheat ranks tenth among the most cultivated cereals in the world in terms of production (Brocanello et al., 2023) [4]. The annual global production of durum wheat ranges between 35 and 40 million tonnes (De Vita and Taranto, 2019; Xynias et al., 2020) [6, 24]. representing approximately 7% of total wheat production (Brocanello et al., 2023) [4], a percentage that is continuously decreasing, because of climate change. Currently, Canada is the main producer of durum wheat, cultivating an annual total of 5.2 million tonnes, closely followed by Italy and Turkey, with a production of 4.3 and 3.7 million tonnes, respectively (Xynias et al., 2020; Sabella et al., 2020) [23, 19].

The aim of the study is to analyze the impact of agricultural policies on increasing wheat productivity emphasizing on: subsidies, financial support schemes, pricing policies, investment incentives, and environmental regulations.

MATERIALS AND METHODS

The study adopts a mixed approach, integrating the bibliometric analysis of the scientific literature from 2016–2025 on the relationship between agricultural policies and wheat productivity with a descriptive statistical analysis of the main agro-economic indicators for the year 2024, at the European level and in the South-East Region of Romania. The bibliometric data were extracted from international databases (Web of Science) [23], based on relevant keywords (agricultural policies, wheat productivity), and were processed using the specialized software VOSviewer. The empirical component used official data provided by Eurostat [9] and the National Institute of Statistics [17]. The analysis included descriptive indicators and thematic cartographic representations to highlight the spatial distribution of areas and production, as well as assessing the relationship between the level of productivity, the size of holdings and the political-economic framework, highlighting the influence of support and regulatory mechanisms on the performance of the cereal sector.

RESULTS AND DISCUSSIONS

The bibliometric analysis performed in VOSviewer based on 458 articles indexed in Web of Science (2016–2025) highlights a thematic structure strongly concentrated around the concepts: climate change, food security, wheat and irrigation, which form the core of the network. The results indicate that research on the relationship between agricultural policies and wheat productivity is dominated by the perspective of climate change adaptation, with an emphasis on water use efficiency, water deficit management and

climate resilience, especially in regions such as South Asia, China and India (Figure 1).

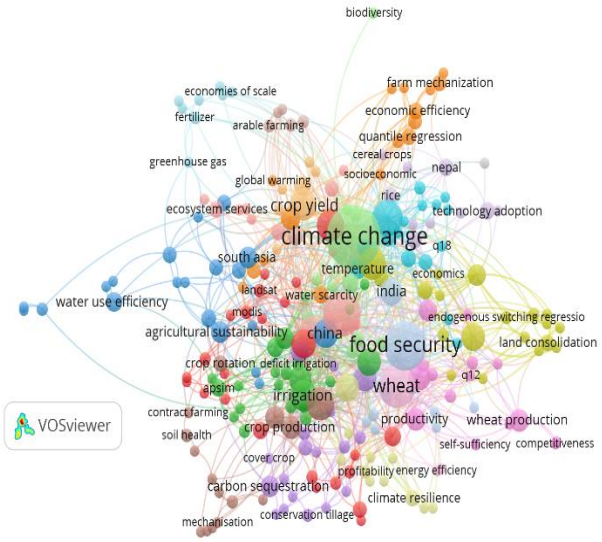


Fig. 1. Keyword co-occurrence network on the relationship between agricultural policies and wheat productivity (2016–2025).
Source: Web of Science database [23] generated with VOSviewer.

The sustainability dimension is reflected through themes such as carbon sequestration, soil conservation practices and ecosystem services. Overall, the literature from the period under review reveals an increasingly pronounced integration between agricultural policies, productive performance and climate sustainability objectives (Figure 1).

Three main axes are observed: climate axis (climate change - water scarcity - irrigation - crop yield - food security), economic axis (land consolidation - productivity - competitiveness – profitability) and sustainability axis (carbon sequestration - conservation tillage - ecosystem services - agricultural sustainability) (Figure 1).

This is the overlay visualization map made in VOSviewer based on articles from the Web of Science (2016–2025), where the color indicates the average year of appearance of the keywords (blue = older, yellow = more recent). The network confirms that climate change, food security and wheat remain the central concepts of the field, but the overlay highlights a clear thematic dynamic in recent years (2023–2025).

Terms such as China, India, South Asia remain constant, indicating that the Asian region continues to be the primary laboratory for agricultural policy analysis on wheat productivity. The overlay view shows a thematic evolution from initial concerns about climate impact and crop yield to more recent themes such as climate resilience, energy efficiency, competitiveness and technology adoption, reflecting the field's maturation and orientation towards applied solutions (Figure 2).

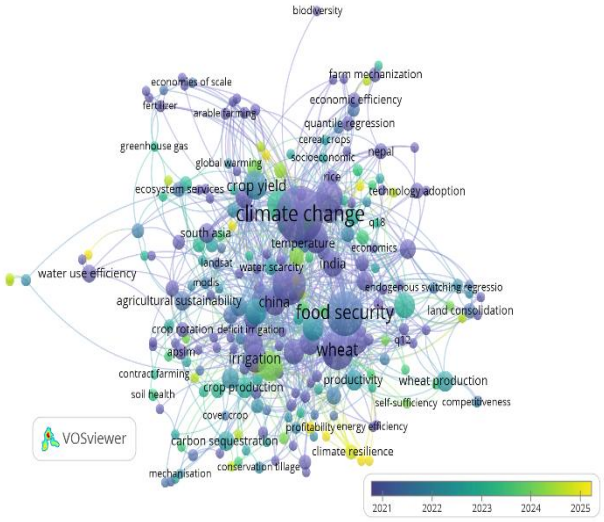


Fig. 2. Overlay visualization of the temporal evolution of keywords in the literature on agricultural policies and wheat productivity (2016–2025).
Source: Web of Science database [23] generated with VOSviewer

This is a density visualization map created in VOSviewer based on the 458 articles indexed in the Web of Science (2016–2025). In this type of representation, the color indicates the density and frequency of occurrence of keywords: yellow = high intensity (dominant themes), green = medium relevance, blue = low/peripheral relevance. The density map confirms the centrality of the "climate change–food security–wheat" axis, with a strong geographical focus on China and South Asia, while themes such as biodiversity, carbon sequestration and soil health remain relatively peripheral, indicating emerging research directions. Overall, the results highlight the progressive integration of climate, economic and sustainability dimensions in the analysis of wheat productivity in the context of contemporary agricultural policies (Figure 3).

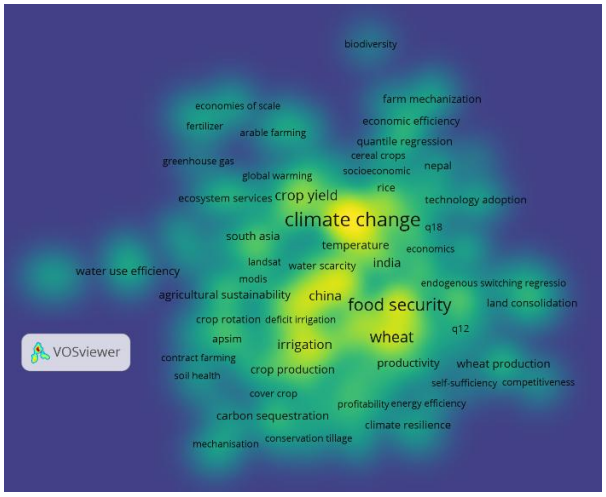
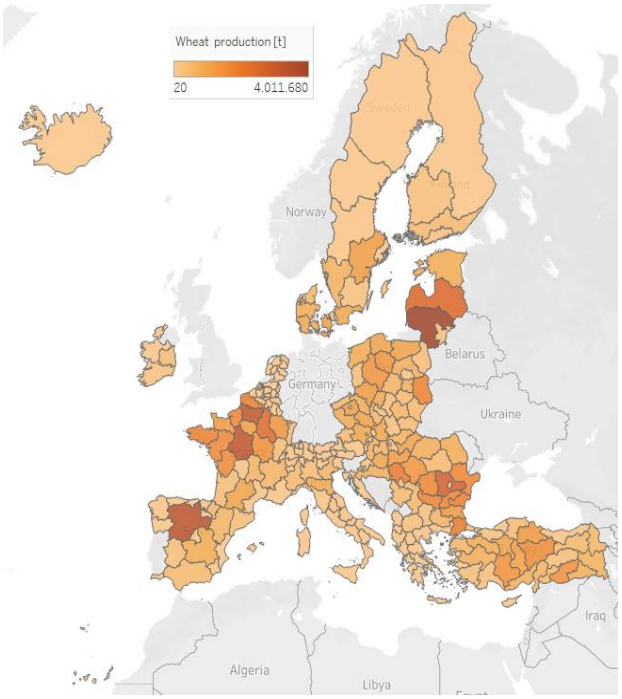


Fig. 3. Density visualization of the main research topics in the field of agricultural policies and wheat productivity (2016–2025).
Source: Web of Science database [23] generated with VOSviewer.

The map illustrates the regional distribution of wheat production in Europe, highlighted by a chromatic scale from light orange (low production) to dark orange (high production). A concentration of high production is observed in the regions of the west and south-west of the continent, especially in France and Spain, but also in certain areas of Central and Eastern Europe, including Romania and Poland. In contrast, the northern regions (Scandinavia) and some mountainous or colder climate areas show lower values, which suggests the influence of climatic conditions, soil fertility and available agricultural areas on the level of production. The distribution thus reflects the agro-climatic and economic differences between European regions (Map 1).

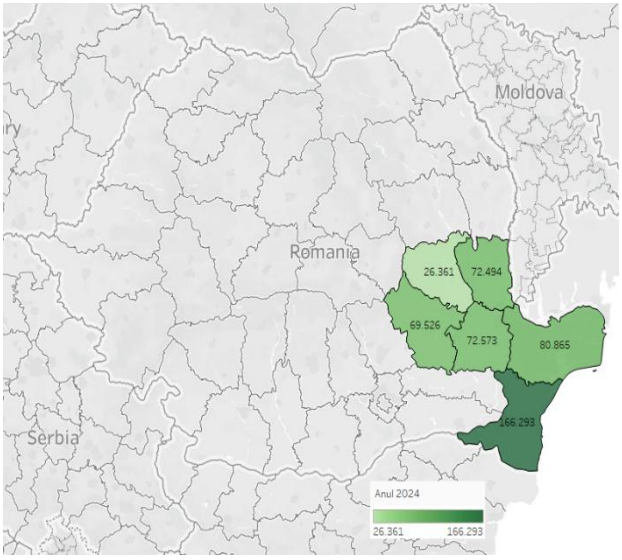
Map 1 highlights the areas cultivated with wheat in the counties of the South-East Region of Romania in 2024, expressed in hectares, through a chromatic scale from light green (lower values) to dark green (higher values).

A significant difference is observed between the counties, with Constanța recording the largest cultivated area (166,293 ha), which reflects the high agricultural potential of Dobrogea and the important share of cereal crops in this area.



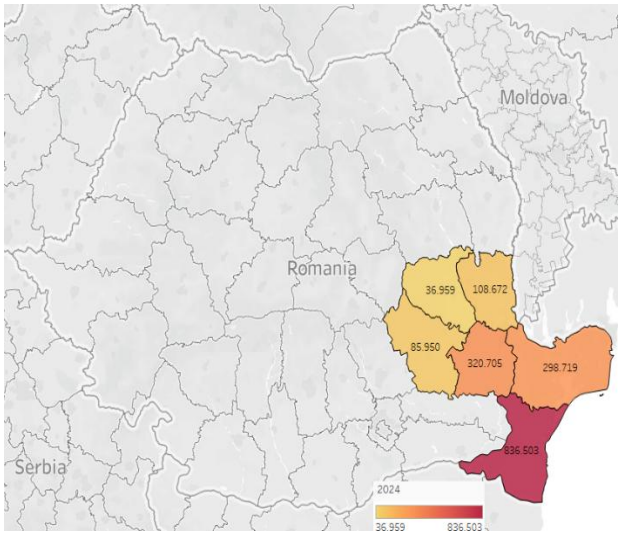
Map 1. Production of common wheat and spelt expressed in tons, at European level, 2024.
Source: Eurostat database [9], generated with Tableau.

At the opposite pole, Vrancea has the smallest area (26,361 ha), while Brăila, Buzău, Galați and Tulcea counties present intermediate, relatively close values (approximately 69,000–81,000 ha). The distribution shows the predominance of wheat cultivation in the plain areas and confirms the strategic role of the South-East region in the cereal production of Romania (Map 2).



Map 2. Areas cultivated with wheat in the counties of the South-East Region of Romania, in 2024, expressed in [ha].
Source: NIS database [17], generated with Tableau.

The South-Eastern Region of Romania (South-East Region) highlights in 2024 significant differences in wheat production between counties, with Constanța County in first place (836,503 t), followed at a great distance by Brăila County (320,705 t) and Galați County (298,719 t). An average level is observed in Buzău County (108,672 t) and Vrancea County (85,950 t), while Tulcea County records the lowest production (36,959 t).

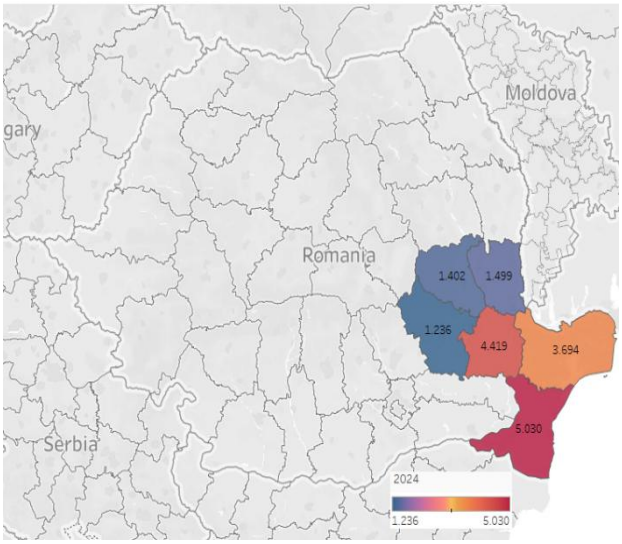


Map 3. Wheat production in the counties of the South-East Region of Romania, in 2024, expressed in [t].
Source: NIS database [17], generated with Tableau.

The distribution reflects the pedoclimatic advantages and the extensive agricultural areas in the plain and plateau area, especially in Constanța and Brăila, where favourable conditions and intensive exploitation support high yields, compared to counties with more fragmented relief or smaller cultivated areas (Map 3).

In the South-East Region, the average wheat productivity in 2024 highlights clear contrasts between counties: Constanța County records the highest value (5,030 kg/ha), followed by Brăila County (4,419 kg/ha) and Galați County (3,694 kg/ha), which confirms the efficiency of land exploitation in the plain areas with fertile soils and high-performance agricultural technologies.

At the opposite pole, Buzău County (1,499 kg/ha), Vrancea County (1,402 kg/ha) and especially Tulcea County (1,236 kg/ha) present lower yields, possibly influenced by less favourable pedoclimatic conditions, land fragmentation or rainfall variability. Overall, the southeast of the region (Constanța–Brăila) concentrates the highest levels of productivity per hectare, outlining a high-performance agricultural core within the region (Map 4).



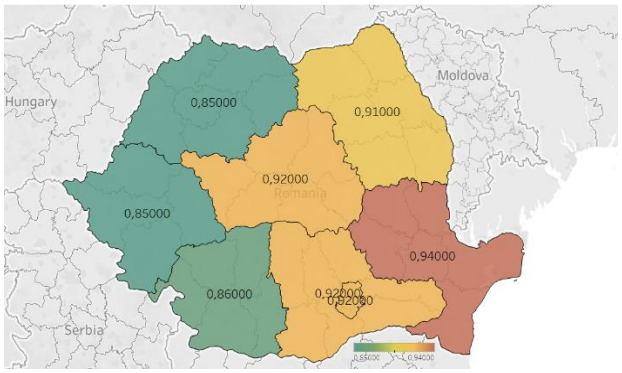
Map 4. Average wheat production in the counties of the South-East Region of Romania, in 2024, expressed in [kg/ha].
Source: NIS database [17], generated with Tableau.

In 2024, average farm gate prices for wheat in Romania vary moderately between development regions, ranging between 0.85 and 0.94 lei/kg. The highest values are recorded in the South-East Region (0.94 lei/kg), followed by the South-Muntenia Region and the Center Region (approx. 0.92 lei/kg), which may reflect both the high level of production and the easy access to markets and infrastructure (port or processing).

An intermediate level appears in the North-East Region (0.91 lei/kg), while the lowest prices are in the North-West Region and the West Region (0.85 lei/kg), respectively in the South-West Oltenia Region (0.86 lei/kg).

Overall, regional differences are relatively small, suggesting a relatively integrated national market, with variations mainly determined by logistics costs, proximity to exports and local demand dynamics (Map 5).

The integrated analysis of total production, yield per hectare and farm gate prices highlights significant territorial disparities in Romania, with a concentration of agricultural performance in the South-East Region.



Map 5. Average farm gate prices of wheat, by development regions, in Romania, in 2024, expressed in [lei/kg].
Source: NIS database [17], generated with Tableau.

It is noted that Viduino ir vakaru Lietuvos records the highest production, of approximately 4 million tonnes, clearly exceeding the other regions. The following positions are occupied by Castilla y León, Centre-Val de Loire and Picardy, each with values ranging between approximately 3 and 3.3 million tonnes, which highlights the important role of these regions in the total wheat production of the EU (Fig. 4).
The Sud-Muntenia region is also among the regions with high production, with almost 2.8 million tonnes.

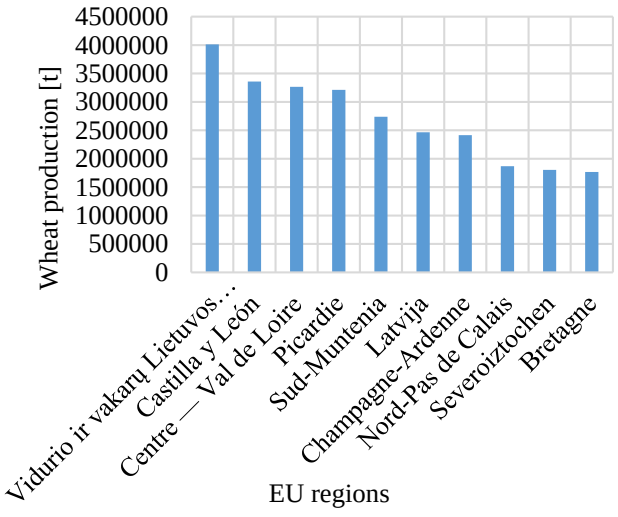


Fig. 4. Wheat production for the top 10 EU regions, in 2024, expressed in [t].
Source: Eurostat database [9], generated with Excel.

The rest of the regions in the ranking, such as Latvija, Champagne-Ardenne, Nord-Pas-de-Calais, Severozapaden and Brittany, record more moderate productions, located approximately between 1.7 and 2.5 million tonnes. Overall, the graph highlights a greater concentration of wheat production in a few very productive agricultural regions, while the others contribute somewhat smaller volumes, but remain important in the structure of total production in the European Union (Fig. 4).

CONCLUSIONS

The research is strongly dominated by the climate change perspective. Agricultural policies are predominantly analysed through their impact on productivity, water use efficiency, climate resilience. There is a clear integration between economic approaches (quantitative models) and sustainability approaches. Emerging regions in the analysis are South Asia and China. There is a focus on land consolidation and energy efficiency policies.
The density map confirms that the "agricultural policy – wheat productivity" domain is dominated by the climate change and food security paradigm, with a focus on water management and crop yield. The economic and sustainability components are well represented, but topics such as biodiversity, climate resilience and carbon sequestration still appear on the periphery of the network, indicating potential future research development directions.
Overall, the two cartographic representations highlight the concentration of production and areas cultivated with wheat in plain regions with high pedoclimatic potential, both at European level and in the South-East Region of Romania, while also underlining the determining role of agricultural policies - through financial support mechanisms, subsidies and regulations within the Common Agricultural Policy - in stimulating and maintaining the competitiveness of the cereal sector.
The overlay visualization shows a clear evolution of research, from analysing the impact of climate change on wheat productivity to integrated approaches that combine climate resilience, energy efficiency, competitiveness and sustainability of

agricultural systems. The field is thus becoming more oriented towards applied public policies and economic performance in an uncertain climate context.

The correlation between high volumes and superior productivity reflects not only pedoclimatic advantages, but also the impact of agricultural policies – through financial support mechanisms, investments in technology and market measures – on the intensification and efficiency of production. At the same time, moderate price variations indicate the functioning of a relatively integrated market, influenced by the framework of national and European agricultural policies. Overall, the results highlight the strategic role of public intervention in strengthening the competitiveness of the cereal sector.

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VOLUNTARY CARBON MARKETS IN AGRICULTURE: A COMPARATIVE ANALYSIS BETWEEN ROMANIA AND THE EUROPEAN UNION

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Abstract

The transition to climate neutrality has increased the importance of agriculture in reducing greenhouse gas emissions. In this context, voluntary carbon markets are increasingly being used to promote conservation agriculture practices, but the application of carbon certification at the farm level remains limited by technical difficulties and economic uncertainties. The aim of this study is to identify the differences between the voluntary carbon market in Romania and the voluntary carbon market in the European Union. The scientific approach has two objectives: aiming to assess technological gaps by benchmarking three European reference platforms against initiatives in Romania based on four performance indicators — MRV technology, certification standards, access costs, and payment model, as well as identifying operational mechanisms capable of increasing farmers net income. The study tests the hypothesis that remote sensing integration cuts monitoring costs by over 50% compared to physical sampling methods and that compliance with international standards is essential for access to foreign markets. The results confirm that satellite monitoring is a lower-cost solution with better performance than solutions based on physical samples and field visits.

Key words**:** *carbon farming, carbon markets, digital MRV, economic sustainability*

INTRODUCTION

European agriculture is at the heart of decarbonization efforts, and carbon credit initiatives create incentives for adopting sustainable practices. Agricultural soils can store significant amounts of carbon, but their actual contribution depends on the implementation of reliable systems for assessing, reporting, and selling credits.

Most European regulations are still being developed, and farmers face uncertainty regarding the security of their loans and the market in which they are sold (Paustian et al., 2019) [28]. Given that the European Union is aiming for climate neutrality by 2050, carbon farming mechanisms can contribute both to reducing emissions and to generating additional income for farmers (European Commission, 2022) [13]. The quality of a credit depends on compliance with criteria such as additionality, the establishment of baselines, the permanence of sequestration, the prevention of leakage, and rigorous measurement (Schneider, 2009) [30].

Additionality refers to the fact that the carbon sequestration or emission reduction would not have occurred in the absence of the project (Nabuurs et al., 2022) [25]. The lack of a well-founded framework creates a risk of over-crediting, and numerous analyses of forestry projects have highlighted problems related to the static estimation of baselines and the crediting of multiple hypothetical sequestrations (Badgley et al., 2023) [3].

In agriculture, assessment methods must consider soil variability, changes in management practices, and the dynamics of organic carbon (Lal, 2020) [22]. The adoption of these practices at the farm level in Romania depends directly on economic feasibility and incentive policies, factors that have recently been shown to be essential for farmers' profitability.

Methodologies recognized by international standards establish approaches based on direct

measurements (soil samples) or models (biogeochemical simulation models) to estimate carbon stocks (Lindsey & Bird, 2019) [23]. The Gold Standard protocol for soil organic carbon (Gold Standard, 2021) [16] and the Verra VM0042 methodology (Verra, 2023) [35] require dynamic base models adjusted annually, with corrections for uncertainty and risk.

The Intergovernmental Panel on Climate Change (IPCC) recommends a tiered approach: Tier 1 uses generic emission factors; Tier 2 uses region-specific factors; Tier 3 involves detailed modelling and measurements. The correct application of these tiers is essential for obtaining legitimate credits (IPCC, 2019) [18].

Credits are reported through monitoring, reporting, and verification (MRV) systems, which include data collection, report preparation, and verification by independent third parties (Lindsey & Bird, 2019) [23]. The ISO 14064-2:2019 and ISO 14064-3:2019 standards provide guidelines on the reporting and verification of emission reduction projects. The GHG Protocol Project Guidance (WRI, 2005) [37] and the recent SBTi initiative (SBTi, 2024) [31] emphasize the necessity of transparent reporting to prevent double counting of reductions. The use of digital registries (e.g., Verra, Gold Standard) ensures the traceability of certificates and reduces the risk of fraud (Carbone 4, 2022) [7].

In Europe, carbon credits are not part of the mandatory EU ETS system, but initiatives such as the Carbon Removal Certification Framework (CRCF) propose voluntary mechanisms for certifying soil sequestration and for integrating these credits into climate policies (European Commission, 2022) [13].

The literature reveals numerous gaps. First, existing methodologies are primarily tailored to forestry projects; their application in agriculture requires adjustments to account for crop rotations, the incorporation of crop residues, and soil management (Lindsey & Bird, 2019) [23]. On the other hand, current MRV systems are costly, and digital technologies and satellite data have not yet been widely integrated into reporting schemes (Coffield et al., 2022) [11]. Furthermore, agricultural carbon markets are fragmented, and farmers in Eastern Europe do not benefit from clear eligibility rules or financial compensation commensurate with their investment efforts (Paustian et al., 2019; Stefan et al., 2025) [28, 34].

Between 2020 and 2025, the structure of voluntary carbon markets (VCMs) underwent a significant structural transformation, characterized by a shift from a model focused primarily on quantitative expansion to one based on strict compliance and integrity requirements. This reconfiguration was driven by a loss of credibility resulting from the exposure of methodological limitations in certain existing standards, which necessitated the internalization of the actual costs associated with scientific verification processes.

In 2023 - 2024, there were big changes in prices and many market participants became hesitant, but 2025 shows the start of a stabilization process, helped by the new Core Carbon Principles (CCP) created by the Integrity Council for the Voluntary Carbon Market (ICVCM). In this context, agriculture which sits at the intersection of being a source of emissions and having the potential to sequester and store carbon in soil (SOC) has emerged as the primary testing ground for the new standards. These principles have forced current standards, such as Verra and the Gold Standard, to revise their methodologies, phasing out outdated versions and imposing strict labelling that distinguishes emissions reductions from actual sequestration (Climate Focus, 2025) [8].

The transition to carbon-neutral agriculture goes beyond strictly environmental considerations, representing a key pillar for the long-term economic growth and development of rural areas (Stefan, 2012) [33]. At the European Union level, the overall performance and competitiveness of the agricultural sector are directly dependent on farmers' ability to integrate innovative and sustainable solutions (Coca et al., 2023) [10]. Adopting these best-practice models requires accelerated digitization of agricultural audit and management processes. However, the

implementation of digital systems and decision-support tools at the farm level remains constrained by specific structural barriers, such as operating costs and factors limiting technology adoption (Bodescu et al., 2023) [5].

In this context, the aim of this research is to identify the structural differences between the voluntary carbon market in Romania and that of the European Union, with a view to optimizing national mechanisms.

The scientific approach has two objectives: (1) to assess technological gaps by benchmarking three European reference platforms against local initiatives based on four performance indicators (MRV technology, certification standards, access costs, and payment model) and (2) to identify operational mechanisms capable of increasing farmers' net income.

MATERIALS AND METHODS

The study employs a mixed-methods approach, structured around two lines of analysis. In the first phase, three platforms representative of the European market were selected and analyzed: Agreena (Denmark), Soil Capital (Belgium/United Kingdom), and eAgronom (Estonia). The main selection criterion was their regional relevance in Central and Eastern Europe (Bera, 2024) [4]. The necessary technical data was extracted by analyzing official white papers and MRV methodology reports published between 2023 and 2024, which were subsequently compared with commercial offers from soil science and environmental consulting service providers in Romania.

The gaps were assessed using a benchmarking matrix that incorporated four key performance indicators. The analysis focused on MRV technology to determine the degree of automation through satellite imagery versus physical sampling, as well as on the certification standard used, distinguishing between international accreditations such as Verra or Gold Standard and domestic standards.

In addition, the cost structure was evaluated to identify barriers to entry, specifically the difference between fixed costs, issuance and trading fees, and the payment model, while analyzing the speed of cash flow to farmers.

To ground the economic analysis in actual agronomic data, the study incorporated a model of carbon sequestration potential at the farm level. The database included a representative sample of 13,693 hectares. The areas analyzed are cultivated with Romania's main arable crops, namely wheat, corn, sunflowers, and rapeseed.

Based on these datasets, the study's key indicators were determined: average carbon input (kg C/ha), humified carbon (kg/ha), and carbon dioxide equivalent (CO_2e). Carbon was converted to carbon dioxide equivalent (CO_2e) using the standard conversion factor of 3.67.

Table 1. Coefficients applied in estimating carbon fluxes according to crop type and tillage system

Coefficients	Tillage system	Crop			
		Wheat	Maize	Sunflower	Rapeseed
RET	CT	0.3	0.2	0.95	0.95
	MT	0.45	0.3	0.95	0.95
	NT	0.6	0.4	0.95	0.95
h	CT	0.2	0.2	0.2	0.2
	MT	0.28	0.28	0.28	0.28
	NT	0.34	0.34	0.34	0.34
RD	CT	0.03	0.03	0.03	0.03
	MT	0.05	0.05	0.05	0.05
	NT	0.07	0.07	0.07	0.07
RPR	CT/MT/NT	1	1	2	2
R:S	CT/MT/NT	0.25	0.2	0.15	0.2
Cfrac	CT/MT/NT	0.45	0.45	0.45	0.45

Source: adapted according to Ispas, 2026 [20].

The estimation of carbon fluxes involved the use of a set of crop-specific coefficients derived from the literature: the straw-to-grain ratio (RPR), the root-to-above-ground biomass ratio (R:S), the carbon fraction (Cfrac), retained residue fraction (RET),

humification coefficient (h), and rhizodeposition (RD).

These coefficients were taken from the table presented by Ispas (2026) [20], which in turn is firmly grounded in the IPCC guidelines (IPCC, 2019; IPCC, 2006) [18, 19] and recent studies and reviews [21, 6, 9, 27, 14, 29, 17]. The average values used are presented in Table 1.

In Table 1, the following abbreviations were used for the three tillage systems: CT - conventional tillage, MT - minimum tillage, and NT - no tillage.

RESULTS AND DISCUSSIONS

In Europe, numerous initiatives are promoting the voluntary market. Companies such as Soil Capital in Belgium and Regen Network are using blockchain technology to track carbon credits. The Spanish platform Nori and the German platform Carbo Farm are digitizing MRV procedures, making it easier for farmers to connect with buyers. In addition, pilot projects supported by the French Ministry of Agriculture are testing the integration of credits into payments for ecosystem services (OECD, 2023) [26]. In Romania, such programs are still in their early stages, with some cooperatives exploring partnerships with technology firms to access voluntary markets.

Agreena has established itself as one of the leaders in the European carbon farming market, managing a portfolio of over 2 million hectares across 17 countries (Agreena, 2025) [2]. Methodologically, the company uses the Verra VM0042 standard (Improved Agricultural Land Management), recognized as one of the most robust globally. This involves a combination of emissions modelling and verification via remote sensing. Agreena's business model is designed so that farmers retain ownership of the certificates generated.

The company charges an issuance and trading fee of approximately 15% and, optionally, a sales commission when it acts as an intermediary in the transaction. It also offers an “early payout” mechanism to provide farmers with liquidity prior to the official issuance of the loans (Agreena, 2025) [2].

In terms of innovation, Agreena focuses its efforts on scalability, using satellite imagery to monitor agricultural practices—such as identifying bare soil or detecting plowing—without the need for costly on-site visits to each plot.

Soil Capital was the first platform to launch a certified carbon farming program in 2020, adopting an approach strongly focused on agronomy and on supporting farmers’ technical transition.

From a methodological standpoint, the platform is based on the Cool Farm Tool (CFT), an internationally recognized carbon footprint calculator, supplemented by an annual audit conducted in accordance with the ISO 14064 standard by TÜV Rheinland (Soil Capital, 2024) [32].

Soil Capital provides farmers with a guaranteed minimum price of roughly €27.50 per ton, safeguarding them against adverse market fluctuations. The business model is primarily defined by value-chain integration, as a substantial share of the credits is sold to companies within the food chain that collaborate with the farmers.

The platform distinguishes itself through its robust focus on agronomic consulting, regarding carbon as a byproduct of healthy soil rather than a primary objective.

eAgronom operates mainly in Central and Eastern Europe, including Poland, the Baltic states, and Romania, integrating farm management software with a platform focused on the carbon market.

The company employs a hybrid financing model, collaborating with prominent banks like Swedbank to provide farmers with advantageous credit terms for their participation in the carbon program. Sustainability is directly incorporated into the farm's financial risk profile (Global AgInvesting, 2024) [15].

From a technological perspective, eAgronom employs blockchain technology to guarantee the traceability of loans and offers farmers pre-financing mechanisms aimed at addressing the initial costs of transition—costs that pose a substantial obstacle for small and medium-sized farms in the region (eAgronom, 2024) [12].

The key difference lies in the Monitoring, Reporting, and Verification (MRV) process. European platforms incorporate Sentinel-2 satellite data and artificial intelligence algorithms to remotely validate agricultural practices (Agreena, 2023) [1].

This automation enables the simultaneous monitoring of millions of hectares at minimal expense to the farmer.

The most precise method to ascertain variations in soil carbon content on a specific parcel of land is to obtain physical samples and quantify the carbon content prior to and after alterations in management practices. Nevertheless, this is exceedingly expensive. In return, the farmer provides the intermediary firm with information on soil conditions and management practices. The firm uses this information, along with specialized computer models, to estimate the additional amount of carbon that would be sequestered over a given period.

Generally, these carbon sequestration estimates are then verified by a third party before the transaction is recorded in a third-party registry that prevents the credits from being double counted. The farmer then begins the new practice, the company initiates the agreed-upon payment program for the farmer, and the company sells the verified number of credits to individual or corporate consumers. Because estimation procedures are not perfectly accurate, there remains a degree of uncertainty regarding the exact amount of carbon sequestered in the registered field.

To calculate carbon sequestration, physical samples must be collected from various depths. For arable land, samples must be taken at 20, 40, 60, and 100 cm, and for non-arable land, samples must be taken at 10, 20, 50, and 100 cm, since the highest concentration of carbon in the soil is found in the top 15 centimeters of the subsoil.

As shown in Figure 1, the global price of carbon credits in 2025 varies from continent to continent and from country to country.

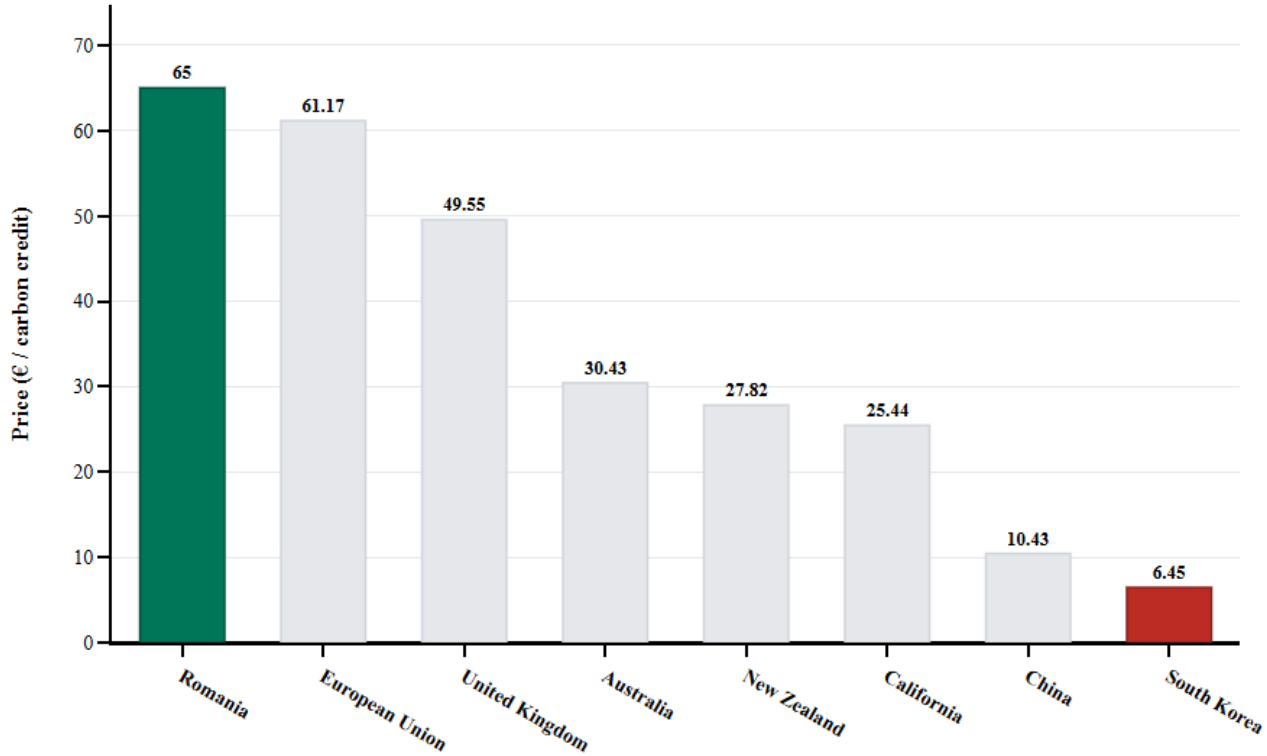

Fig. 1. The global price of carbon in 2025
Source: adapted from the World Bank [36]

In Romania, a consultative approach dominates the ecosystem, necessitating physical validation of carbon stocks. Romanian farmers are required to hire

accredited soil laboratories to collect soil samples, a complex and costly logistical process (Popescu A., 2023) [29].

The cost of this manual validation is the main economic barrier. Our study shows that recurring physical assessments (required every 3–5 years) incur a cost of approximately 10–15 euros per hectare, which must be paid in advance regardless of whether the carbon certificate is sold or not.

This cost structure reduces profitability for small farms in Romania. Unlike the European "freemium" model, where the platform charges only a listing and trading fee (e.g., 15% at Agreena), Romanian farmers bear the full initial investment risk (Bera, 2024) [4].

Another issue identified is the lack of international standardization. Western platforms have quickly adopted the Verra Standard (VCS), which ensures the liquidity of credits on the global voluntary market. In Romania, the use of domestic standards makes the certificates difficult to sell.

Table 2. Assessment of soil carbon sequestration for major agricultural crops

Crops	A[1] (ha)	Qm[2] (kg/ha)	CIn[3] (kg C/ha)	hC[4] (kg C/ha)	CO_2e[5] (kg/ha)
Wheat	7,493	4,981	1,826.78	365.36	1,340.86
Maize (Corn)	1,426	6,111	1,682.97	336.59	1,235.30
Sunflower	2,078	2,577	2,740.83	548.17	2,011.77
Rapeseed	2,696	2,700	3,059.37	611.87	2,245.58
Total /Average	**13,693**	**4,285**	**2,193.20**	**438.64**	**1,609.81**

Source: Own source.

Legend: [1]A - cultivated area. [2]Qm – average yield per hectare. [3]CIn – average carbon input. [4]hC – humified carbon. [5]CO_2e – average carbon dioxide sequestration potential.

Evaluating the efficacy of trading platforms necessitates comprehension of the prospective volume of carbon sequestered at the agricultural level. An analysis of agronomic data covering an area of 13,693 hectares reveals an average soil carbon input of 2,193.20 kg/ha (Table 2). This analyzed organic input generates an average sequestration potential of 1.61 tons of CO_2e per hectare (Figure 2).

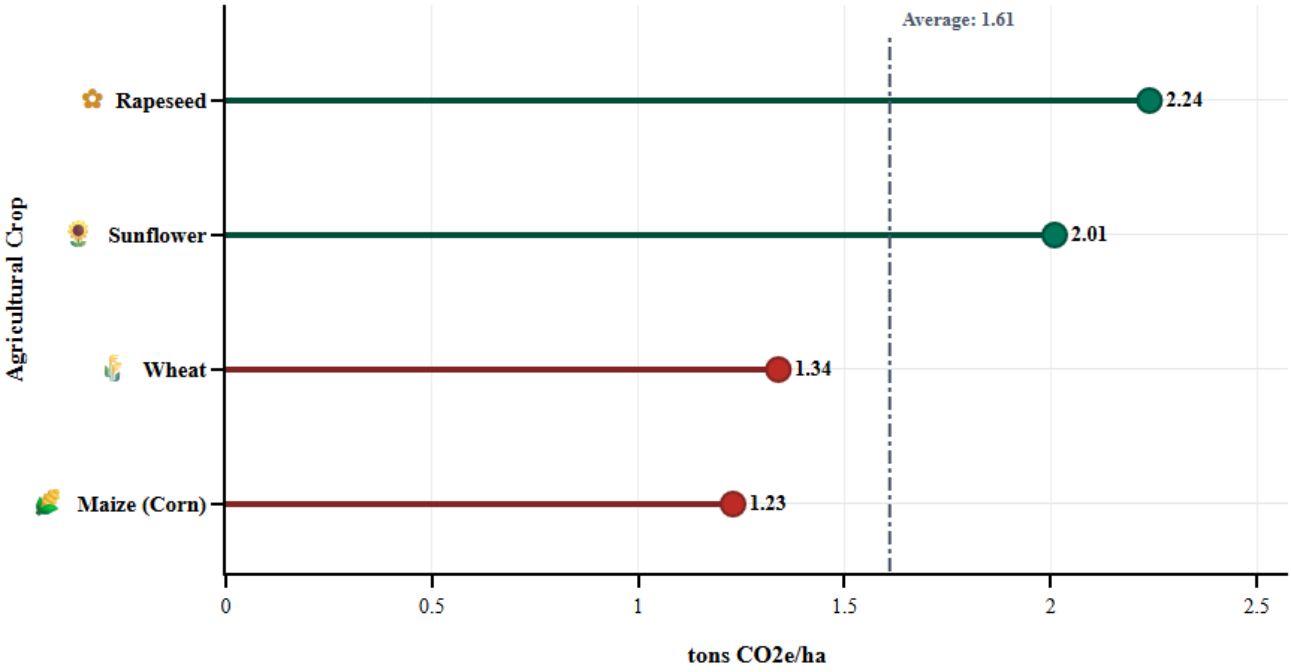

Fig. 2. Average sequestration potential (tons CO_2e/ha)
Source: Own source.

The highest potential sequestration values were recorded for rapeseed, at 2.24 tons of CO_2e/ha. This is followed by sunflowers, indicating a high potential for both fall and spring crops to generate biomass. However, voluntary markets monetize only the additional sequestration generated through conservation practices, limiting the number of eligible credits.Thus, the monitoring technology selected directly influences the economic viability of the transition to carbon farming. A comparative analysis of operating mechanisms reveals a profound technological asymmetry between the mature markets of Western Europe and the emerging market in Romania. The European platforms analyzed have adopted the digital MRV model, which is based on satellite imagery and artificial intelligence. This automation enables the remote validation of agricultural practices, significantly reducing marginal costs for farmers (Agreena, 2025) [2].

In Romania, a consultative approach dominates the ecosystem, necessitating physical validation of carbon stocks. Farmers are required to hire soil laboratories to collect soil samples. This logistical procedure incurs a fixed cost of 10–15 EUR/ha, payable in advance, constituting the primary economic obstacle to market entry (Bera, 2024) [4].

Table 3. Benchmarking carbon platforms: EU digital models vs. traditional models

Indicator	Agreena (DK)	Soil Capital (BE/UK)	eAgronom (EST)	Romania
MRV Technology	Satellite + AI	Cool Farm Tool + Soil Analysis	Hybrid (Software + Satellite)	Manual / Soil Analysis
The Standard	Verra (VM0042)	ISO 14064 / Intern	Verra (VM0042)	Intern / ISO
Cost type	Issuance and trading fees	Annual subscription	Subscription + Fee	Fee
Total cost	15–20% of the carbon credit value	€288 fixed cost + €3.50/ha per year	15–20% of the carbon credit value	10-15 €/ha
Payment	Annual	Annual	At the sale of carbon credits	At the sale of carbon credits

Source: Own source.

An analysis of the operational models demonstrates the direct impact on cash flow (Table 3). The European digital model converts fixed costs into variable operational costs, deducted in the form of an issuance and transaction fee charged exclusively at the time of payment. European farmers benefit from a zero-risk system, while Romanian farmers bear the full initial investment risk.

Another weakness identified is the lack of international standardization for local projects.

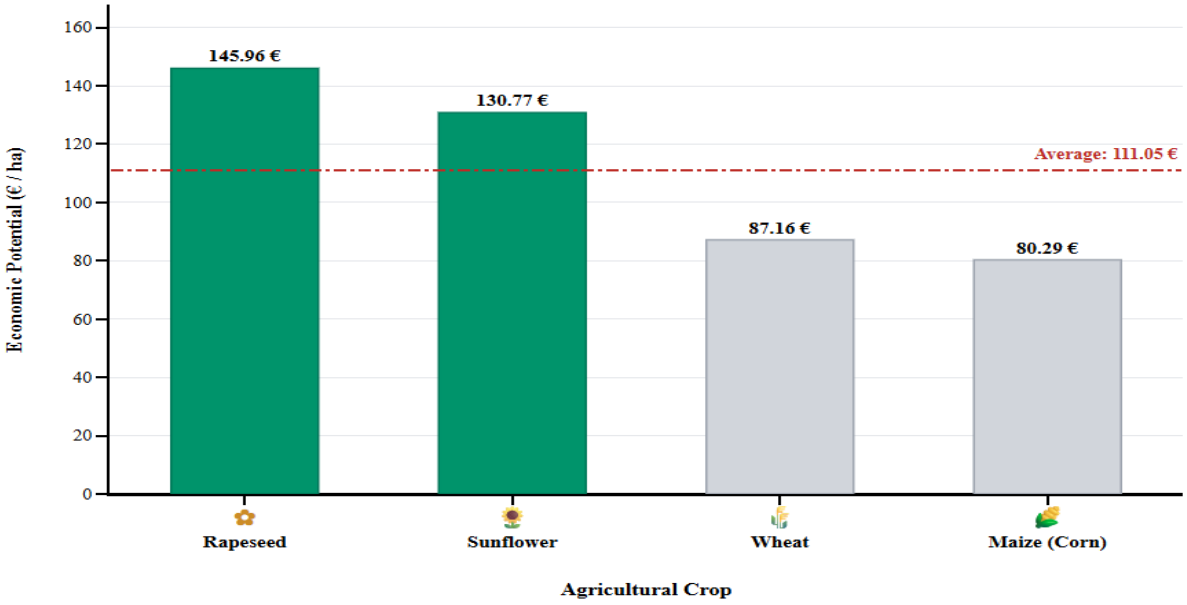

Fig. 3. Economic potential for farmers by crops (€/ha)
Source: Own source.

Western platforms have quickly aligned themselves with the Verra standard, ensuring the liquidity of credits on the global voluntary market. The use of domestic standards in Romania makes the resulting credits vulnerable to accusations of greenwashing and difficult to sell to corporations.

To assess the economic potential of carbon sequestration per hectare, a reference price of €65 per ton of CO_2e was utilized for carbon credits in Romania (World Bank) [36], as 1 ton of CO_2e corresponds to 1 carbon credit. The potential revenue per hectare, denoted in €/ha, was determined based on the projected quantities of CO_2e sequestered for each crop.

The results highlight variations in economic potential among the crops analyzed, with values ranging from €80.29/ha (corn) to €145.96/ha (rapeseed), with an average of €111.05/ha. Rapeseed has the highest economic potential, followed by sunflower (€130.77/ha), with both exceeding the analyzed average. In contrast, wheat (€87.16/ha) and corn have values below the average.

CONCLUSIONS

The carbon credit market around the world has big price differences. For example, in South Korea, a credit costs €6.45, while in the European Union, it costs €61.17. These differences are due to the different rules, the age of the markets, and the climate policies that are in place. In Romania, the value of a carbon credit is estimated to be €65 per credit. This is higher than the average level in the European Union, which suggests that Romania is in line with European trends and has the potential to compete in the carbon market.

For the sample analyzed, the average revenue per hectare from the sale of credits is €111.05. From this gross revenue, the farmer pays between 15–20% of the certificate price for carbon credit validation.

Farmers can choose from various carbon credit validation technologies depending on the service provider and the MRV technology (satellite, AI, soil analysis, etc.)

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ASSESSING THE SUPPORT NEEDS OF FARMERS IN PERI-URBAN AREAS: EVIDENCE FROM ILFOV COUNTY, ROMANIA

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Abstract

The agricultural sector in Ilfov County is characterised by a high degree of structural heterogeneity, ranging from small subsistence farms to large commercial farms operating under increasing economic and institutional pressure. In this context, the paper aims to identify the main support needs of farmers from peri-urban areas. The research is based on semi-structured interviews conducted at the level of 44 farms in 9 localities in Ilfov County. The dataset includes information on farm location, type of production, agricultural areas used, farm size category, market integration, access to advisory services, training programmes, public subsidies, financial support instruments and perceived price constraints. Using a descriptive and exploratory approach, the study analyses farmers' needs according to farm typology and territorial distribution. The results highlight disparities between communes in the north and south of the county and by farm size categories. Small and semi-subsistence farms mainly require financial support, market access and professional training. Larger farms emphasize advisory services, managerial support and legislative clarity. The study thus provides empirical evidence on the real support needs of farmers in peri-urban areas of Ilfov County.

Key words**:** *farmers, support needs, peri-urban agriculture, farm typology, Ilfov County*

INTRODUCTION

Agriculture in peri-urban areas presents specific challenges, such as increasing pressure from urban expansion [2], difficulties in market integration [1] [11], and environmental constraints [12[[13]. Farms located near large urban centers combine opportunities related to market proximity with challenges such as land fragmentation, higher input costs and the need to adapt to rapidly changing demand structures [8].

In Romania, peri-urban agricultural areas play an important role in ensuring the food supply of nearby cities [10]. However, these areas do not display a uniform development pattern and still lack modern organizational forms for product valorisation, such as cooperatives or producer associations [9]. The structure of farms is highly heterogeneous, ranging from small subsistence and semi-subsistence farms to large commercial holdings [7]. This diversity generates different needs at the farm level and influences the type of support required by farmers.

The complex agricultural framework of Ilfov County, located in the immediate vicinity of Bucharest, makes it a relevant case study for analyzing these dynamics. The coexistence of small farms, semi-subsistence holdings and large commercial farms creates a diverse production landscape that generates different types of constraints and development opportunities. Despite its proximity to an important urban market, farms in the county face difficulties related to market access, access to financial resources, participation in training activities and compliance with legislative requirements.

Previous research has emphasized that access to information, financial resources and institutional support strongly influences the development of the agricultural sector [5] [14]. Small and medium-sized farms often encounter difficulties in accessing markets and investment resources, while larger farms

require specialized advisory services, management support and clearer regulatory frameworks [4] [6] [3]. Understanding these differentiated needs is essential for improving the functioning of agricultural systems, especially in peri-urban areas where competition for land and resources is more intense. In this context, the present study aims to assess the main support needs of farmers operating in the peri-urban areas of Ilfov County. The research seeks to identify differences in needs according to farm size and territorial location. By using an exploratory approach based on farm-level data, the paper aims to provide a clearer understanding of the structural constraints and support priorities of farms in this heterogeneous agricultural environment.

The results contribute to a better understanding of the diversity of support needs among farms operating in peri-urban areas and highlight the importance of considering farm size and territorial context when analyzing agricultural development challenges.

MATERIALS AND METHODS

The research is based on a field study conducted in 2025 on 44 farms located in nine rural localities in Ilfov County (1 Decembrie, Măgurele, Gruiu, Nuci, Dărăști, Afumați, Moara Vlăsiei, Copăceni and Brănești) (Fig. 1). The farms interviewed present a heterogeneous structure in terms of size, production profiles and degree of market integration.

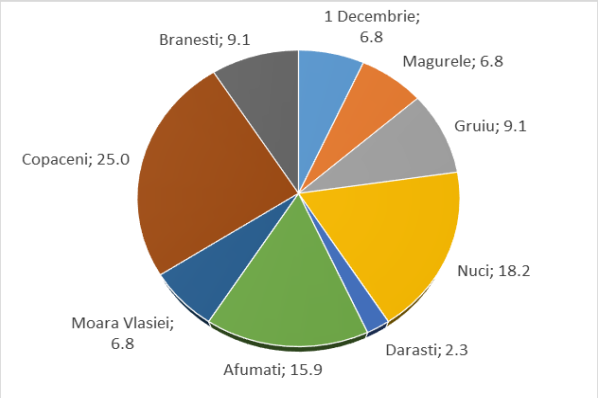

Fig.1. Distribution of farms by villages (%)
Source: own processing.

Data were collected through semi-structured interviews with farm owners or managers. The questionnaire included information on farm characteristics (type of production, utilised agricultural area, size category), access to markets, participation in training programmes, access to subsidies and financial instruments, as well as perceived constraints and support needs.

The analysis follows a descriptive and exploratory approach. Farms were grouped according to territorial location (north vs. south of the county) and size categories. The results are presented using percentage distributions and comparative analysis across farm typologies. This approach allows the identification of differentiated support needs and structural disparities within the peri-urban agricultural system.

RESULTS AND DISCUSSIONS

The results highlight the structural heterogeneity of farms in Ilfov County and the differentiated support needs expressed by farmers. The analysis is structured according to territorial location, farm size and categories of needs to better understand the main constraints faced by farms in the study area.

Farm characteristics and territorial differences

The spatial distribution of agricultural production highlights structural differences between the northern and southern parts of Ilfov County. Farms located in the southern area are predominantly specialised in crop production (especially vegetables), while in the northern area, both crop farms and mixed farms (80.8%) and mixed farms (cattle breeding and beekeeping) (19.2%) (Fig. 2). This indicates a higher level of diversification in the northern localities, while in the southern area we find a clear agricultural specialization.

Differences also appear in the distribution of farm sizes. Farms located in the northern part of the county are predominantly very large (57.7%), while subsistence farms account for 19.2% (Fig. 3).

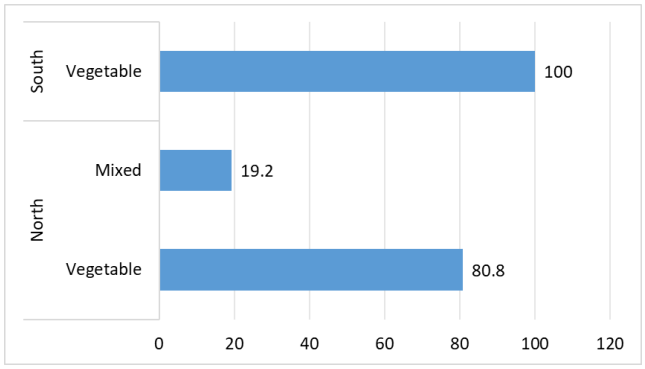

Fig. 2. Type of farm production by location (%)
Source: own processing.

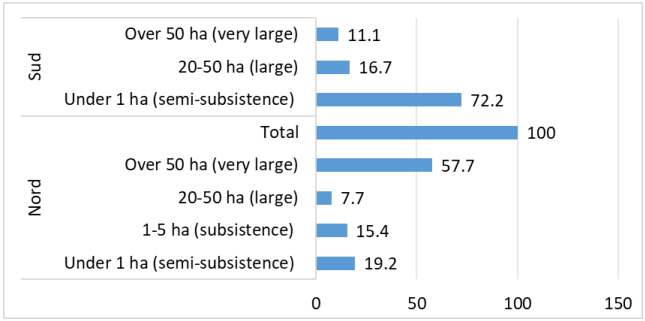

Fig. 3. Distribution on the farms by size and location (%)
Source: own processing.

Farms with sizes between 20 and 50 hectares' account for only 7.7%. In contrast, the southern area is dominated by semi-subsistence farms (72.2%), while very large farms account for only 11.1%. Medium-sized farms (20-50 ha) account for 16.7%. These findings reveal a dual agricultural structure at the county level, with large commercial farms concentrated in the north and small farms predominantly in the south.

Main support areas

Across the entire sample, the most frequently mentioned support area is that of advisory and consultancy services (36.7%), followed by access to markets (22.4%) and financial support and subsidies (22.4%).

Figure 4 shows a less frequent mention of legislative support (12.2%) and managerial support (6.1%).

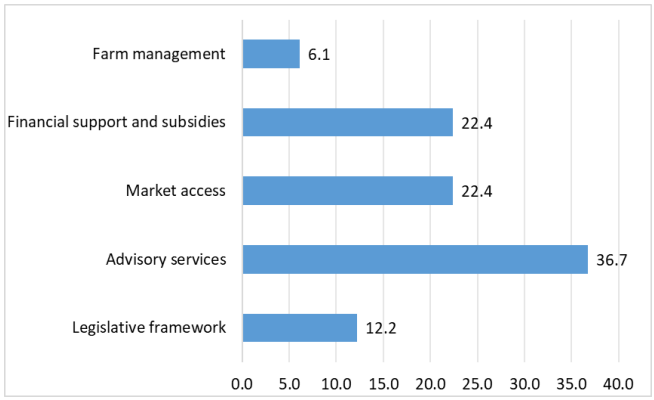

Fig. 4. Main support areas identified by farms (%)
Source: own processing.

The territorial analysis presented in Table 1 highlights significant differences between the communes located in the north and south of Ilfov County. Farms located in the south mainly request support related to subsidies and financial instruments (31.8%), access to

markets (27.3%), legislative aspects (22.7%) and managerial support (13.6%). In contrast, farms in the north emphasise the importance of advisory and consultancy services (63%), followed by market access (18.5%) and financial support (14.8%) (Table 1).

Table 1. Main support areas by territorial location (%)

	Gruiu	Nuci	Afumați	Moara Vlăsiei	Brănești	North Total	01.dec	Copăceni	Dărăști	Măgurele	South Total
Legistlative framework		12.5				3.7	60.0	7.7		33.3	22.7
Advisory services	50.0	37.5	71.4	100.0	80.0	63.0		7.7			4.5
Market access	25.0	25.0	14.3		20.0	18.5	20.0	38.5			27.3
Financial support and subsidies	25.0	25.0	14.3			14.8	20.0	46.2			31.8
Farm management									100.0	66.7	13.6

Source: own processing.

The analysis by farm size (Table 2) highlights important differences in the type of support needed. Semi-subsistence farms mainly require financial support and support for facilitating market access, these two areas account for approximately 73% of the responses. Subsistence farms particularly identify the need for specialist advice (75%). Large farms mention that they mainly need support for farm management (60%), as well as specialist advice for developing economic activities (40%).

Table 2. Main support areas by farm size (%)

	Under 1 ha (semi-subsistence)	1-5 ha (subsistence)	20-50 ha (big)	Over 50 ha (very big)
Legistlative framework	13.6			16.7
Advisory services	13.6	75.0	40.0	55.6
Market access	36.4	25.0		11.1
Financial support and subsidies	36.4			16.7
Farm management			60.0	

Source: own processing.

Very large farms place particular emphasis on technical advice (55.6%), also mentioning the need for improvements in the legislative framework and financial support (approximately 33%). Overall, specialist advice services and facilitating market access are the areas of support most frequently requested across all farm categories.

These results suggest that smaller farms are more dependent on financial support and market integration measures, while larger farms require specialised advice and guidance on field regulations.

Categories of needs

Across the sample, training and education are the most important category of needs (36.5%), followed by facilitating access to markets (19.2%), minimis support (15.4%), professional farm management (11.6%) and financial support for development (9.6%) (Table 3).

Table 3. Main categories of needs (%)

	%
Financial support for farm development	7.7
Training and education	36.5
Market access	19.2
Financial support (like subsidies)	9.6
Minimis support scheme	15.4
Professional farm management	11.6

Source: own processing.

The territorial analysis presented in Table 4 again highlights clear differences between the northern and southern areas.

Farms in the northern part of Ilfov County consider training and education to be the most important need (54.8%), followed by financial support (16.1%) and market access (12.9%). In the southern area, farmers mainly express the need for minimis support scheme (38.1%), followed by market access (28.6%), professional management (14.3%) and financial support for development (9.5%). The

territorial context strongly differentiates support needs, as these results confirm.

Table 4. Main categories of needs by territorial location (%)

	Gruiu	Nuci	Afumați	Moara Vlăsiei	Brănești	North Total	01.dec	Copăceni	Dărăști	Măgurele	South Total
Financial support for farm development	25.0	10.0				6.5	25.0	7.7			9.5
Training and education	50.0	30.0	55.6	100.0	80.0	54.8		7.7		33.3	9.5
Market access		20.0	11.0		20.0	12.9	25.0	38.5			28.6
Financial support (like subsidies)	25.0	30.0	11.1			16.1					
Minimis support scheme							50.0	46.2			38.1
Professional farm management		10.0	22.2			1.7			100.0	66.7	14.3

Source: own processing.

Categories of needs by farm size

The analysis by farm size, presented in Table 5, confirms the differentiated nature of farmers' needs. Semi-subsistence farms require support in three main directions: financial support through the minimis support scheme (36.4%), assistance to facilitate market access (31.8%) and financial support for farm development (13.6%). Subsistence farms indicate, with the increase in farm size, a greater need for skill development through participation in specialised courses (75%), as well as the need for support in capitalising on production in the market (25%). Large farms, already at a higher level of competitiveness, mainly highlight the need for more professional management at the farm level (66.7%), but also the interest in accessing training and education programmes (33.3%).

Table 5. Main categories of needs by farm size (%)

	Under 1 ha (semi-subsistence)	1-5 ha (subsistence)	20-50 ha (big)	Over 50 ha (very big)
Financial support for farm development	13.6			5.0
Training and education	13.6	75.0	33.3	55.0
Market access	31.8	25.0		10.0
Financial support (like subsidies)	4.5			20.0
Minimis support scheme	36.4			
Professional farm management			66.7	10.0

Source: own processing

Very large farms indicate as their main needs participation in training programmes in emerging areas such as climate change, digitalisation or the use of modern technologies (55%), as well as access to financial support for investments (20%).

These results highlight the differentiated nature of farmers' needs depending on the size of the holding. Small farms are more dependent on financial support and facilitating access to markets, while large and very large farms show a greater need for advisory services, professional management and access to specialised knowledge.

Implications for farmers

The research results highlight the need for differentiated adaptation strategies at the level of agricultural holdings in peri-urban systems, especially in the context of pressures generated by the proximity of large urban centers and market dynamics. In the case of farms in Ilfov County, under the direct influence of the Bucharest market, strategic adaptation becomes an essential factor for medium and long-term economic sustainability.

For small-sized holdings, characterized by a high dependence on financial support and market access, it is recommended:

-strengthening associative forms, in order to increase bargaining power and reduce transaction costs;

-orientation towards short supply chains and capitalizing on the advantage of proximity to

the urban consumer;
-diversifying production and increasing added value, through primary processing or specific certifications (e.g. local, organic products);
-improving financial management skills, including cost monitoring and product profitability analysis.
These measures can contribute to reducing economic vulnerability and increasing decision-making autonomy.
Medium-sized farms, in a consolidation phase, can benefit from:
-professionalization of management, through the use of strategic planning and financial control tools;
-partial integration in the value chain, through investments in storage, packaging or processing;
-digitization of production and management processes, to optimize the use of inputs;
-diversification of marketing channels, in order to reduce the risks associated with dependence on a single trading partner.
These directions can facilitate the transition to more stable and competitive business models.
In the case of large-scale farms, where the main need is for advisory services and advanced management, it is recommended to:
-develop medium- and long-term development strategies based on clearly defined performance indicators;
-invest in human capital, through continuous training and attracting specialists;
-adopt innovative technologies, including precision agriculture and energy efficiency solutions;
-implement risk management mechanisms, such as agricultural insurance and crop diversification.
These measures can increase the resilience of farms to market volatility and structural changes in the peri-urban area.

CONCLUSIONS

The study highlights the heterogeneous structure of farms operating in the peri-urban area of Ilfov County and confirms the differentiated nature of farmers' support needs depending on farm size and territorial location. The coexistence of small- and semi-subsistence farms with large commercial holdings generates distinct priorities in terms of financial support, access to knowledge, management practices, and interactions with institutional frameworks.
Small and semi-subsistence farms are more dependent on financial support and on measures facilitating access to markets. These farms frequently mention the need for financial resources to sustain production and support business development, particularly in the vegetable sector. For this category, access to subsidies, financial aid, and support programs is an essential condition for maintaining activity and ensuring economic viability.
Medium and large farms express a stronger interest in improving managerial and technical competencies. Modern agricultural practices such as regenerative agriculture, climate change adaptation, financial planning, and the use of resistant crop varieties are the focus of training needs. Mixed farms also highlight the need for specialized knowledge related to animal nutrition, soil testing, and pest control, especially in light of regulatory restrictions on certain inputs.
Larger farms additionally highlight the importance of support for project implementation and access to updated technical information. At the same time, large farms underline the relevance of the legislative framework and institutional interaction. Farmers cite the need for clearer eligibility conditions for support programs; faster administrative procedures, timely payments, and improved communication regarding legislative changes.
People also are becoming more interested in modern farm management practices in all types of farms. Farmers stress the importance of crop rotation, using adapted varieties, managing risk through crop insurance, and better planning of production activities. These trends indicate a growing emphasis on professionalisation and adaptability to economic and weather fluctuations. The adaptation of farmers in peri-urban farming systems cannot be uniform, but must be calibrated according to farm size, production profile and territorial positioning. Proactive

strategies adopted at farm level can significantly contribute to increasing the competitiveness and strengthening the sustainability of the agricultural sector in peri-urban areas.

Overall, the findings confirm that support needs differ significantly according to farm size, production profiles, and territorial context. Smaller farms are more dependent on financial support and market access, while large farms have a greater need for advisory services, training and management-related knowledge. The findings offer empirical evidence regarding the varied needs of farms within peri-urban agricultural systems and enhance the understanding of the challenges encountered by farmers in Ilfov County.

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INEQUALITIES IN ACCESS TO HEALTH SERVICES BETWEEN RURAL AND URBAN ENVIRONMENTS IN THE EU AND IMPLICATIONS ON SUSTAINABLE DEVELOPMENT

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Abstract

The study examines the disparities in healthcare service access between rural and urban regions in a few EU member states and their effects on population health. In a sample of 10 European nations, the primary goal of the study was to demonstrate the connection between perceived health status and access to healthcare services, as shown by the degree of unmet medical requirements. The approach employed was based on a comparative examination of statistical data from Eurostat for the years 2016–2024, which were organized depending on the level of urbanization. Descriptive statistical methods were used in the analysis, such as arithmetic mean and rural–urban gap analysis, as well as tools for analysing the relationships between indicators, including the correlation coefficient. The results obtained highlight the existence of significant differences between urban and rural areas, both in terms of perceived health status and the level of unmet medical needs. Northern and Western European countries have high health status values and low levels of unmet needs, while Central and Eastern European countries have lower health indicators but show a trend of convergence. The analysis of rural-urban disparities highlights the fact that the rural population faces persistent disadvantages, reflected in the levels of unmet medical needs and, in some cases, in lower values of perceived health status. The conclusions of the study show that access to medical services directly influences the health status of the population, but is not the only determining factor, and it is necessary to take into account socio-economic factors and living conditions. Reducing inequalities between rural and urban areas requires integrated public policies, aimed at improving access to medical services and increasing the quality of life of the population, thus contributing to achieving the sustainable development objectives existing at European level.

Key words: *health inequalities, access to healthcare services, rural-urban disparities, perceived health status, unmet medical needs, European Union, sustainable development*

INTRODUCTION

Due to their direct influence on social cohesion and sustainable development at the European Union level, it is crucial to analyze health service access disparities between rural and urban regions. Equitable access to health services is recognised as an essential element of the population's well-being, but also a fundamental condition for achieving the sustainable development objectives, in particular in terms of reducing inequalities and ensuring a healthy life for all. In this context, the disparities between rural and urban areas reflect structural imbalances that affect not only the health status of the population, but also economic productivity, social inclusion and the sustainability of health systems. Therefore, understanding these differences and the factors that determine them is an important element for the development of effective public policies, capable of reducing inequalities and supporting the balanced development of European regions.

The literature extensively addresses the issue of health inequalities, highlighting the existence of persistent differences both between European Union Member States and between various socio-demographic

categories [5, 20, 21]. These differences are explained by the influence of social determinants of health, such as income level, education and living conditions, as well as by variations in the organization and performance of health systems [1, 2, 4, 25]. In this context, recent research pays particular attention to the contrast between urban and rural environments, highlighting the role of differential access to health services in explaining variations in the health status of the population.

According to other research, a group of variables known as the social determinants of health such as living circumstances, education, and income determine the population's health. [7, 8, 10, 29]. In this context, differences between urban and rural areas become particularly relevant, since populations in rural areas frequently face limited access to health services and a higher incidence of health problems [6, 16, 27].

Access to health services is related to a key determinant of health, but the literature highlights that it is not sufficient to explain the differences recorded between populations [9, 15, 19]. Even in conditions of similar access, health outcomes can vary significantly, depending on the efficiency of health systems and their organization [18, 24, 28].

Comparative studies at European level show that health inequalities are influenced by both the characteristics of health systems and the social policies adopted in each country. [3, 11, 17]. In this context, the differences between urban and rural areas reflect not only the differential access to health services, but also distinct living conditions, which directly influence the health status of the population [23, 26].

The importance of the topic addressed derives from the need to reduce these inequalities, given that they affect both the quality of life of the population and the sustainability of health systems [5, 22]. The specialized literature emphasizes that reducing health disparities requires an integrated approach, which includes both improving access to health services and interventions on social determinants [4, 20].

In this context, the main objective of the paper is to analyze the relationship between perceived health status and access to health services, expressed by the level of unmet medical needs, in selected European Union member states. At the same time, the paper aims to highlight the differences between urban and rural areas and identify trends during the analyzed period.

By including a comparative perspective and employing pertinent indicators for the concurrent evaluation of health status and access to medical care, the study strategy adds to the specialist literature and presents a cohesive picture of the current disparities in the European area.

MATERIALS AND METHODS

The data used in the analysis come from the Eurostat database, being selected in such a way as to allow the assessment of the perceived health status and access to medical services according to the degree of urbanization. The analyzed indicators were expressed as percentages and allowed comparisons to be made between urban and rural areas, as well as between the Member States of the European Union. The analysis was carried out for the period 2016–2024, which allowed the highlighting of developments over time and the identification of trends.

The sample of analyzed states was constructed using multi-criteria selection, which had the role of ensuring the representativeness and relevance of the analysis at the level of the European Union, the criteria used being the following:

– the geographical criterion, which aimed at the inclusion of states from the main regions of the European Union (Northern, Western, Southern and Eastern Europe);

– the criterion of the level of economic development, which allowed the inclusion of both developed states and those in the process of convergence;

– the relevance criterion for the analysis of rural-urban disparities, by selecting states in which there are significant variations in the analyzed indicators.

Based on these criteria, ten European Union member states were selected, representative of the economic and social diversity of the European space, these being: Denmark, Germany, Spain, France, Italy, Hungary, Netherlands, Poland, Portugal, Sweden.

The analysis followed two main indicators:

– the percentage of the population that reports having very excellent or good health is known as perceived health status;

– the percentage of the population that did not receive medical care because of expenses, travel time, or waiting times is known as unmet medical needs.

These indicators allowed us to simultaneously evaluate the results of the health system and access to medical services.

In order to process and analyze the data, descriptive and comparative statistical methods were used, as well as synthetic indicators, as follows:

– *arithmetic mean, calculated according to the relationship*:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad \text{.....(1)}$$

where:

x – arithmetic mean of the analyzed indicator;

x_i – the indicator value for each state;

n – number of states included in the analysis.

– *standard deviation, used to measure the dispersion of values*:

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad \text{.....(2)}$$

where:

s – the standard deviation;

x_i – individual value of the indicator;

$\bar{x}$– arithmetic mean;

n– the number of observations;

$(x_i - \bar{x})$ – the deviation of each value from the mean;

Σ– sum of squared deviations.

– *the coefficient of variation, which expresses the relative stability of the indicators*:

$$CV = \frac{s}{\bar{x}} \times 100 \quad \text{.....(3)}$$

where:

CV – coefficient of variation (%);

s – the standard deviation;

$\bar{x}$– arithmetic mean;

– *Pearson correlation coefficient, used to assess the relationship between perceived health status and unmet medical needs*:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \quad \text{.....(4)}$$

where:

r – Pearson correlation coefficient;

x_i – values of the independent variable (unmet medical needs);

y_i – values of the dependent variable (perceived health status);

x,y - the averages of the two variables;

$(x_i - x)$, $(y_i - y)$ - deviations from the average.

– *rural–urban gap*, calculated as:

$$D = V_{rural} - V_{urban} \quad \text{.....(5)}$$

where:

D– the difference between rural and urban areas;

V_{rural}– the value of the indicator in rural areas;

V_{urban}– the value of the indicator in the urban environment.

These methods allowed both the analysis of developments over time and the identification of relationships between indicators and territorial differences.

RESULTS AND DISCUSSIONS

The analysis carried out in this research targeted the population of the Member States of the European Union and used indicators relating to the perceived health status and access to medical services, based on Eurostat data. In this context, the evolution of these indicators during the period 2016–2024 was monitored, as well as the differences recorded between the urban and rural areas.

The information in Table 1 illustrates some broad trends in the evolution of perceived health status in metropolitan settings across the nations examined. First, we can see that nations in Northern and Western Europe have high and comparatively steady levels of perceived health status, which reflects the efficiency of health systems and the high level of quality of life in these countries, such as Sweden and Denmark, where the indicator values are constantly maintained at a high

level throughout the analyzed period, or Germany and the Netherlands, characterized by a relative stability of the perception of health status. Second, we can note a trend of slight deterioration in the perception of health status in the recent period, especially after 2020, a phenomenon that is due to the impact of the global health crisis and the pressure it exerts on health systems.

Table 1. Evolution of perceived health status in urban areas in the EU in the period 2016–2024 (% population with good or very good health)

Country	2016	2017	2018	2019	2020	2021	2022	2023	2024
Denmark	74.7	77.4	75.3	75	76.1	71.5	67.3	66.3	72.6
Germany	66.3	66.7	65.9	66.3	66.1	65.8	66.5	67.2	66.7
Spain	73.7	75.3	74.8	76.0	74.9	72	71.4	71.1	70.6
France	68.9	70.2	69.8	69.4	70.6	69.6	68.0	67.5	69.7
Italy	72.0	77.3	74.4	72.7	**	73.3	74.4	74.2	74.6
Hungary	63.6	63.2	64	60.1	64.4	67.9	66.5	68.6	68.9
Netherlands	74.4	74.7	74.8	73.5	77.8	73.3	70.4	68	68.9
Poland	60.9	61.9	61.7	62.3	63.3	66	62.8	63.2	64.4
Portugal	51.5	51.5	53	53.1	55.2	54.9	53.5	54.6	58.2
Sweden	75.5	79.1	78.2	78.8	79.4	75.6	69.1	70.6	70.9

Source: own processing, Eurostat [12].

Also, Central and Eastern European countries record lower levels of perceived health status, but show a gradual convergence trend towards the values recorded in more developed countries, suggesting improvements in living conditions and access to medical services, such as the case of Poland and Hungary, where an upward trend in the indicator is observed during the analyzed period, as well as Portugal, which, although starting from lower values, has recorded a gradual improvement in recent years.

As a result, we can see both the persistence of state-to-state disparities and shared tendencies at the European Union level, which are marked by relative long-term stability and mild volatility during times of crisis.

Table 2. Evolution of perceived health status in rural areas in EU, in the period 2016–2024 (% population with good or very good health)

Country	2016	2017	2018	2019	2020	2021	2022	2023	2024
Denmark	69.5	66.7	68.9	65.5	66.3	62.7	58.9	61.3	62.8
Germany	64.2	64.2	64.3	63.8	61.8	60.5	62.3	64.7	62.7
Spain	69.2	71.1	69.8	72.4	69.6	67.5	66.2	66.7	67.6
France	64.7	65.2	65.6	63.7	67.8	67.4	64.0	63.7	64.9
Italy	68.9	75.6	71.2	71.0	**	72.1	72.5	72.7	76.2
Hungary	56.2	57.3	57.6	56.5	58.7	61.3	59.8	61.2	61.8
Netherlands	79.4	77.3	78.2	78.4	80.4	72.8	73	69.8	69.7
Poland	57.1	56.5	57.7	58.2	60.7	62.8	62.4	62.2	64.4
Portugal	39.4	40.6	41.9	42.9	42.5	41.8	40.1	42.6	44.8
Sweden	73.7	72.5	73.2	72.8	74.3	67.5	63	62.7	61.2

Sursa: Source: own processing, Eurostat [12].

The information in Table 2 shows how perceived health status has changed over time in rural regions of the nations under study, with more noticeable variations than in urban areas. First, it is noted that the level of perceived health status is generally lower in rural areas, which reflects more limited access to medical services and less favorable living

conditions. Also, in the countries of Northern and Western Europe, relatively high values are maintained, but they are lower than those recorded in urban areas, such as the case of Sweden and Denmark, where, although the level of the indicator remains high, a slight decrease is observed over time, as well as the Netherlands, where the downward trend is more evident in recent years.

Central and Eastern European countries record lower levels of perceived health status in rural areas, but show a trend of gradual improvement, an aspect highlighted by Poland and Hungary, where an upward trend in the indicator is observed, but also by Portugal, which, although starting from low values, has recorded a gradual recovery in recent years.

At the same time, the evolution of the indicator shows the existence of some fluctuations in the recent period, especially in the context of the years 2020–2022, which is due to the pressures exerted on the health systems and the impact of external factors on the rural population. There are structural elements that affect the quality of life and access to health care in rural regions, as evidenced by the greater variety in reported health status and the persistence of state-to-state disparities. The observed differences are also correlated with the higher prevalence of long-term health problems in certain states, highlighted in Eurostat data [13], which helps to explain the lower levels of perceived health status.

Table 3. Differences between rural and urban areas in terms of perceived health status in EU countries in the period 2016–2024 (%)

Country	2016	2017	2018	2019	2020	2021	2022	2023	2024
Denmark	-5.2	-10.7	-6.4	-9.5	-9.8	-8.8	-8.4	-5.0	-9.8
Germany	-2.1	-2.5	-1.6	-2.5	-4.3	-5.3	-4.2	-2.5	-4.0
Spain	-4.5	-4.2	-5.0	-3.6	-5.3	-4.5	-5.2	-4.4	-3.0
France	-4.2	-5.0	-4.2	-5.7	-2.8	-2.2	-4.0	-3.8	-4.8
Italy	-3.1	-1.7	-3.2	-1.7	**	-1.2	-1.9	-1.5	1.6
Hungary	-7.4	-5.9	-6.4	-3.6	-5.7	-6.6	-6.7	-7.4	-7.1
Netherlands	5.0	2.6	3.4	4.9	2.6	-0.5	2.6	1.8	0.8
Poland	-3.8	-5.4	-4.0	-4.1	-2.6	-3.2	-0.4	-1.0	0
Portugal	-12.1	-10.9	-11.1	-10.2	-12.7	-13.1	-13.4	-12	-13.4
Sweden	-1.8	-6.6	-5.0	-6.0	-5.1	-8.1	-6.1	-7.9	-9.7

Sursa: own processing, Eurostat [12].

Table 3 allowed us to directly assess the differences between rural and urban areas in terms of perceived health status, highlighting both the intensity and persistence of these gaps in the analyzed countries. The existence of distinct patterns between countries is observed. Thus, a first group is formed by countries characterized by small and relatively stable differences over time, such as Germany or the Netherlands, which indicates a high degree of balance in the distribution of medical services between urban and rural areas. A second group includes countries in which the differences are moderate but persistent, such as Spain or France, where the gaps are maintained throughout the analyzed period, suggesting the existence of structural imbalances. On the other hand, countries such as Portugal or Hungary are distinguished by large and constant differences between rural and urban areas, as a result of lower access to medical services in rural areas and a lower capacity to compensate for these disparities. Additionally, due to the trend of convergence between rural and urban regions, certain nations, like Poland, have seen a tendency in recent years to lessen these distinctions. As a result, disparities between rural and urban areas are noted; these disparities are not consistent across the European Union and are contingent upon the degree of development and the effectiveness of national health systems.

To highlight the size and stability of the differences between rural and urban areas, we calculated the average of the gaps for each

country analyzed, the results indicating that countries such as Portugal and Hungary record the highest average differences, while Germany and the Netherlands have values close to zero, due to the high level of equilibrium.

Also, the analysis of the variability of these differences highlights the fact that in some countries the gaps are relatively stable over time, while in others more pronounced fluctuations are observed, due to the less uniform evolution of access to health services.

Table 4. Statistical analysis of health disparities between rural and urban areas in the EU, 2016–2024

Country	2016	2017	2018	2019	2020	2021	2022	2023	2024
Denmark	1.5	0.9	1.6	1.9	2.2	1.6	2.4	3.1	3.0
Germany	0.3	0.3	0.2	0.6	0.1	0.1	0.3	0.3	0.9
Spain	0.4	0.2	0.2	0.2	0.6	1.1	1.4	1.9	2.0
France	1.4	0.9	1.4	1.4	2.7	3.0	3.5	3.4	4.0
Italy	5.5	2.0	2.4	2.0	**	2.0	2.0	1.8	2.1
Hungary	1.7	1.2	1.0	1.8	1.4	1.6	2.7	1.5	1.2
Netherlands	0.2	0.1	0.3	0.2	0.2	0.3	0.3	0.4	0.8
Poland	7.8	3.7	4.6	4.8	2.2	2.8	3.0	4.4	3.7
Romania	5.0	3.2	4.3	3.6	3.7	3.2	4.1	4.8	1.8
Sweden	1.9	1.8	1.6	1.5	1.6	1.5	1.9	2.3	2.6

Sursa: own processing, Eurostat [12].

The accessibility of medical services in urban areas was analyzed through the share of the population that did not benefit from medical services due to barriers such as costs, distance or waiting time, based on the data in Table 4. Significant differences are observed between the analyzed countries in terms of the capacity of health systems to meet the needs of the population. There are countries in which the level of unmet medical needs remains low and relatively constant, such as Germany or the Netherlands, which indicates an efficient and accessible health system for the urban population. Other countries, such as France or Poland, are faced with higher levels of this indicator, due to the existence of dysfunctions in access to medical services even in urban areas. Also, the evolution of the indicator demonstrates the existence of a recent upward trend in several analyzed countries, due to the increasing pressure on health systems, especially in the context of external factors that have affected the capacity to provide medical services. At the same time, in some countries there is a trend towards a reduction in unmet medical needs after the peak period, as a result of the gradual adaptation of health systems and improved access to medical services. Although urban areas generally benefit from better access to medical services, there are still differences between countries, determined by the efficiency of health systems and their capacity to respond to the needs of the population.

The increased vulnerability of rural areas in terms of access to health services is measured by higher levels of unmet medical needs (Table 6). Compared to urban areas, the values recorded in rural areas indicate the existence of persistent structural barriers, generated by factors such as the reduced accessibility of medical infrastructure and the limited availability of specialized services.

Significant differences are observed between countries, depending on the capacity of health systems to cover the territory evenly. Because health services are well integrated at the territorial level, unmet medical needs are minimal even in rural regions in nations like Germany and the Netherlands. In contrast, in countries such as Romania or Poland, higher levels of this indicator are observed, highlighting persistent difficulties in ensuring equitable access to health services for the rural population. France has also recorded increasing values in recent times, due to the intensification of pressure on the health system in rural areas.

Table 6. Evolution of unmet medical needs in rural areas in the EU in the period 2016–2024 (% population)

Country	2016	2017	2018	2019	2020	2021	2022	2023	2024
Denmark	1.2	1	1.1	1.8	1.1	0.9	1.7	2.3	4.0
Germany	0.2	0.2	0.2	0.1	0.2	0	0.1	0.1	0.6
Spain	0.7	0.1	0.1	0.1	0.2	0.9	0.9	1.5	1.6
France	1.1	1.1	1.1	0.9	2.3	2.4	3.0	3.7	4.3
Italy	5.8	1.8	2.5	1.9	**	2	1.6	2.6	1.9
Hungary	1.4	0.8	0.5	0.4	0.4	0.8	0.3	0.7	0.4
Netherlands	0.1	0.1	0	0	0	0	0.1	0.1	0
Poland	5.5	2.7	4.0	3.3	1.5	2.7	1.9	3.2	3.6
Romania	8.1	6.0	5.1	5.4	5.7	5.8	5.4	5.9	2.6
Sweden	1.2	0.7	0.6	1.1	1.5	1.0	1.8	1.5	1.6

Sursa: own processing, Eurostat [14].

The evolution of the indicator also shows the existence of fluctuations over time, highlighting the sensitivity of the rural environment to changes in the health system and to external factors that affect the availability of medical services.

Thus, the rural environment remains more exposed to the risk of exclusion from the health system, and the differences between states are largely determined by the level of development and the efficiency of public policies in the field of health.

Table 7. Rural and urban differences in unmet medical needs in the EU, 2016–2024 (%)

Country	2016	2017	2018	2019	2020	2021	2022	2023	2024
Denmark	-0.3	0.1	-0.5	-0.1	-1.1	-0.7	-0.7	-0.8	1.0
Germany	-0.1	-0.1	0	-0.5	0.1	-0.1	-0.2	-0.2	-0.3
Spain	0.3	-0.1	-0.1	-0.1	-0.4	-0.2	-0.5	-0.4	-0.4
France	-0.3	0.2	-0.3	-0.5	-0.4	-0.6	-0.5	0.3	0.3
Italy	0.3	-0.2	0.1	-0.1	**	0	-0.4	0.8	-0.2
Hungary	-0.3	-0.4	-0.5	-1.4	-1.0	-0.8	-2.4	-0.8	-0.8
Netherlands	-0.1	0	-0.3	-0.2	-0.2	-0.3	-0.2	-0.3	-0.8
Poland	-2.3	-1.0	-0.6	-1.5	-0.7	-0.1	-1.1	-1.2	-0.1
Romania	3.1	2.8	0.8	1.8	2.0	2.6	1.3	1.1	0.8
Sweden	-0.7	-1.1	-1.0	-0.4	-0.1	-0.5	-0.1	-0.8	-1.0

Sursa: own processing, Eurostat [12, 14].

The disparities in unmet medical requirements between rural and urban regions are clearly shown by the statistics in Table 7. Access to medical services is not evenly distributed among the nations under study; rather, it reflects the unique characteristics of national health systems and territorial development. There is a high degree of fairness in access to medical care in certain nations, including Germany and the Netherlands, where the inequalities between rural and urban regions are negligible and mostly consistent across time. In contrast, in other countries, the differences are more pronounced, highlighting the existence of persistent territorial imbalances. A relevant case is represented by Romania, where positive values of the differences indicate a higher level of unmet medical needs in rural areas, due to the difficulties related to ensuring uniform access to medical services. Poland also highlights differences in favor of the urban area, but with a tendency to decrease in recent years, as a result of improved access to services in these areas. At the same time, in some countries variations in the differences are observed over the analyzed period, due to the dynamics of access to medical services that are influenced by economic and institutional factors.

The existence of rural-urban inequalities in access to medical services is observed, but their size and evolution differ between countries, highlighting the determining role of public policies and the organization of health systems.

Table 8. Correlation between perceived health status and unmet medical needs in the EU, in 2024

Variables analyzed	Pearson Coeficient
Unmet medical demands and perceived health condition in cities	0.43
Unmet medical demands and perceived health condition in remote regions	-0.35
Disparities in unmet medical requirements and perceived health status between rural and urban areas	-0.52

Sursa: own processing, Eurostat [12, 14].

To highlight the complexity of the relationship between perceived health status and access to medical services, the correlation analysis was extended to several dimensions, the results indicating the existence of different relationships depending on the area of residence (Table 8). Thus, in urban areas, a moderate positive correlation is observed, due to the influence of additional factors on health status. In contrast, in rural areas, the relationship becomes negative, as a result of the higher level of unmet medical needs which is associated with a lower perceived health status. Also, the analysis of rural-urban differences highlights a more pronounced negative correlation, confirming the fact that inequalities in access to medical services directly influence the health status of the population.

Table 9. Descriptive statistical indicators of perceived health status and unmet medical needs in the EU, in 2024

Indicator	Average	Minimum	Maximum	Standard deviation	Coefficient of variation (%)
Perceived state of health	68.55	58.2	74.6	4.62	6.74
Unfulfilled medical requirements	2.03	0	4.0	1.31	64.73

Sursa: own processing, Eurostat [12, 14].

Descriptive statistical measures show how the examined nations differ in terms of perceived health and the degree of unmet medical needs. Thus, perceived health status records relatively high average values, but with variations between countries, due to the existence of differences in the quality of life and the efficiency of health systems. At the same time, unmet medical needs present a higher variability, highlighted by the standard deviation and the coefficient of variation, as a result of the existence of disparities related to access to medical services. The minimum and maximum values show that, while some health systems manage to ensure almost complete access to medical services, others face significant difficulties in meeting the needs of the population. The statistical analysis highlights the fact that the variability of access to medical services is more pronounced than that of perceived health status, as a result of the existence of additional factors that influence health status.

Comparative analysis by groups of countries highlights significant differences between developed and transition economies in terms of perceived health status. Thus, developed countries record higher average values of this indicator, reflecting a higher level of quality of life and greater efficiency of health systems. Regarding unmet medical needs, the differences between the two groups are smaller, because although access to medical services is relatively similar on average, its distribution and the efficiency of service use can vary significantly (Table 10).

Table 10. Comparative analysis of perceived health status and unmet medical needs by group of countries, in 2024

Group of countries	Average value of perceived health status (%)	Average medical need unmet (%)
Developed countries (DE, NL, SE, DK)	69.8	1.8
Transition countries (RO, PL, HU, PT)	63.9	1.2

Sursa: own processing, Eurostat [12].

It follows that the level of economic development directly influences the health status of the population, but the relationship between access to medical services and health is complex and influenced by additional factors, including: the standard of living of the population, which plays an essential role, influencing both living conditions and the possibility of adopting a healthy lifestyle; the level of education, which contributes to the formation of preventive behaviors and the efficient use of medical services, which can lead to a better health status, even in conditions of access limitations; the lifestyle of the population, reflected in nutrition, physical activity level or consumption of harmful substances, which directly influence health status, independently of access to medical services; at the same time, the efficiency of health systems, expressed in the quality of services and their organization, can determine differences between countries, even under similar levels of access; last but not least, the demographic structure of the population and environmental factors contribute to variations between countries, influencing both the incidence of health problems and the perception of them. These factors explain why the relationship between access to medical services and perceived health status is complex and multidimensional.

CONCLUSIONS

The analysis carried out reflects the complexity of the relationship between access to medical services and perceived health status, demonstrating that this relationship cannot be reduced only to a direct correspondence between the two indicators. Although access to medical services represents a fundamental element in ensuring the health of the population, the results obtained demonstrate that their impact is conditioned by a series of additional factors, which vary significantly between countries and which reflect not only the level of access to medical services, but also the capacity of health systems to efficiently use available resources and respond to the needs of the population. Therefore, success in the health sector is influenced not only by the availability of services but also by their quality, institutional organization, and level of adaptability to regional and demographic particularities. At the same time, the inequalities existing between urban and rural areas are not uniform, they depend on the socio-economic context and the level of development of each country. In some cases, these differences are small, due to effective territorial balancing policies, while in others, there are larger gaps, which are due to difficulties in ensuring equitable access to medical services.

The statistical results also highlight the fact that the variability of access to medical services is more pronounced than that of perceived health status, which shows that the health of the population is influenced by a broader set of determinants, which include economic, educational, behavioral and environmental factors, which underlines the multidimensional nature of health and the need for an integrated approach in its analysis. At the same time, the relationships identified between the indicators demonstrate that improving access to health services will not automatically lead to an increase in the level of perceived health, in the absence of complementary policies that aim at prevention, health education and the reduction of socio-economic disparities. Thus, the efficiency of interventions in the field of health depends on their capacity to integrate multiple dimensions of the population's well-being.

We believe that a systemic approach to public health is needed, in which access to health services is correlated with measures aimed at improving living conditions and individual behaviors. Reducing health inequalities cannot be achieved only by expanding the medical infrastructure, as it requires the implementation of integrated policies, adapted to the specifics of each state and oriented towards ensuring balanced and sustainable development.

Based on the conclusions formulated, public policies must go beyond the paradigm exclusively focused on expanding access and

aim for an integrated approach, oriented towards efficiency, quality and equity. First, it is necessary to develop policies to strengthen primary and community medicine, by stimulating the presence of doctors in rural and disadvantaged areas (financial incentives, service housing, tax facilities), simultaneously with the expansion of telemedicine services to reduce geographical barriers. In parallel, mechanisms must be implemented to evaluate the quality of medical services, not only access, through standardized indicators at national and European level, correlated with performance-based financing. A flexible institutional reorganization is also required, allowing the adaptation of services to regional demographic and epidemiological particularities, including through controlled decentralization and local partnerships between authorities and service providers.

Secondly, to respond to the multidimensional nature of health, policies must integrate interventions from outside the medical system itself. Thus, national prevention and health education programs, focused on life cycles and vulnerable groups, as well as intersectoral policies that reduce socio-economic inequalities (education, income, housing conditions, environment) are essential. In this regard, it is recommended to introduce "Health in All Policies" strategies, through which the impact on health is assessed in all major public policies. At the same time, integrated data monitoring and analysis systems must be developed, allowing the rapid identification of territorial disparities and the adaptation of interventions in real time. By correlating access to services with prevention, education and social inclusion measures, it is possible to ensure not only the improvement of perceived health status, but also the sustainable reduction of inequalities between populations and regions.

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EVALUATING THE PRECIPITATION DEPENDENCE OF CROP FARMS - CASE STUDY IN THE ROMANIAN PLAIN

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Abstract

Cereal crops in the Romanian Plain are increasingly affected by drought, with significant economic consequences for farmers. The study analysed a 10-year period of wheat, corn, and sunflower production in a non-irrigated vegetable farm, where the only source of water was natural precipitation. The aim was to assess the correlation between yield variation and monthly precipitation levels in the critical development phases of each crop. An analysis of the production process capability was applied under current working conditions, but also in two simulated scenarios: partial irrigation and full coverage of water requirements. The results highlight high economic risks associated with rain-fed agriculture, especially in the case of corn. Sunflower presented the greatest productive stability under drought conditions, while corn proved to be the most vulnerable. The study emphasizes the essential role of irrigation in reducing variability and ensuring production security in the Romanian Plain. Targeted investments in irrigation systems, especially for medium-sized farms, are essential for increasing agricultural resilience and aligning with Sustainable Development Goal 2 – Zero Hunger of the 2030 Agenda.

Key words**:** *weather dependence, wheat, corn, sunflower, drought, agriculture*

INTRODUCTION

Weather dependence is a common phenomenon on farms in Romania. A pervasive study on the current state of agriculture in Romania, during the period 1990-2021, presents the evolution of the average cereal production and the amount of precipitation during that period. The evolution trend of both indicators is visibly similar, which demonstrates the high dependence of agricultural production on precipitation [39]. Ensuring the water requirement for crops in many areas of the world remains a difficult problem to solve. Various irrigation methods to ensure production and food security are of permanent scientific interest [10, 26, 49].

The large variations in agricultural production on farms where the only water comes from precipitation frequently make it impossible for farmers to cover production expenses in certain years.

Capability analysis is an economic-mathematical method that consists of analyzing a series of initial data relating to a production process and predicting whether the process can produce outputs that meet initially established requirements. If two limits are set, one lower and one upper, relating to outputs, production processes that have high variability will have difficulty fitting between the two limits. When the variability of the process is low, fitting within the set limits occurs more frequently, and therefore the economic risks of farmers will manifest themselves less frequently. The value of capability indices provides an image of these situations [50]. Capability analysis has a multitude of applications, in manufacturing processes [30], quality engineering [27], or in the economic field [17].

The southern area of Romania is mostly plain in shape. The Romanian Plain covers this geographical area. It is located north of the Danube, in the lower course of the river. Its surface area is approximately 49,594 km2. The average annual temperature is approximately 11-13 degrees Celsius. The average annual frost-free time is 200-220 days. July has the highest average

temperature, 21-23 degrees Celsius. However, anthropogenic factors bring multiple climate changes [21]. The proximity to the Danube makes it possible to irrigate farms in this area, but it also brings with it large investments and the obligation to comply with environmental protection requirements. Under these conditions, the properly irrigated agricultural area is only approximately 10% of the total [4, 22, 42]. Due to the large investments, the dilemma faced by farmers is how to choose to irrigate their land or even to continue their activity without irrigation.

The Romanian Plain is an agricultural area with an important tradition for the cultivation of cereals. Some climate changes are making their presence felt in this area, but slowly. Farmers sometimes notice a lack of precipitation at the right time. The phenomenon of desertification of large areas of Romania is recognized [8, 11, 37]. The concrete, local economic implications of such phenomena remain to be evaluated and updated.

This study attempts to fill a gap in the specialized literature regarding the assessment of the current risks faced by farmers in the Romanian Plain who practice a cereal cropping system in the absence of irrigation when relying exclusively on water from precipitation.

Field research is hampered by the lack of reliable statistical data that accurately describes the response of local cereal production in the absence of irrigation. The restitution of old properties, which began in 1990 in Romania, has led to a significant degree of land fragmentation. Many owners own and work small areas of agricultural land. They practice a form of subsistence agriculture. Cereal production yields differ from one owner to another due to the different production technologies they use. Moreover, cereal production is often financially supported by its income, other than the direct ones involved in agricultural production. This is because the products of vegetable farms are used for their consumption or the livestock farms, they own. Economic data cannot be quantified in value in an exact form. An assessment of the economic risks involved in the absence of irrigation on small farms may be inconclusive.

On the other hand, there are also large farms in the Romanian Plain, which use modern technologies and irrigation. These farms are protected from drought. Even in this category, the risks brought by the absence of precipitation cannot be studied.

Therefore, only a certain category of medium-sized farms that constantly monitor the production they obtain and which, at the same time, are weather-dependent, regarding the provision of water necessary for crops, remain a useful source of statistical data.

Currently, there are associations among farmers to bring the water needed for irrigation, but in this case, it is possible that the water requirement is not completely covered. In the paper, a scenario with a partial coverage of the water requirement was created and studied. There are also cases in which farmers have developed their irrigation systems that can bring them their full water requirement. This case is studied in a second scenario.

Since, on the other hand, intensive use of irrigation in agriculture is sometimes unsustainable, policies on agricultural irrigation need to be developed at the level of the entire area and not at the level of an individual farm. Thus, it is necessary to have a clearer picture of the economic impact of different scenarios regarding the size of water resources used.

Literature review

Water plays an essential role in the entire food cycle and ensuring its quantity and quality is becoming increasingly difficult. Drought warnings and alerts often appear in Europe for large areas. Periods of heavy rainfall are observed followed by the absence of rainfall. The implications for agriculture but also the implications that agriculture has on water resources were the subject of a European Parliament Resolution on the consequences of drought and other negative phenomena [40].

Water is not always used sustainably in agriculture, and the European Court of Auditors has noted this and called for the

CAP (Common Agricultural Policy) to be aligned with EU water policies [16]. The inequalities resulting from the absence of traditional water sharing not only lead to inefficient use of water resources globally but also to conflicts between irrigators in France [43]. It is also proposed, where possible, to change cropping technologies, land use, and the establishment of other crops that require less water, to use resources sustainably [24].

In Romania, the coexistence of very large and very small farms in the same area is common. These large disparities entail negative phenomena regarding sustainability [38]. There is also the phenomenon of the concentration of resources, including water, towards large farms, with direct negative socio-economic implications in the rural environment. In Romania, many of the irrigation systems were built before 1989. If cooperative agriculture was the predominant form during that period, the changes that occurred regarding ownership, especially the high number of different properties, can lead to difficulties in the management and maintenance of irrigation systems. In the eastern part of the country, their degree of degradation reaches 40-60% [29]. Water losses are important and also make efficient irrigation impossible. The response of different crops under the effect of different irrigation systems is also studied in Romania, indicating the efficiency of higher value plants that can be adapted to water shortages [44].

Of the total population of the South-West Region, which includes the study area, 63.4% of people were connected to the public water supply system and only 48.2% to the sewage systems [33, 34]. A large part of the water consumed is therefore not subjected to the purification process but is discharged directly into the ground through pits. In addition, in the absence of a connection to the sewage system, the input-output correlation is difficult to follow, and losses cannot be estimated correctly.

The European Union policy is one that understands the water deficit in agriculture, especially during certain periods of the year. It recognizes the importance of irrigation in agriculture, but at the same time imposes restrictions to conserve water resources, maintaining a continuous balance. The legislative framework provides important support in support of this balance. Reusing wastewater can be an effective solution, given that currently most rural localities in the Romanian Plain have recently been connected to water networks. The minimum requirements for water reuse are regulated by law [14]. Water losses in distribution networks, sources of pollution that can make water unsuitable for reuse, but also other aspects that give water the quality of a heritage asset that must be protected, are regulated by Directive 2000/60/EC [13]. CAP 2023-2027, brings changes in the sense of supporting smaller farms and ensuring equity [15], along with a diverse list of measures aimed at sustainable development and achieving positive results and performances [2, 7, 12, 41]. The conclusions of the literature study indicate the need for sustainable water use in agriculture. This must be regulated at the national level in Romania, and not just individually at the level of agricultural holdings. Such steps must be preceded by a good knowledge of the concrete situation at the level of the economy of individual farms, knowledge of the economic risks and the factors that involve them, respectively of the regional particularities.

In this context, the goal of this research is to evaluate the relationship between yield change depending de monthly precipitations during the period of vegetation of wheat, sunflower and maize and to develop two scenarios: one which involves partial irrigation and the second which assure the coverage of the water needs of the crops. Finally, the risk evaluation was estimated in care of water insufficiency in the local conditions in order to claim for financial support for the producers who could be affected by production and income losses.

MATERIALS AND METHODS

The study is based on data obtained within a mixed crop farm, where wheat (60%),

sunflower (30%), and corn (10%) predominate. The farm has approximately 200 hectares and is located within the administrative boundaries of Mehedinți County, near the Pătulele locality.

The land is located in several plots with different areas ranging from 1 hectare to 40 hectares.

Statistical observations were used for a period of 10 years, from 2014-2024, regarding the average production per hectare but also regarding certain financial details, for the establishment and maintenance of the agricultural crop and the valorization of the products.

The following abbreviations are used in this manuscript: NMA - National Meteorological Administration, NIS - National Institute of Statistics, CAP - Common Agricultural Policy, National Research and Development Institute for Pedology, Agrochemistry and Environmental Protection - NRDIP.

The research involved a literature review and discussions with farmers, owners of agricultural holdings in the study area.

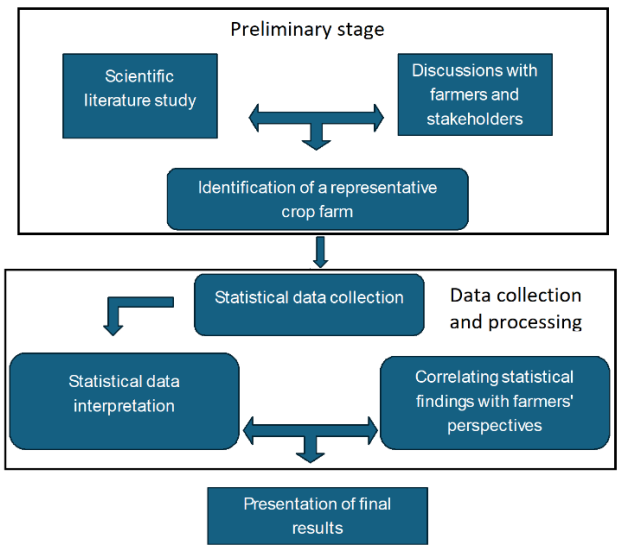


Fig. 1. Representation of research procedure design
Source: Authors' original representation.

The holding where the case study was conducted has the advantage of having multiple plots of different sizes, which from a statistical point of view, by being located in different locations, ensures a good representativeness of the studied territory. The essential steps followed are described in Figure 1.

The average annual production obtained and used as statistical data was calculated by dividing the total production to the cultivated area.

The approximate position of the farm and its location on the map of Romania is shown in Map 1.

Map 1. Location of the studied vegetable farm in the Romanian Plain
Source: Authors' original processing after Google Maps [20] and Geoportal [19].

The formula used to calculate the process capability was:

$$C_{pk} = min(\frac{USL - m}{3\sigma}, \frac{m - LSL}{3\sigma}) \quad \ldots\ldots \quad (1)$$

where:
USL - Upper Specification Limit,
LSL - Lower Specification Limit,
m – Mean
σ - Standard deviation of the data series.

LSL values represent a minimum economic threshold of production. A production value lower than this threshold could not cover the production costs of the farm.

USL values represent a maximum desired threshold which, if exceeded, would lead to environmental degradation due to excessive fertilization or pesticide application but also to production costs that are much too high compared to the farm budget.

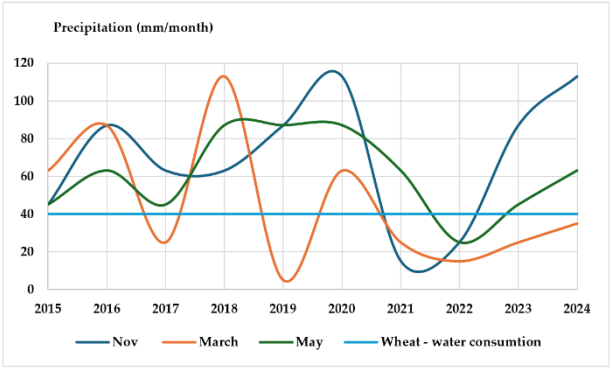
Both values, LSL and USL, are specific to each crop within a farm. C_{pk} values <1 show that a production process has no capability. C_{pk} values between 1 and 1.33 represent a low-capability process. C_{pk} values greater than 1.33 show that a process is capable. Depending on the particular requirements of the production, sometimes even higher indices are pursued, 1.67 or even 2 [31,50].

The precipitation values in the studied area were the subject of a correlation analysis with the agricultural production obtained. The multiple correlation coefficient was used. This coefficient indicates the intensity of the link between the predictor variables xi and a dependent variable y. With the notation $\bar{y}$ for the average of the values of the series y and $\bar{y}$ calculated by the linear regression model, the expression of the multiple correlation coefficient is:

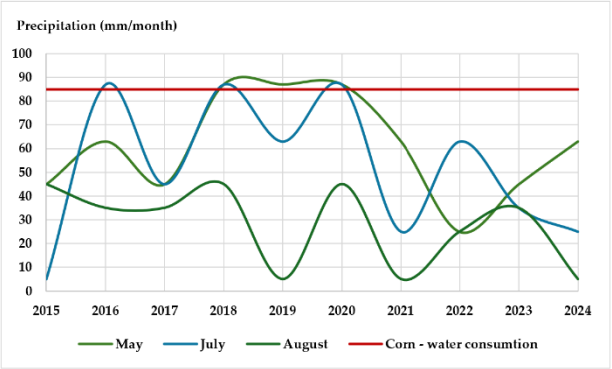
$$R_{y/xi} = \sqrt{1 - \frac{\sum(y_i - y_{xi})^2}{\sum(y_i - \bar{y})^2}} \quad \ldots\ldots\ldots \quad (2)$$

The C_{pk} values for the entire farm will be calculated by formula:

$$C_{pk} = C_{pk_1} \times p_1 + C_{pk_2} \times p_2 + C_{pk_3} \times p_3 \quad \ldots\ldots\ldots\



(a)



(b)

Fig. 2. Precipitation level and water consumption.
(a) Evolution of monthly precipitation in November, March, and May, during the period 2015–2024, compared to the average water requirement for the wheat crop.
(b) Evolution of precipitation in May, July, and August, during the period 2015–2024, compared to the average water requirement for the corn crop.
Source: Authors' original representation using NMA data [35].

The study on the correlation between the average production of cultivated cereals and precipitation was carried out under the following conditions:
-The dependent variable is average production
-For wheat, per hectare over the 10 years, and the independent variables are the rainfall in the farm area in November, March, and May of the years related to the crop.
-For corn and sunflower the dependent variable is the average yield per hectare, and the independent variables are the rainfall in the farm area in May, July, and August of each year studied.
Those months of the year in which precipitation is essential for plant development were chosen for statistical analysis. Furthermore, from a mathematical point of view, the predictive capacity of models with a large number of variables can be subject to errors and this fact led to the idea of testing weather dependence using only three independent variables as predictors.
The values of the multiple correlation coefficients, R, calculated for each agricultural crop are: R_{wheat}=0.56, R_{corn}=0.76 and $R_{sunflower}$=0.48 respectively. R values are often considered to indicate a medium level of correlation when they are between 0.4 and 0.7. Values between 0.7-0.9 indicate a high correlation [9].
Corn is the plant whose production was strongly correlated with the amount of precipitation that fell in the three essential months. Specifically, low corn productions are related to dry years, and on the other hand, high corn productions were obtained when precipitation was quantitatively sufficient, given that the cultivation technology was not modified. Wheat and sunflower have a medium level of correlation regarding weather dependence. The lowest coefficient is for sunflower. This is the plant whose production is therefore the least affected by the amount of water available.
The statistical summary describing the agricultural production values, expressed in kg/ha, are presented in Table 2.
During the 10 years, in the period 2015-2024, under conditions in which the lands were not irrigated, the average wheat production was 4,700 kg/ha. It is slightly higher than the average wheat production in that period in Romania, of 4,230 kg/ha. In the same time interval, the South-West Oltenia Region has an average wheat production of 4,111 kg/ha. In corn, the average production obtained on the farm is also higher than the national average, 4,976 kg/ha, and the regional average, 4,700 kg/ha. And in sunflower, the average production of 2,710 kg/ha exceeds the national average, 2,294 kg/ha and the regional average, 2,335 kg/ha, according to NIS - AGR110A [32]. Even in the absence of irrigation, the establishment and maintenance of agricultural crops were carried out properly. We can therefore assume that the main factor that is absent is water, in dry years.

Table 2. Statistical summary for on-farm cereal production in the period 2015-2024, under No irrigation (weather-dependent) conditions

	Wheat	Corn	Sunflower
Mean	4,700	5,350	2,710
Std Dev	879.3	1,546.5	455.7
Minimum	3,000	3,000	2,000
Maximum	6,000	8,500	3,400
rank	3,000	5,500	1,400
Coeff of Variation	18.7	28.9	16.8
Lower Quartile	4,000	4,000	2,300
Upper Quartile	5,200	6,000	3,000

Source: Authors' original calculation using SAS Studio of statistical data from the studied farm.

Corn has the highest coefficient of variation, range, and standard deviation. In the case of other plants, important changes in agricultural production are also observed from one year to the next. For wheat, the LSL value was estimated at 3,700 kg/ha and is based on average production costs, including subsidies granted by the Romanian Agricultural Payments and Interventions Agency.

The USL value for wheat was estimated at 8,000 kg/ha. Similar calculations were made for corn, where the LSL value was estimated at 4,500 kg/ha and the USL at 12,000 kg/ha. For sunflower, the LSL value was estimated at 2,000 kg/ha and the USL at 4,500 kg/ha.

Following certain studies carried out in Romania, due to irrigation, production increases were observed with values of 1,000-1,500 kg for wheat and 2,500-3,000 kg for corn in years when the rainfall level was normal and even double in years when there was drought, compared to non-irrigated lands [36] and approximately 1,000 kg for sunflower [48]. Rainy years do not lead to production increases due to irrigation, as it is not necessary.

Starting from the values of quartiles 1 and 3 for the data series of grain production on the farm according to the data in Table 1, the years with low and high production in the statistical series were delimited. By making the value corrections of the type above on the productions obtained, the productions were estimated in the case of two irrigation scenarios.

Scenario 1, Irrigation – partial protection, consists of incomplete irrigation of the lands and thus brings only partial protection of crops against drought.

Scenario 2, Irrigation – full protection, consists of irrigating the lands with a sufficient quantity of water to ensure grain production with values similar to those in the years with high production.

This scenario would therefore induce a total protection of crops in drought conditions.

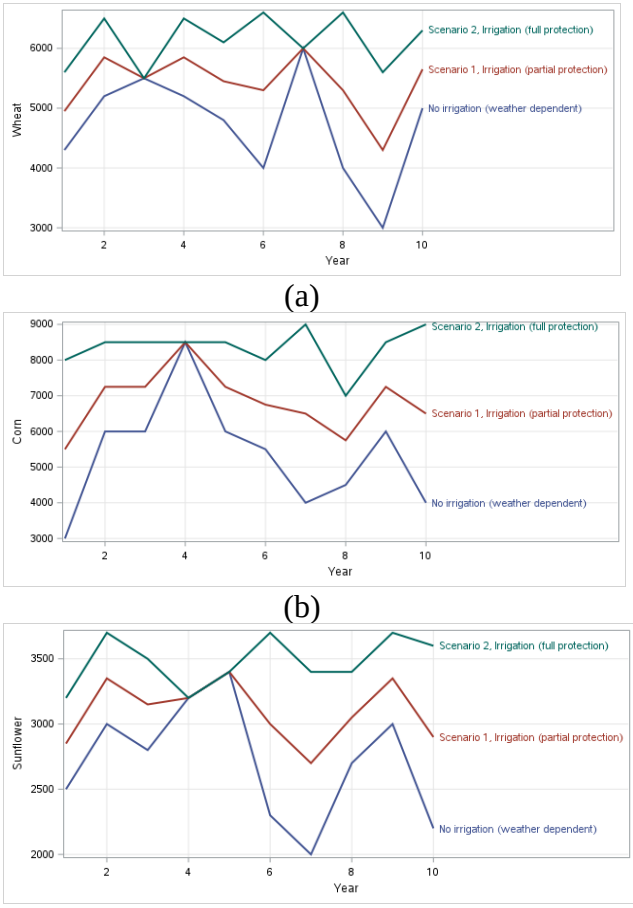


Fig. 3. Wheat (a), corn (b), sunflower (c) production, obtained on the farm over 10 years (2015-2024) in the absence of irrigation (weather dependent), and two scenarios with estimated production under partial and total irrigation conditions

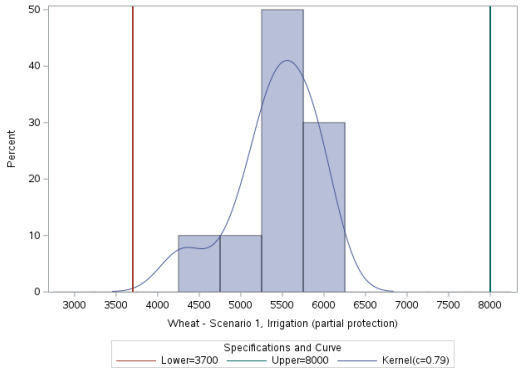
Source: Authors' original representation using SAS Studio of statistical data from the studied farm.

As a reference, the series of real productions, obtained without irrigation, in a weather-dependent manner, regarding naturally fallen precipitations, is also analyzed.

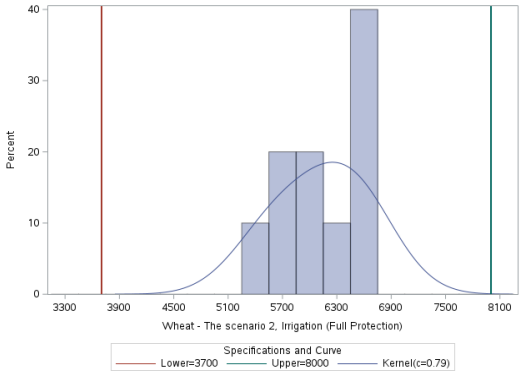
This case is generically referred to the paper as *No irrigation – weather dependent.*

The three cases, two scenarios proposed following the calculations, along with the actual production obtained in the absence of land irrigation, for each cereal crop, are presented in Figure 3 (a) for wheat, Figure 3 (b) for corn, Figure 3 (c) for sunflower.

Starting from the scenario values presented in Figures 3, data processing using Capability Analysis involved determining the percentage frequencies of production values, estimating the evolution curve of the probability density function, for each scenario, for each cereal crop in particular, in Figures 4 a)-i), then determining the statistical parameters useful within the formula for determining Cpk and the concrete calculation of Cpk values (Table 3).



(a)



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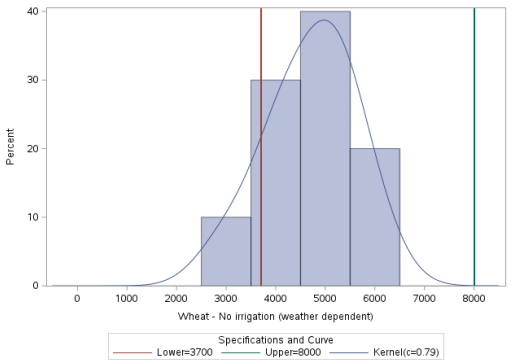

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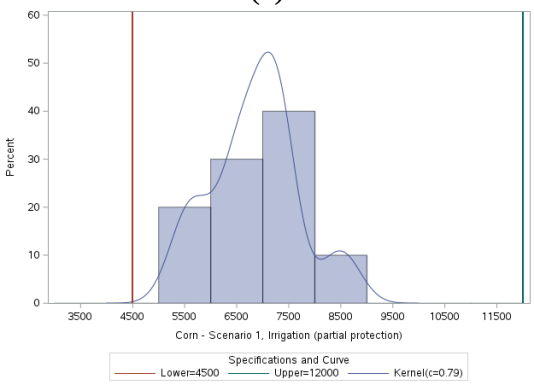

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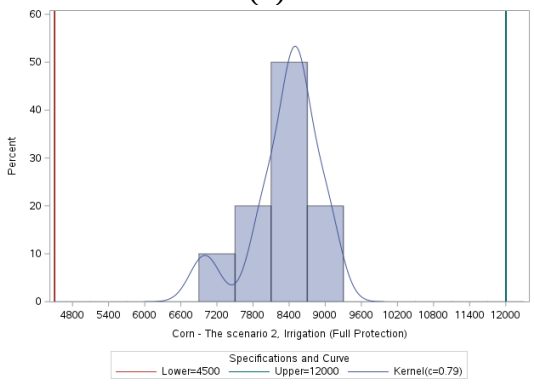

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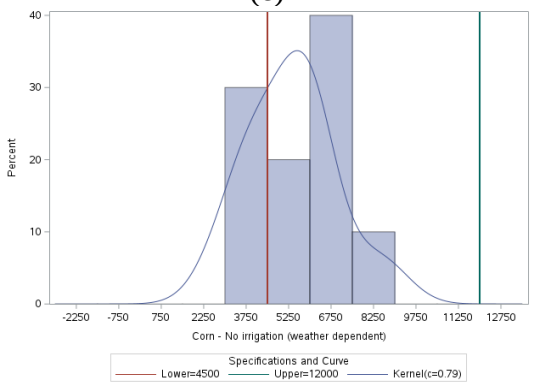

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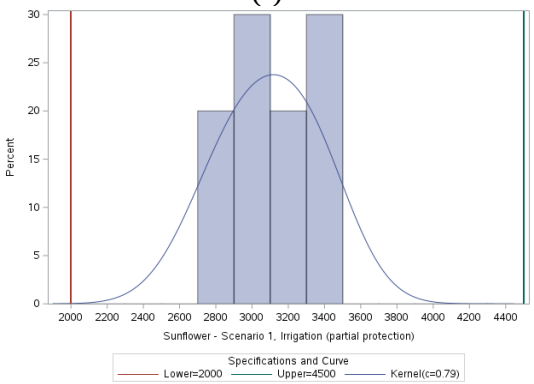

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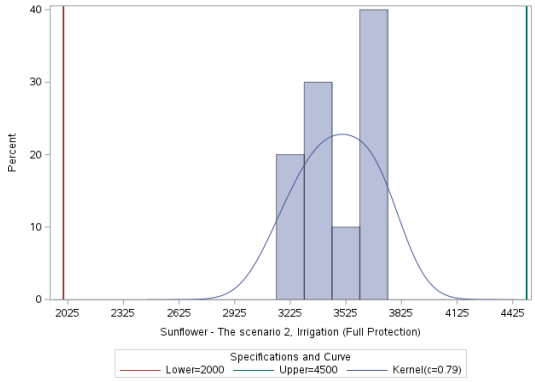

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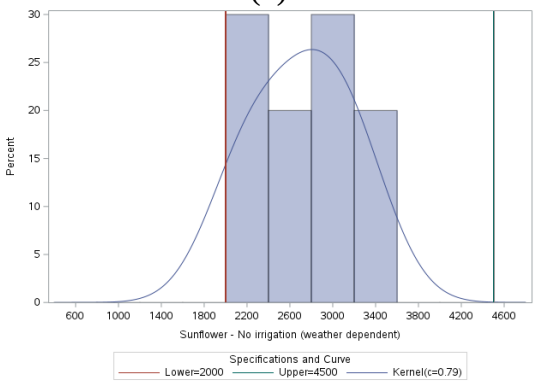

(i)

Fig. 4. Percentage frequency of production values for wheat (a,b,c), corn (d,e,f), and sunflower (g,h,i) during the period 2015-2024, in irrigated and non-irrigated scenarios

Source: Authors' original representation using SAS Studio of statistical data from the studied farm.

The prolonged drought during the growing season of agricultural crops often compromised the entire process. Even though there were years when favorable conditions for agricultural crops led to high-yield crops, for the entire analyzed period, unsatisfactory results were obtained regarding capability analysis (Table 3).

Table 3. Capability index values Cpk under current farm conditions (No irrigation - weather dependent) compared to Cpk values under the two irrigation scenarios

	No irrigation (weather dependent)	Scenario 1 Irrigation - partial protection	Scenario 2 Irrigation - full protection
Wheat	0.37	1.13	1.42
Corn	0.18	0.91	2.09
Sunflower	0.51	1.54	1.75

Source: Authors' original calculation using SAS Studio.

The capability thresholds of the Cpk values are 1 – up to which the process is not capable, 1.33 – up to which the process is slightly capable, after which above 1.33 – the process is capable.

In wheat, the absence of irrigation, as is currently the case on the farm, shows the absence of production process capabilities (Cpk=0.37). The risks of production falling below the LSL threshold are high, which is also observed in Figure 5 c by the leftward crossing of the LSL threshold by the estimated curve. Scenario 1, with incomplete irrigation of the wheat crop, indicates a weakly capable process (Cpk=1.13), and this one is also at risk. Only in the case of Scenario 2, the value Cpk=1.42 indicates a capable production process.

In corn, in the absence of irrigation and even Scenario 1 of incomplete irrigation, Cpk values are lower than 1. The production process is subject to significant risk. Only Scenario 2 brings an index Cpk =2.09 which shows that the process is capable.

In sunflowers, only the absence of irrigation presents a process that is not capable. At the same time, partial irrigation is sufficient so that the risks decrease significantly. The value Cpk=1.54 in Scenario 1 of partial irrigation shows this fact. If irrigation is fully carried out, Scenario 2 brings a Cpk=1.75 index so it shows that the production process is capable.

Noteworthy are the associations between the Cpk values that describe the capability of the production process and the values of the multiple correlation coefficients R, between production and the amount of precipitation. Thus, plants whose production correlated with precipitation led to a low capability and vice versa. Specifically, the highest correlation coefficient was obtained for corn, R=0.76. Corn is the plant whose production correlated most strongly with the amount of precipitation but on the other hand it had the lowest capability index Cpk=0.18 under non-irrigated crop conditions. The lowest multiple correlation coefficient, R=0.48 for sunflower shows that among the plants grown on the farm, sunflower production is least influenced by precipitation.

Cpk values for the entire farm were calculated using formula (3). The results show that for the crop variant in the absence of irrigation, Cpk=0.393 was obtained. For the scenario with partial coverage of the water requirement Cpk=1.231 and for the scenario with complete irrigation Cpk=1.586. The current variant in which the production process is carried out on the farm indicates the absence of capability, i.e. an increased risk of financial failure. Also, a poorly capable process is described by the case of partial irrigation. The complete irrigation variant brings a higher capability index.

The economic risks of vegetable farms in the Romanian Plain can be reduced by irrigation. An additional amount of water compared to that obtained naturally through precipitation, even in incomplete conditions, with partial protection, can bring reduced economic risks for wheat and sunflower crops compared to the current state.

Although Romania has one of the most extensive irrigation networks in South-Eastern Europe, the effectively irrigated agricultural area remains significantly below the optimal level, with a national average of less than 15%, compared to Member States such as Spain, Italy or Greece, where the percentage of irrigated land frequently exceeds 30–40% [47].

The agricultural production capacity, analyzed by the Cpk indicator, confirms that the lack of irrigation negatively affects the stability of the production process, especially during the critical periods for the development of wheat (March–May) and corn (July–August). Subunit values of this indicator in the absence of irrigation suggest high economic risks, which are reflected in unstable yields and potential losses for farmers. Under climate change, these risks become recurrent, with a direct impact on regional and national food security.

Medium-sized farms – between 10 and 100 ha – are the most vulnerable in this context. Large farms generally have sufficient financial resources to invest in high-performance irrigation systems, while small farms, focused on self-consumption, are less dependent on the economic stability of production. In contrast, medium-sized farms play an essential role in the local and national food chain, being responsible for a significant part of the marketed production, but do not benefit from sufficient technical and financial support to implement modern irrigation solutions [47].

This reality runs counter to the goals of the 2030 Agenda, in particular SDG 2 – Zero Hunger, which aims to ensure access to safe, nutritious and sufficient food for all, as well as to build resilient agri-food systems in the face of climate and economic stress. Access to water for irrigation is not only a technological issue, but also one of equity and sustainability. Investments in agricultural infrastructure, primarily oriented towards medium-sized farms, contribute directly to reducing poverty in rural areas (SDG 1 : No Poverty) and to creating conditions for sustainable economic growth (SDG 8: Decent Work and Economic Growth) [18].

At the same time, the expansion of irrigation must be carried out in compliance with sustainability requirements, following SDG 6: Clean Water and Sanitation, through the efficient and rational use of water resources. In addition, in the face of the intensification of extreme climatic events, irrigation plays an essential adaptation role in achieving SDG 13: Climate Action. Although the new framework of the Common Agricultural Policy does not provide for direct and explicit funding lines for irrigation systems, investments can be indirectly supported through Pillar II interventions and through measures to modernize agricultural infrastructure, provided that the principles of eco-efficiency and climate change adaptation are integrated [45].

To capitalize on this potential, a coherent national strategy is needed, which identifies medium-sized farms in vulnerable areas and prioritizes technical, financial and logistical support for the rehabilitation and expansion of irrigation systems. This direction is not only an opportunity for economic growth, but also an essential condition for fulfilling the commitments assumed through the 2030

Agenda and for building a sustainable and equitable food system in Romania.

Furthermore, the importance of irrigation systems can also be analyzed through the four pillars of food security: availability, accessibility, utilization, and stability. Irrigation contributes directly to food availability by increasing yields and reducing the risk of losses due to drought. At the same time, it improves the economic accessibility of food by stabilizing supply and prices in Romania [3]. In terms of utilization, constant access to water can support the diversification of production, including in crops with high nutritional value. Ultimately, the stability of the food system - in the short and long term – depends on the capacity of agriculture to respond to climate variability, and irrigation is a key tool in this regard.

We thus observe that: water losses through water distribution networks are significant in Romania; rural localities have recently been largely connected to drinking water supply networks but wastewater collection and reuse systems are lacking; there is an obvious inequity regarding the use of water for irrigation by large farms compared to small farms; individual agricultural properties are excessively fragmented in many areas; associations between owners are rare, and all of these are factors that make it difficult to develop concrete plans regarding water use in agriculture in the Romanian Plain.

Therefore, the need for an integrated national strategy for the rehabilitation of irrigation systems, with a focus on medium-sized farms in vulnerable areas, is highlighted. This direction would bring multiple benefits, not only in economic terms, but also in terms of social equity, climate sustainability, and the fulfillment of the commitments assumed through the 2030 Agenda. Public investments and effectively targeted political support can transform irrigation into a factor of balance and progress for Romanian agriculture.

Even though the study was conducted at the level of an agricultural region in Romania, the situation is not much different in other geographical regions, and the technical results of the study can be extended to multiple other geographical areas facing similar problems related to water management. Furthermore, such an approach could successfully complement the efforts regarding sustainable rural development plans in Romania, which are currently intensively researched.

CONCLUSIONS

The current conditions for the production process for mixed production - wheat, corn, sunflower, without irrigation, bring high economic risks. Incomplete irrigation, which brings partial protection against drought, improves risk management.

Wheat behaves as a plant that brings economic risks in drought conditions, but even an additional amount of water, even if incomplete, would reduce the economic risks of the farm. Positioning farms in a particular way in low relief areas brings immediate benefits in conditions of moderate rainfall.

Sunflowers also pose risks in drought conditions, but incomplete irrigation is sufficient for economic risks to decrease and the production process to become viable. However, even if it is more economically secure, the crop requirements for sunflower regarding successive cultivation require the establishment of much smaller areas compared to wheat.

Corn is becoming a very drought-sensitive agricultural plant in the Romanian Plain, according to calculated statistical indices. The fact that farmers who do not have irrigation systems at their disposal still choose to grow corn is due to the need for crop rotation, but also to the needs related to raising animals on their farms. Practical observations of farmers confirm that corn is most affected by drought, while sunflower is not. Due to this fact, attempts are frequently made to reduce the area cultivated with corn and increase the area cultivated with sunflowers. However, the need for crop rotation imposes restrictions in this regard.

All three cultivated plants thus bring significant risks to the farm in a situation where the water needed by the plants is provided only by meteorological conditions.

The large differences between the maximum and minimum production values during the analyzed period are 3,000 kg/ha for wheat and 5,500 kg/ha under weather-dependent conditions. However, farmers who cultivate small areas of land do not attach particular importance to risks and continue their activity constantly without irrigating the farm. They use the obtained crops in their own regime, even if they are smaller and can cover their losses due to drought from other sources. However, important economic activities, from farms that cultivate larger areas of land, are strongly affected by drought in non-irrigated conditions. Multiplying the above-mentioned differences with the cultivated area leads to differences that cannot be neglected.

In the perspective of sustainable development of agriculture in the Romanian Plain, the results of this study support the need to formulate an integrated national strategy for the rehabilitation and expansion of irrigation systems, with a focus on medium-sized farms in vulnerable areas. Irrigation can not only significantly reduce economic risks in drought conditions but also contributes significantly to achieving major public policy objectives, such as poverty reduction (SDG 1: No poverty), food security (SDG 2: Zero Hunger), sustainable use of water resources (SDG 6: Clean Water and Sanitation), rural economic growth (SDG 8: Decent Work and Economic Growth) and climate change adaptation (SDG 13: Climate Action.). In this sense, coordinated and equitable investments in agricultural infrastructure are fundamental for achieving the commitments assumed through the 2030 Agenda and for building a resilient agri-food system in Romania.

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The amount of precipitation on the territory of Romania is recorded by National Meteorological Administration, Statistical analysis related to economic risk analysis is found in the SAS Studio modules.

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SUSTAINABLE CIRCULAR PRODUCTION AND CONSUMPTION TRENDS AND POLICIES IN THE EUROPEAN UNION

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Abstract

Advancing the Sustainable Development Goals (SDGs) and circular economy (CE) are crucial components of the planned European Green Deal and quite a foundational value of the European Union. Sustainable development plans and recognized public regulations are progressively aligning with the principles of a circular economy. After conceptually highlighting the synergetic correlation between the circular economy and sustainable development, this research seeks to examine how the change to a circular economic system in the EU might facilitate environmentally friendly production and consumption, as required by the SDG 12 Responsible consumption and production, eventually with the help of well thoroughly designed new policies and instruments. The methodology is based on the literature review, outcomes from the own previous research, the processing for analysis of data with tables and graphs, and the analysis and synthesis of some recent strategic and policy documents from the EU and Romania. The conclusions and recommendations refer to the premises and prospects of circular economy trends and instruments for the promotion of the Sustainable Development Goals, also with reference to the SDG 12 as a priority issue.

Key words**:** *circular economy, sustainable, production, consumption, policies*

INTRODUCTION

Sustainable development efforts have been and are constantly challenged by increasingly frequent or stronger financial or environmental constraints, increasing the need to develop new conceptual and policy approaches, such as green growth and the circular economy.

Consequently, the most critical concerns raised by the principles of sustainable development, including the design of socio-economic development to support the actual capacity of ecosystems, the decoupling of economic growth from environmental destruction, and the long-term preservation of the system's overall viability with all its components, have become even more stringent nowadays. (Frone & Frone, 2020) [22].

With the goal to achieve a modern, efficient, and equitable society and economy, nations should embrace the Sustainable Development Goals, or the 2030 SDGs and persist in investing in knowledge, research, creativity, and technological advances. This will aid societies transition to more sustainable practices of consumption and manufacturing.

According to the European Union's strategic and reflection papers, immediate action is required to stop global warming and the deterioration of ecosystems and biodiversity, which endanger wellbeing, sustainable economic development, and even life altogether. (COM(2019)22) [7].

One of the most important Sustainable Development Goals is SDG 12, called Responsible Consumption and Production [14]. Within the EU framework, the oversight of SDG 12 emphasizes advancements in decoupling environmental pressures from economic growth, promoting the green economy, and managing waste generation.

The primary goal of the current agenda is to emphasize and analyse the problems, goals, procedures, and features of these sustainability trends and measures pertaining to the circular economy.

The EU has recently created numerous regulations and rules to address various aspects of the Sustainable Development Goals, particularly SDG 12 Responsible Consumption and Production, such as the Ecodesign Regulation for Sustainable Products and the call for a European directive on common guidelines supporting repairing of standard products. These key policy initiatives have been briefly analysed in the paper to highlight their main characteristics and the potential impact of sustainable development from a circular economy (CE) perspective.

The main objective of the research is to examine the link between the circular economy transition and progress in Sustainable Development, particularly towards the SDG 12 Responsible Consumption and Production in recent years.

The originality of the paper lays in the theory refinement and extension by researching the conceptual grounds of circular economy and sustainable development; evidence integration and identification of patterns from the literature review and data analysis, by using specific indicators monitoring circular economy and progress towards SDG12 targets; spotlight of main issues of heterogeneity and insufficiency of progress towards the SDGs targets, both common for the entire EU or particular for some countries; the inductive aggregation of findings for prospects and recommendations.

MATERIALS AND METHODS

The paper has a mixed methodological approach of:

(i) Conceptual analysis and synthesis (for the economic theories backgrounds and the literature review of the synergetic link between the circular economy principles and mechanisms correlation with Sustainable Development indicators, particularly the SDG 12 Responsible consumption and production);

(ii) Comparative dynamic analysis of the data identifying main trend and patterns of progress in some SDG 12 indicators which are also circular economy monitoring indicators: the material footprint (RMC), the CMUR and the Waste generated;

(iii) Analysis and synthesis of recent or upcoming policies of the European Union rules, and norms targeted at the shift to a circular economy (CE) and advancement toward the SDG.

Therefore, the methodology that was used by the authors in this research is based on: literature review; theoretical grounds analysis; outcomes and findings of own previous research; analysis of the trends in some key Sustainable Development Goals Indicators and Circular Economy indicators for the European Union states; European Commission and Parliament official and strategic documents and papers.

Data used is both own processed Eurostat recent data and secondary data from EU, European Commission and Eurostat reports and documents. The data source is represented by both the Eurostat Statistics Explained database and reports (in terms of the complex methodology and trends regarding the EU eco-innovation index) and the Eurostat database, namely the EU Circular Economy and Sustainable Development Indicators.

Figures and graphs are either taken as is from recent studies or European Commission and Eurostat reports on the SDGs or indicators (where access to primary data was sometimes not available) or are produced by the authors by creating a database and processing existing data at Eurostat. Nonetheless, the authors own the data based analysis remarks regarding patterns and prospects.

RESULTS AND DISCUSSIONS

Theoretical backgrounds

By incorporating sustainability concepts into economic theories and models that may successfully support a systemic transition, the circular economy (CE) can help achieve the Sustainable Development Goals (SDGs). Recognizing the Sustainable Development Goals' (SDGs) comprehensive character is fundamental, considering the major interconnections and synergies that exist among them, since this has become a prominent subject of worldwide and national academic interest. (Frone et al., 2020a) [20].

Below is a brief synthesis of the main economic theories and concepts that underlie the theoretical foundation of the role of the circular economy in sustainable development and implicitly, in achieving the SDG Sustainable Development Goals.

Ecological Economics (Eco-economics)

Eco-economy (ecological economy) is a concept proposed by (Brown Lester, 2001) that refers to an economy that can develop in the long term without affecting its own support system (natural capital, respectively the environment).

Thus, the ecological economy sees the economy as a subsystem of the biosphere, emphasizing the limits of natural capital. The concept contradicts neoclassical economics by recognizing biophysical boundaries (e.g., the framework of planetary boundaries) and the laws of entropy (the second law of thermodynamics). Policies such as green taxation, natural capital accounting and full-cost pricing can internalize environmental externalities, which are essential for the implementation of the SDGs.

SDGs like SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land) are thought to be in line with the circular economy (CE) in Eco-economics, by its mechanisms minimizing resource extraction and environmental degradation.

Steady State Economics (Herman Daly)

The key principle this economic theory is based on is that it advocates an economy that does not grow and thus operates within the limits of the Earth's carrying capacity. That is why it proposes quantitative ceilings for the production of materials and energy. Today, Herman Daly's ideas are recognized, and Steady-State economics is considered to be the leading work on sustainability economics (Daly H., 1996) [4]. In addition, the link of this theory with the CE and the SDGs lies in the idea that circularity supports a stationary economy by decoupling economic activity from resource consumption. With an emphasis on well-being, equality, and sufficiency, the theory supports SDG 8 (Decent Work and Economic Growth) by qualitative progress rather than statistical growth in GDP. It also supports SDG 12 (Responsible Consumption and Production), which promotes the dematerialization of production.

Innovation and Evolutionary economics

Evolutionary economics is a school of economic thought that is inspired by evolutionary biology Evolutionary economists believe that the economy is dynamic, ever-changing, and chaotic, rather than always tending toward a state of equilibrium. The production of goods and the purchase or consumption of goods involve many processes that change as technology develops. Reputed economists, such as (Joseph Schumpeter,1939) [35] have studied entrepreneurship and innovation using this term, but not in the Darwinian sense.

Evolutionary economics focuses on the role of technological innovation, institutional change and path dependency. Within this framework, the circular economy is an evolutionary transition from linear to regenerative industrial metabolism. In terms of the application to the SDGs, it may be considered that SDG 9 (Industry, Innovation and Infrastructure) and SDG 11 (Sustainable Cities) benefit from innovation-based CE models such as industrial symbiosis, product-service systems and collaborative economy platforms. (Witt U., 2002) [36].

Endogenous economic growth theory

Endogenous growth theory argues that investment in human capital, innovation, and knowledge contribute significantly to economic growth. The theory of endogenous growth also focuses on the positive externalities and spillover effects of a knowledge-based economy that will lead to economic development.

In Paul Romer's (1990) [33] endogenous growth model, the expansion of aggregate knowledge results from learning externalities between firms. In fact, the higher the level of capital stock in an economy, the more productive each firm will be through a process of "learning by doing". In endogenous economic growth theory, economic growth is considered to be driven by the effects of knowledge propagation, human capital, and innovation.

The circular economy and the SDGs provide a perspective according to endogenous growth theory, in the sense that the CE improves resource productivity and innovation-based competitiveness (e.g. digital tools in material tracking, artificial intelligence AI in predictive maintenance). While supporting SDG 4 (Quality Education) and SDG 8 (Decent Work and Growth) with the promotion of skills and jobs in green or green sectors, endogenous growth must be aligned with environmental biophysical boundaries to avoid rebound effects (the Jevons paradox), which can undermine the progress of the SDGs in the long term (Fich et al., 2022) [18].

Bioeconomy and thermo-economy

The bioeconomy refers to the production of goods and services using renewable biological resources supported by biotechnologies and innovative technologies, with the aim of moving from a fossil fuel-based economy to a bio-resource-based economy.

In his paradigmatic work, (N Georgescu-Roegen,1971) [24] considered the father of the bioeconomy, argues that economic deficit is rooted in physical reality: the earth's carrying capacity—that is, its ability to support human population and consumption—is destined to decline at some point in the future due to the extraction and use of its limited supply of mineral resources. All natural resources are irreversibly degraded when used in economic activity.

As a result, the world economy as a whole is expected to head for an inevitable future collapse, eventually leading to human extinction.

The relevance for the circular economy and the implications for the SDGs of the bioeconomy lie in the fact that bio-mimetic design, low-entropy production and energy efficiency are promoted, thus aligning with SDG 7 (Clean and Affordable Energy) and SDG 13 (Climate Action). The bio-economy also emphasizes the limitations of recycling and the necessity of downsizing and renewal rather than only material reuse. Fundamental viewpoints on sustainable development and the circular economy are also provided by other economic theories.

The research hypothesis of this study is: There is a synergy between circular economy transition and progress towards Sustainable Development Goal 12 in the European Union.

The research questions or problems are:

(i)What are the main research results demonstrating the correlation and synergy between progress in the circular economy and that of sustainable development towards the SDGs?

(ii)Is the progress achieved towards the SDG 12 targets enough in the EU and uniform within the European Union countries?

(iii)Did current EU strategies and policies provide efficient and sufficient framework of synergy between the European Union transition to circular economy and the progress towards the Sustainable Development Goals (SDG12)?

Synergy between the SDGs and the circular economy: a review of the literature

The actual literature is next highlighted indicating that there is a strong and significant correlation between the circular economy and sustainable development.

The development of a more energy and resource-efficient society that makes sensible use of resources and organizes industrial processes to minimize waste in all important areas is expected to be a reflection of the objectives of economic sustainability. Although the circular economy concept and model are far more challenging, they are still complementary to a sustainable economy. (Frone S., Constantinescu A., 2015) [23].

The EU's Sustainable Development Goal 12, "Responsible consumption and production," states that every economic activity should be conscientious of the environment. Many studies have tried to find how the circular economy transition can promote responsible consumption and production.

(Friant et al., 2021) [19] provides a startling analysis of the EU's CE strategy and policies, demonstrating that the EU's current responsible consumption and production policies frequently prioritize recycling and waste management, as "end-of-pipe solutions" (focused on the management of waste after it has been created, instead of preventing waste

generation through design, production, and consumption practices).

In this literature review there are emphasized more mechanisms and features of the circular economy that are implemented along the life-cycle of products and can also contribute to progress in the SDGs. Nevertheless, the various impacts and issues of recycling for the CE in the EU have been previously analysed in (Platon et. al 2022, 2023; Constantinescu et al., 2022) [27, 28, 3], unveiling a significant contribution of materials recycling both to the circular economy and sustainability advancement in the European Union. For instance, in (Platon et al., 2023) [28] it was highlighted that reduction in raw material consumption is an important direction for promoting sustainable development, revealed by the Sustainable Development Goals adopted in 2015 by the United Nations. SDG 12 is introduced, which intentionally incorporates strategies for responsible production and consumption, tracking metrics including (a) domestic material consumption (DMC) and (b) material footprint (MF). The material footprint, also called raw material consumption (RMC) [16], is one of the indicators of SDG 12 Responsible consumption and production. It represents the requirement for the exploitation of raw materials (minerals, metal ore, biomass, and fossil energy materials) due to the use of commodities or services within a specific region. By examining the results of a panel data regression analysis conducted for the 27 EU countries over a ten-year period (2010–2019), the article demonstrated the strong reverse association between the circular economy (CMUR) and the material footprint of the EU and all of its member states. Actually, the higher the CMUR, the lower the material footprint RMC in a country, so there is a synergy between increasing circular economy and sustainable development. By increased recycling of materials and this way, reducing the extraction of raw materials, the material footprint of the economy is decreasing, therefore there is progress in one of the most important SDG 12 indicators, as will be analysed in the next section of this paper. Another significant study by Reike et al. (2018) [29] examines a variety of strategies to preserve the value of goods and materials (and this way, reducing indirectly the pressure on the environment) from longer loops such as recycling and energy recovery to shorter loops like reuse, repair, refurbish, and remanufacturing. The authors state the importance of policies focusing on shorter loops, particularly those closer to the consumer, like refurbishment and remanufacturing. The differentiation between the terms reuse, recycling and recovery is presumably quite important for the understanding and application of the targets stated in EU waste legislation. The general trend in the European Union is to improve and strengthen all of the waste management activities, from the quantity of waste generated to the disposal of the materials, in light of a more sustainable and circular economy. (Frone D.F. et al., 2020b) [21].

In the notable study by Knäble et al. (2022) [25] the authors employ a regression model to examine how the three facets of SD—economic, environmental, and social—are affected by the cycles and sources of value of the CE.

Table 1. Primary indicators and variables for diverse circular economy "R" value streams

Value sources of CE	**Lasting Resource**	**CE markets**	**Longer life cycles**	**Linked value chains**
Main target	Renewable energy sources	Optimal use of product	Prolonged life cycle of products	Reduction of waste
Indicator area	Renewable resources	Reuse and share	Repair and remanufacturing	Recycling
Proxy variables	Renewable energy consumption	Number of employees working in second hand shops	Number of firms in repairing activities	Waste recycling rate, CMUR

Source: own adaptation from (Knäble et al., 2021) [25].

They processed a panel data set based on a sample of 25 European countries for the period 2010 to 2019. It is interesting and useful to observe the variables and indicators used in the model, in order to analyse the impact of the CE specific value sources, respectively the Rs (renewable, recovery,

recycling, reuse, repair, remanufacturing etc.) on sustainable development (Table 1)

The findings show that the end-of-life strategy of repair and remanufacturing create noticeable sustainability benefits, in line with the outcomes of Yang et al. (2018) and Liu et al. (2016) [37, 26]. According to current studies, remanufacturing and repair are essential for the shift to a circular economy (Rogers et al., 2021) [30]. Additionally, in line with earlier studies, the findings of Knable et al. (2022) demonstrate that repair and refurbishment contribute to economic increase in terms of GDP per capita (All-Party Parliamentary Sustainable Resource Group, 2014) [1], so circular economy means sustainable economic growth and development.

Recent studies confirm the trends in the contribution of the CE to the reaching of the SDG12 objectives. The study (Cifuentes-Faura, 2025) [2] creates a composite index to gauge how well EU nations are adopting sustainable patterns of production and consumption. The analysis reveals notable performance disparities throughout the area by ranking EU member states according to their commitment to important SDG 12 (Responsible Consumption and Production) objectives. Significant differences in EU circular economy (CE) progress are revealed by this analysis, which identifies France, Italy, and the Netherlands as leaders in SDG 12 compliance while pointing out large gaps in other countries.

The next section approaches these issues from the point of view of the authors.

Key sustainable development trends in the direction of SDG 12 Responsible production and consumption inside the European Union

SDG 12 demands that companies, legislators, and consumers take a wide range of steps to adjust to sustainable practices. It promises sustainable production and consumption built on cutting-edge technology, resource efficiency, and less waste worldwide.

Overall, during the evaluated five-year period, 2018-2023 the EU's trend of progress toward SDG12 has been mostly positive, as represented by the tachometer in Figure 1.

This is mainly due to the fact that EU has seen improvements in the consumption patterns of raw materials, chemicals, CO2 emissions from automobile fleets, and energy productivity, while the value provided from the green services and products sector has increased significantly. (Eurostat Statistics Explained, accessed January 2025) [14]. Conflicting trends still exist in the production and management of waste, which inevitably affects the level of development of the circular economy (CE). The EU's use of circular materials is not growing fast enough to meet the 2030 target, despite a decline in solid waste output.

Fig. 1. Overall trend of SDG 12 in 2025 in the EU
Source: Eurostat, Statistics explained, https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=SDG_12_Responsible_consumption_and_production, Accessed on 10 January, 2026 [14].

Table 1: Indicators measuring progress towards SDG 12, EU

Table 2: Explanation of symbols for indicating progress towards SD objectives and targets

Fig. 2. Trends and progress of specific indicators towards SDG 12 in the EU
Source: Eurostat, Statistics explained, https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=SDG_12_Responsible_consumption_and_production, Accessed on 10 January, 2026 [14].

In Figure 2 there are two tables with the purpose of showing the trends of progress of the main indicators of SDG12, according to the official reporting of the European Union. On a positive note, the value added from the environmental goods and services sector has been growing. (Figure 2, Table 1 and Table 2, provides a legend for the arrow symbols indicating the patterns of the indicators in Table 1). The following discusses some of the major patterns SDG12 indicators that the strategies of sustainable consumption and production under consideration seek to attain as well as their current level of performance. First, there are the main indicators of consumption patterns: material footprint and consumption footprint. In general, there are issues of progress towards the SDG 12 targets for the following indicators:

1)The Material footprint or Raw Material Consumption (RMC) is another term for the global need for the extraction of natural resources (minerals, metal ore, biomass, and fossil fuels) generated by the intake of goods and services in a geographical reference region. The SDG 12 qualitative targets call for a substantial reduction in the material footprint by 2030.

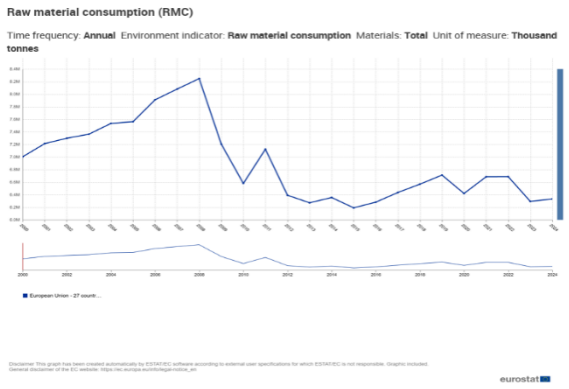

Fig. 3a. Evolution of the RMC in the EU, 2000-2024
Source: Eurostat own processing, Accessed in May, 2026 [16].

The long term trend for 2000-2023 shows significant progress towards SDG 12 objective in the EU (green arrow pointing upwards), due especially to a sharp decrease in the RMC in 2008-2015; however, there was only moderate progress in the period 2018-2023 (oblique green arrow to the right in Table 1) since RMC has been resuming its fluctuations (Figure 3a).

In Figure 3b there are compared the levels of the material footprint (in tonnes/inhabitant) in the EU countries, and the EU average, showing also the trend 2019-2024. The highest material footprint is that of Finland followed by Romania, while the lowest and decreasing material footprint is in Netherlands.

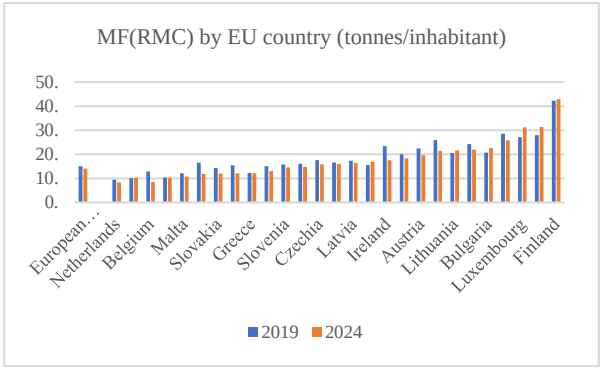

Fig. 3b Material footprint (RMC) by EU country, 2019 and 2024
Source: Eurostat own processing, Accessed in May, 2026 [16].

2) The consumption footprint (CFpt) is a collection of sixteen life cycle assessment (LCA)-based metrics that combine information on consumption intensity and environmental effects of representative items to evaluate the environmental effects of consumption in the EU and its member states (Sanye & Sala, 2023) [34]. For the EU Consumption footprint indicator the average growth rate was positive for the period 2010-2023, so in Table 2 there is a red arrow pointing downwards right (insufficient progress).

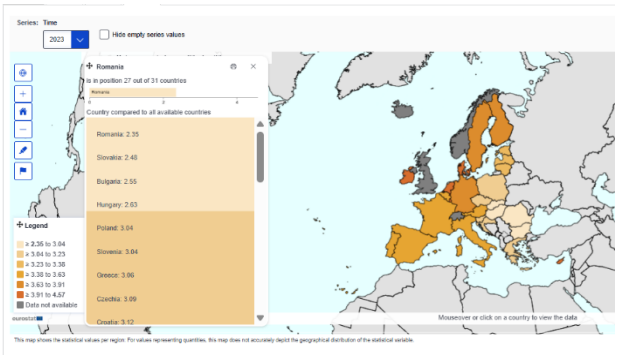

Fig. 4. Map of the consumption footprint in the European Union Member States, 2023
Source: Eurostat, Accessed on October 25, 2025.

It is remarkable that Romania had the CFpt (of only 2.35) in 2023 ranking in the position 27 since the lowest in the European Union (Figure 4).

3) The Circular material use rate. The percentage of materials reclaimed and returned back into the economy in relation to total material usage is measured by the Circular Material Use Rate (CMUR). The ratio of circular material usage to total material utilization is known as the CMUR.

This SDG 12 indicator is of most importance since this is also the main indicator measuring the Circular Economy performance of every state and at the EU level. It is the only SDG12 Responsible consumption and production indicator with a quantitative 2030 target, that is to increase by 100% (the 2020 EU CMUR) [15], to reach at least 22.5% in 2030.

Regrettably, the downward-pointing red arrow indicates inadequate advancement towards the EU SDG12 target, since the increase of the CMUR has been very moderate, rendering the achievement of the 2030 target nearly unattainable for the European Union.

It may be observed in Figure 5 that between 2008 and 2023, the EU circular material use (CMU) rate — the share of used materials derived from collected waste —has increased from 9.1% to 11.8%. Since 2016, the CMU rate has stagnated at between 11.3 % and 11.6 %.

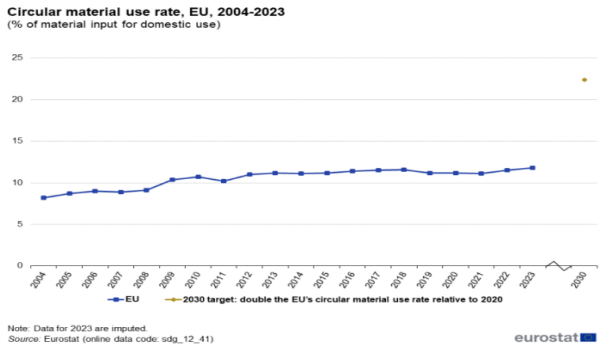

Fig. 5. Evolution of the CMUR in the EU, 2004-2023
Source: Eurostat (online data code sdg_12_41) [15].

Although the average EU CMUR level in 2023 was of only 11%, there are member states advanced in the circular economy, with higher CMUR than the EU: Netherlands (over 30%), Italy (over 20%), Malta, Belgium, Estonia, France, Austria, Germany, Czechia. These are countries with sustainable circular economy (Figure 6, Table 3).

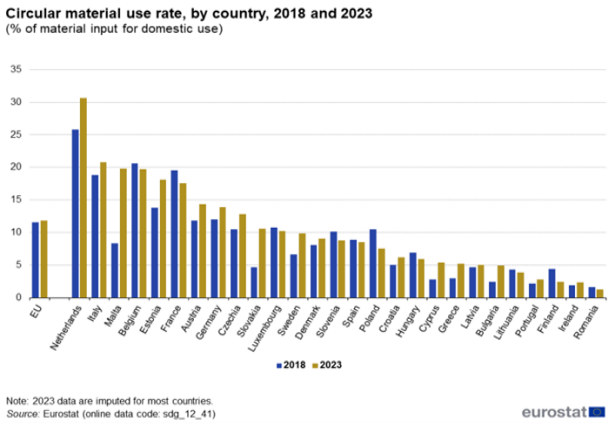

Fig. 6. The CMUR by country, in the European Union, 2018 and 2023
Source: Eurostat (online data code sdg_12_41) [15].

The rest of the EU 27 member states (including Romania on the last place) have not yet reached the average EU CMUR and are still struggling to sustain their recycling and circular economy.

The trend of the CMUR 2020-2024 allows for a prediction on the EU member states who have reached or are likely to meet the SDG 12 target of at least 22.5% in 2030, as in Table. For most member states and the EU, the forecast for achieving the 2030 target is unfavourable (improbable).

Table 3. Summary of CMUR rates and trends in some EU countries

EU countries	**2020**	**2024 (latest)**	**Trend**	**Meeting SDG12 target 2030 CMUR =22.5%**
EU-27 Average	11.2%	12.2%	Increasing	Improbable
Netherlands	28.2%	32.7%	Highest	Exceeded
Belgium	22.9%	22.7%	High	Exceeded
Italy	20.9%	21.6%	High	Probable
Estonia	<10%	20.5%	Strong Increase	Probable
Malta	10%	19.8%	Strong Increase	Probable
France	15.4%	16.8%	Moderate	Improbable
Germany	12.9%	14.8%	Stable/Slight Rise	Improbable
Czechia	11.5%	14.8%	Slight Rise	Improbable
Portugal	2.6%	3.0%	Low	Improbable
Finland	4.8%	2.0%	Decreasing	Improbable
Ireland	1.8%	2.0%	Very Low	Improbable
Romania	1.5%	1.3%	Lowest	Improbable

Source: Own ranking and forecast, based on processing data from Eurostat (online data code sdg_12_41), accessed in May 2026

4) Generation of waste (GW). This indicator is defined as all waste generated in a country. It covers waste generated by industrial production (including the waste management sector itself) and by households.

For the GW, the EU SDG12 target is by 2030, to substantially reduce waste generation through prevention, reduction, recycling and reuse. As can be seen in Figure 7, the total amount of waste generated in the EU has slowly increased between 2008 and 2018, but decreased by 7.9% in 2020, probably due to the economic slowdown caused by the COVID-19 pandemic.

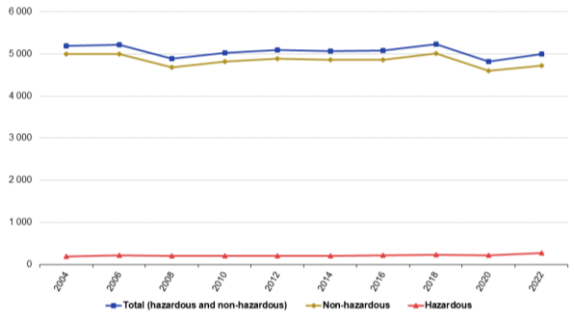

Fig. 7. Evolution of the waste generated in the EU, 2004-2022 (kg/capita)

Source: Eurostat (sdg_12_51) [17] accessed in January 2026.

However, by 2022, waste generation had increased again by 3.7% compared to 2020. Nevertheless, with the exception of mineral wastes, 56% of the solid waste in the EU had been recycled in 2022, indicating a considerable potential for the growth of the circular economy.

Sustainable circular production and consumption policies promoting SDG 12 in the European Union

The above analysed Material footprint or RMC, the Circular Material Use Rate CMUR, and the Waste generated are, first of all, indicators of progress towards SDG 12 Responsible Consumption and Production and the Circular Economy in the European Union. It is necessary to appreciate the dual function of these indicators. They are extremely useful to substantiate strategies and policies for the common market of the European Union, since the recent EU policies of sustainable production and consumption target both the sustainable development and CE transition. This latest set of interconnected sustainable product initiatives was built on previous enforced minimum environmental standards for several products and industries that have helped decrease EU's environmental and climate impact particularly the consumption of energy.

The most comprehensive and significant new regulations and directives adopted are:

- the Eco-design for Sustainable Products Regulation (ESPR) (EU 2024/1781) [9];
- the new EU Directive on the repair of goods (Directive (EU) 2024/1799), also known as the "Right to Repair" Directive. It entered into force on July 30, 2024, with member states needing to apply the rules by July 31, 2026, with the goal to help prolong product lifespans by facilitating accessible repairs for users [11]
- the EU Strategy for Sustainable and Circular Textiles (COM (2022) 141 final) [6] seek to enhance the longevity of textiles, facilitate reuse, repair, and recycling, minimize waste, and furnish consumers with improved information using instruments such as the Digital Product Passport (imposed by the ESPR).
- due to the on-going reforms and policies, the Waste Framework Directive (2008/98/EC) [12] has just been amended on September 2025, by the Directive (EU) 2025/1892 (European Parliament, 2025) [10].

In order to guarantee that consumers continue to actively participate in the transition, the European Commission has also published a legislative proposal to Empower Consumers in the Green Transition COM (2022) 143 [5]. This proposal includes specific modifications to facilitate the requisite "greening" of EU consumer law (Figure 8).

Nonetheless, as represented in the Figure 8, the core of the policy package is the proposal for a ESPR (COM (2022) 142), which broadens the scope of the Eco-design framework to include a wider range of products because product design accounts for up to 80% of a product's life-cycle environmental impact. By standardizing the consumption of sustainable products, the European Union would greatly empower its

consumers for the green circular transition and a sustainable development.

Fig. 8. Overview of recent EU sustainable production and consumption policy initiatives
Source: COM/2022/140 final [13].

The Ecodesign for Sustainable Products legislation (ESPR) is a framework legislation, with particular requirements for product groupings to be implemented gradually by delegated acts in the years to come. The first working plan (2025-2030) was adopted in April 2025; this plan prioritizes eco-design requirements for initial product groups, including textiles, furniture, tires, steel, and aluminium. The requirements are expected to apply around 2027. All economic participants in the value chain are covered by the rule, including importers, distributors, and producers (both within and beyond the European Union). Since the ESPR's main objective is to make environmentally friendly products ubiquitous in the EU, it is a sustainable production policy that is in line with SDG 12. However, it should be noted that the Eco-design for Sustainable Products Regulation (EU 2024/1781) [9] is also an important circular economy policy since it aims to enhance the sustainability of goods sold in the EU by improving their energy efficiency, endurance, circularity, and recycling potential.
The ESPR's primary new features include:

- The Digital Product Passport (DPP), a digital identity card for materials, components, and products that will be introduced by the ESPR. It will hold pertinent data to assist the sustainability of products, foster their circularity, and boost legal compliance.
- By outlawing the destruction of unsold textiles and footwear, the ESPR addresses this practice for the first time in the EU and paves the path for similar prohibitions in other industries.
- By setting required Green Public Procurement regulations for particular products, the ESPR will assist in directing public finances in a more sustainable direction. Consequently, public authorities must purchase products with the best possible performance of sustainability and circularity.

The regulations pertaining to sustainable products are intended to significantly expand the range of environmentally friendly items available to European Union consumers and influence their standard selection.
In Romania, the National Strategy for Sustainable Development NSSD 2030 (Romanian Government, 2018) [32] seeks to accomplish the shift to a circular economy in accordance with SDG 12. The change to a new development paradigm is also suggested by the Romanian National Strategy regarding the Circular Economy NSCE [31] by introducing circular economy elements, increasing resource productivity, decreasing food waste and reducing waste generation at all levels, increasing recycling and reuse, encouraging companies to adopt sustainable practices and integrating information on the sustainability of their activities into the reporting.

CONCLUSIONS

The purpose of this article is to underscore the link between circular economy and sustainable development and further the analysis of the impact and contributions of sustainable production and consumption policy measures for the advancement of SDG 12 on the circular economy's implementation in EU member states.
In order to embrace the circular economy's tenets, economic theories must move toward environmental logic, where resource productivity, resiliency, and sufficiency

become key paradigms of value production. The circular economy serves as a cross-cutting aspect in the 2030 Agenda, offering a comprehensive, systems-based strategy to decoupling human progress from environmental deterioration. The circular economy is receiving a lot of attention from governments, businesses, academia, and officials in order to accomplish the 2030 Sustainable Development Goals (SDGs) that the United Nations (UN) set in 2015. This is particularly the case since the EU issued the Circular Economy Action Plan [18].

SDG 12 addresses one of the most important topics of sustainable development, a key and cross-cutting topic for all the SDGs, namely sustainable patterns of consumption and production – by diverse targets and indicators.

While the EU's overall progress over the five-year period evaluated was largely favourable, there are two trend indicators that signal moderate or insufficient progress towards the EU's 2030 SDG 12 targets. Both analysed indicators, namely the Material footprint or Raw material consumption (RMC) and the Circular material use rate (CMUR), are monitored both as indicators of Sustainable Development and the Circular Economy, and previous research has demonstrated through modelling their significant correlation and synergy. As a conclusion for the first research problem, the analysis of the progress in the SDG12 indicators for the EU countries shows that indeed, in general, the reverse correlation between the rate of circularity and material footprint holds. The country with the highest CMUR, respectively the Netherlands has also managed to have the lowest RMC or material footprint in the European Union, so advancement in the transition towards CE means also progress towards the SDG12 in qualitative and quantitative targets. Due to the insufficient growth of the CMUR in the EU, it is probably no longer possible to achieve the target of doubling the CMUR (2020) so that it reaches 22.5% by 2030. However, as presented in the Table 3, there are only a few EU countries who have reached or are likely to meet the CMUR target for 2030.

In response to the second research question, analysis shows that in the European Union, there is pronounced heterogeneity in Member States' progress towards SDG 12. Overall, countries with good progress in the circular economy (measured by CMUR) are also making significant progress on SDG 12, i.e. in reducing the consumption of raw materials RMC, respectively their material footprint. Romania is may be the least advanced countries in terms of progress both in terms of SDG 12 and the circular economy indicators, which urges the continuation of efforts to develop all circular economy mechanisms (recycling, recovery, reuse, repair and re-manufacturing) in our country. These directions of action are clearly specified both in the National Strategy for Sustainable Development 2030 and in Romania's National Circular Economy Strategy, but progress towards SDG 12 and circular economy targets is still low in Romania. It should be noted that the national CEAP was adopted late in Romania (only in October 2023) while the most advanced in CE countries have implemented their national strategies and policies for a decade (Netherlands and Belgium, since 2016).

Therefore, the conclusion for the third research problem is that apart from more or less effective national strategies regarding the CE, the current EU CEAP is not sufficient for uniform and powerful transition throughout the entire European Union. Harmonizing EU regulations through the new ESPR and other sustainable consumption and production policies is necessary to: avoid market distortions; significantly increase the market for environmentally friendly products and reduce the costs and administrative complexity associated with compliance for companies.

Companies who buy and sell on EU markets will be encouraged to develop and invest in circular business models and the products of the future with a clear unique legislative framework on product environmental sustainability. Therefore, the implementation of the specific policies in the new rules and guidelines on the Right to Repair, ESPR, and the textiles strategy should aid EU governments, businesses, and citizens in their efforts to achieve the Sustainable

Development Goals, including assisting underperforming nations like Romania.

It is essential to ensure that all of these policies complement one another in order to secure a genuine development of the circular economy and sustainable consumption and production inside the European Union.

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THE STATUS OF ORGANIC AGRICULTURE IN ROMANIA COMPARED TO OTHER EUROPEAN UNION MEMBER STATES

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Abstract

The present study aims to assess the current state of organic agriculture in Romania in comparison with other EU member states. Given the complex nature of the subject, the research has been structured based on a holistic approach that integrates multiple dimensions of the issue. This research integrates data from both European and national statistical sources (FAOSTAT, FiBL, MARD, NIS), supplemented with datasets available through open data portals and with a comprehensive review of the relevant scientific literature. Comparisons among Romania and the other EU countries regarding each studied indicator were displayed as maps visualized with www.datawrapper.de. Results show sustained growth of Romania's organic sector, ranking it among Europe's top ten by area. However, the organic share of total utilized agricultural area remains low at 5.75 %, half the EU-27 average (11.14 %). The results highlight the need to intensify the promotion of organic farming practices, increase consumer awareness, and develop local markets and short supply chains, in order to strengthen the role and visibility of organic production in Romania. Overall, the study confirms the growing importance of organic agriculture and the market for organic products.

Key words**:** *organic agriculture, organic farming, sustainable agriculture, sustainable development*

INTRODUCTION

In the current European context, organic agriculture constitutes one of the central pillars of the green transition undertaken by the European Union as part of its strategy for sustainable agriculture [2]. The European Union established in 2020 a strategic objective, presented within the Farm to Fork Strategy as part of the European Green Deal. This objective aims for at least 25% of the utilised agricultural area to be managed under organic farming practices by 2030 [4, 5]. Although organic agriculture has received increasing attention and substantial promotion of its fundamental principles in recent years, this farming system has its origins in much earlier theoretical and practical concerns [9]. The foundations of organic agriculture were laid at the beginning of the 20th century by Rudolf Steiner, who formulated the principles of biodynamic agriculture in 1924 [20, 11], and later by Sir Albert Howard, who contributed decisively to the development of the modern concept of organic agriculture [8, 7]. The emergence of organic agriculture in the second half of the 20th century was driven by multiple factors, among which the most significant was the need to address accelerated soil degradation. This degradation was caused by the adverse effects of chemical fertilization and the intensified use of pesticides in agriculture following World War II [3]. The modern organic agriculture movement consolidated beginning in the 1980s. Although organic farming practices had been applied sporadically since the 1960s, the significant development of organic agriculture materialized in the 1980s, with the introduction of the first national legislation on organic farming (France – 1980, Austria – 1983, Denmark – 1987) [19].

This stage marked the transition from isolated initiatives to the institutionalization and accelerated expansion of organic agriculture. A defining moment in the consolidation of the European regulatory framework was the adoption of Council Regulation (EEC) No 2092/91 in 1991, which harmonized production standards at the Community level. The growth and consolidation of the organic sector was stimulated and supported through

its incorporation into the mechanisms of the Common Agricultural Policy (CAP), which offered both the legislative framework and the financial support necessary to sustain this agricultural system, as well as by the continuous increase in demand for organic products from a group of consumers highly concerned with healthy and sustainably produced food [10, 13]. Under these circumstances, the organic agriculture sector underwent rapid development, evolving from a marginal niche into a strategic pillar of sustainable agricultural development at the European level. From the early 1990s onward, organic farming expanded swiftly across nearly all European countries [21]. Romania, although benefiting from significant natural potential and a long-standing agricultural tradition, entered this trend relatively late, with concrete directions for the development of the organic agricultural sector only beginning to be observed after the 1990s. The first Romanian organic initiatives were initiated in the Transylvania region, where, around 1992, a small group of farmers decided to stop using synthetic fertilizers and chemical pesticides. As a result of this change, these farmers became the pioneers of the organic agriculture movement in Romania. The first Romanian farmers interested in organic agriculture benefited from projects funded by various international organizations. Such projects included, in 1993, courses specialized in organic farming organized by Swiss farmers, as well as practical internships for Romanian farmers interested in adopting and practicing this agricultural system [12].

The development of organic agriculture in Romania has been marked by significant growth following the country's accession to the European Union in 2007. This expansion of organic agriculture sector was primarily sustained and promoted by the financial measures provided by the Common Agricultural Policy. Growth in organically managed agricultural land has benefited from European funding and compensatory payments, which stimulated its expansion, as well as from the continuous increase in external demand for organic products, boosting their export and simultaneously contributing to the consolidation of Romania's organic sector. The area under certified organic farming increasing from around 245 thousand hectares in 2015 to over 780 thousand hectares in 2024. During the 2007–2013 and 2014–2020 programming periods, organic farming benefited from support under the National Rural Development Programme (NRDP), notably through Measure 214 – Agri-environment Payments and Measure 11 – Organic Farming, which targeted both conversion to organic production systems and the maintenance of organic certification [16]. In pursuing the objectives outlined in the Farm to Fork Strategy, Romania has entered a period marked by significant growth in organic farming. Although the organic sector has developed significantly in recent years, it still remains below the European Union average and at a considerable distance from leading member states such as Austria, Spain, France and Italy, highlighting the presence of structural and institutional constraints affecting the sector's convergence trajectory.

This article provides a comparative analysis of Romania's organic agriculture within the context of European Union member states, highlighting both the still untapped opportunities and the challenges that impede progress and hinder the achievement of common European targets.

MATERIALS AND METHODS

The research methodology for this study relies on the examination of data sourced from both national and international statistical repositories.

National sources utilized in this study include publications from:

- The Ministry of Agriculture and Rural Development (MARD) [14];
- The National Institute of Statistics [15];
- The Agency for Payments and Intervention in Agriculture (APIA) [1].

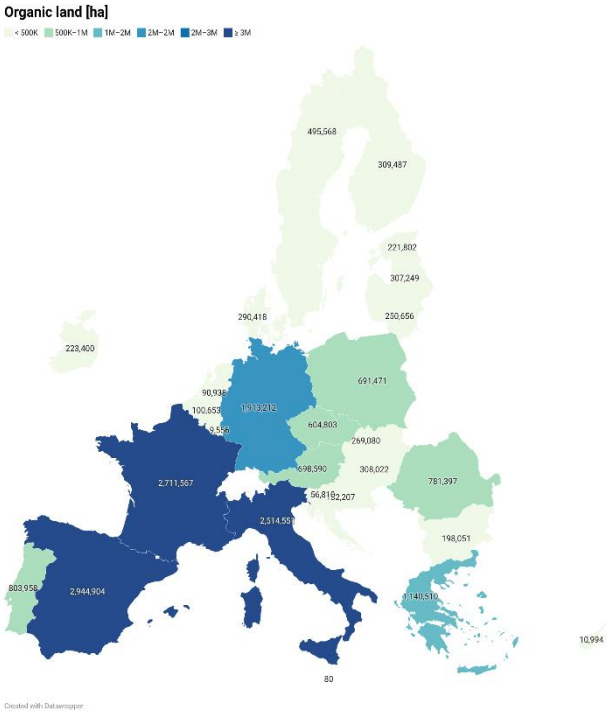
International data were obtained from:

- The FAO Corporate Statistical Database (FAOSTAT) [6];
- The Research Institute of Organic Agriculture (FiBL) [18].

The analysis is focused on the following specific indicators: organically managed agricultural land, both certified and under conversion, the number of organic operators and processors, as well as the consumption of organic products. For Romania, the study also examined the structure of organic crops.
The methodology is based on comparisons among Romania and the other EU countries regarding each studied indicator displayed as a map visualized with www.datawrapper.de [22].

RESULTS AND DISCUSSIONS

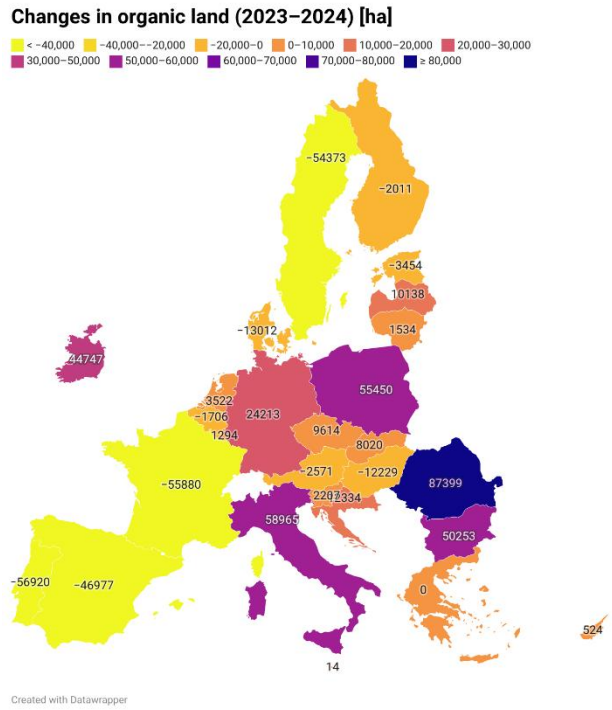
The analysis of agricultural land registered under the organic system in the EU member states was carried out based on the most recent statistical data published by FiBL in 2026, referring to the situation in 2024. The data clearly highlight the existence of major differences between countries regarding organically cultivated land. At the level of 2024, the area of agricultural land managed organically in the EU exceeded 18 million hectares, highlighting the consolidation of the upward trend in the adoption of sustainable agricultural practices across the EU.
Spain accounts for the largest area under organic crop production, having surpassed France in 2023 in terms of organically cultivated land. In 2024, nearly 2.95 million hectares in Spain were managed according to organic farming standards. France ranks second, with an organic area exceeding 2.71 million hectares, followed by Italy with approximately 2.5 million hectares. Collectively, these three countries represent roughly 45% of the total organic area within the European Union (Map 1).
Romania, with over 780,000 hectares under organic farming in 2024, holds a strong position, ranking seventh among the 27 EU member states. Romania's organic agricultural area is larger than that of several Central and Eastern European countries, such as Hungary, Bulgaria, and Slovakia, as well as some Western European states with a long-standing tradition in organic agriculture, including Austria. However, compared to the main European leaders, Spain, France, and Italy, the differences remain significant.



Map 1. Distribution of organic land across EU member states, 2024 [ha]
Source: Map created from own analysis of FiBL statistical data (2026), visualized with www.datawrapper.de [22].

An analysis of changes in organic agricultural area between 2023 and 2024 (Map 2) shows that some member states recorded substantial increases in organic land, while others experienced significant declines.
Romania stands out with one of the largest expansions within the European Union, with its organic area increasing by over 87,000 hectares in a single year, ranking first in terms of growth magnitude. This is followed by Italy, Poland, and Bulgaria, where increases exceeded 50,000 hectares. In contrast, notable reductions in organic land were reported in countries such as Portugal, France, and Sweden, with decreases of approximately 55,000 hectares.
This comparative analysis of organic areas, conducted both in absolute and dynamic terms, show total organic land and the changes recorded during the 2023–2024 period, provides a relevant overview of the pace at which organic agriculture is

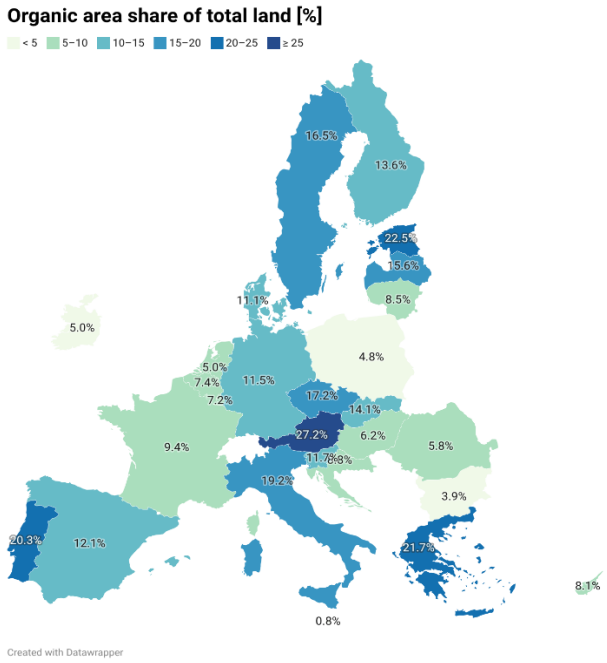
developing within the European Union, as well as Romania's position in this context.
However, an evaluation limited solely to the physical size of the area or to annual variations does not allow for a comprehensive assessment of the degree to which organic agriculture is integrated into the national agricultural structure.



Map 2. Evolution of organic land across EU member states, 2023 vs. 2024 [ha]
Source: Map created from own analysis of FiBL statistical data (2026), visualized with www.datawrapper.de [22].

For a more in-depth structural analysis, it is necessary to relate organic area to each country's total agricultural area. This indicator reflects the actual share of the organic system within overall land use and reveals the level of transition toward sustainable production models.
Thus, shifting from a purely quantitative to a relative analysis enables a more nuanced interpretation of Romania's performance in comparison with other member states and with the European objectives concerning the increase in organically managed farmland.
In 2024, 11.14% of the EU's total farmland was managed organically, indicating a moderate adoption of sustainable agricultural practices, but also highlighting significant disparities among member states. The range of values is particularly wide, varying from 0.75% in Malta to 27.24% in Austria, reflecting a difference of more than 26 percentage points between the two extremes (Map 3).
The comparative analysis reveals a group of high-performing countries where organic agriculture exceeds 20% of total agricultural land. Austria (27.24%) ranks as the European Union leader, followed by Estonia (22.51%), Greece (21.65%), and Portugal (20.26%).
A second group consists of countries above the EU average but below the 20% threshold, including the Czech Republic (17.16%), Sweden (16.49%), Latvia (15.6%), Slovakia (14.09%), Finland (13.63%), Spain (12.05%), Slovenia (11.74%), and Germany (11.52%).

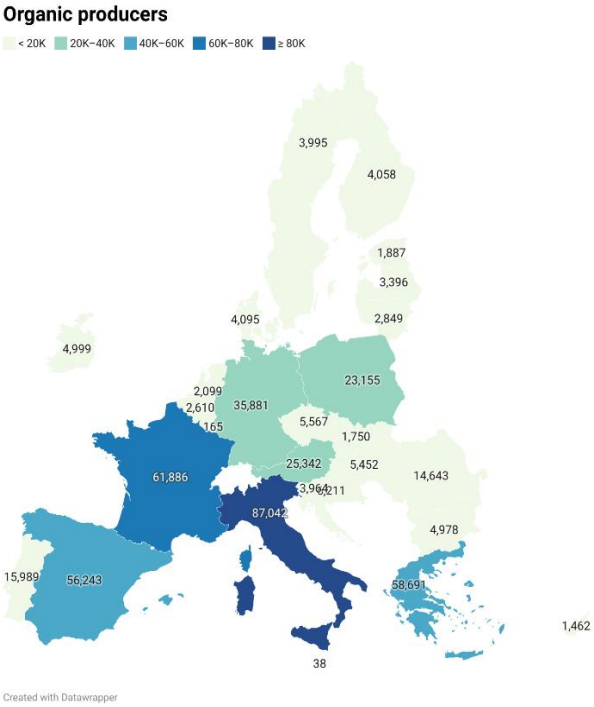
These countries demonstrate a substantial integration of organic practices, indicating a relatively advanced transition process.



Map 3. Organic area share of total land across EU member states, 2024
Source: Map created from own analysis of FiBL statistical data (2026), visualized with www.datawrapper.de [22].

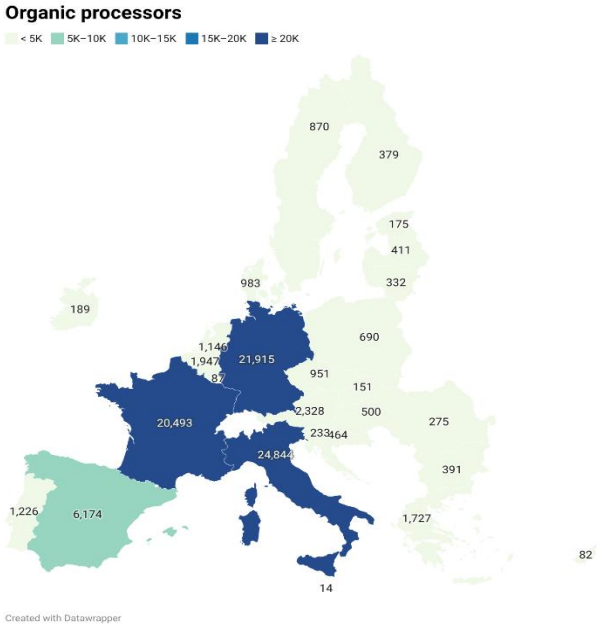
In contrast, a considerable number of member states remain below the EU average, including France (9.38%), Croatia (8.78%), Lithuania (8.52%), Cyprus (8.11%), Belgium (7.36%), Luxembourg (7.23%), Hungary (6.16%),

Romania (5.75%), the Netherlands (5.01%), Ireland (4.95%), Poland (4.76%), and Bulgaria (3.92%). These lower levels may reflect structural barriers such as farm fragmentation, limited access to support schemes, certification costs, or insufficiently developed domestic demand. The growth of organic agricultural land in the European Union should also be considered alongside the number of certified organic producers, as the percentage of land under organic management does not fully capture the distribution of economic operators actively involved in organic farming. In 2024, the European Union registered a total of 438,447 certified organic producers, highlighting the substantial presence of operators actively involved in organic agriculture (Map 4).



Map 4. Organic producers across EU member states, 2024
Source: Map created from own analysis of FiBL statistical data (2026), visualized with www.datawrapper.de [22].

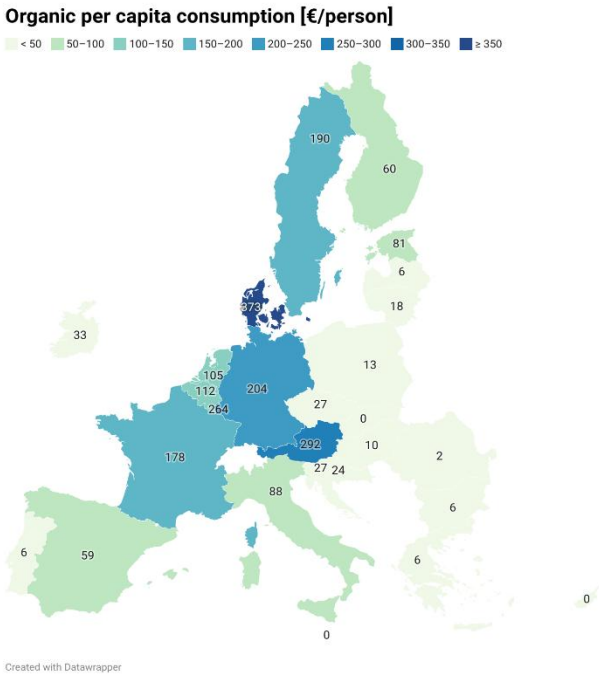
Their distribution is uneven across Member States. Italy (87,042), France (61,886), Greece (58,691), and Spain (56,243) account for the largest numbers of producers, forming the core of Southern European organic agriculture. Germany (35,881) and Austria (25,342) further complete the group of countries with a high density of organic operators. In Central and Eastern Europe, in the case of Poland (23,155) and Romania (14,643), a high number of producers are registered; however, this number is much lower compared to the number of producers in the south-western part of the European Union.
In contrast, countries such as Luxembourg, characterized by limited land and small numbers of farmers, occupy the lower end of the scale.
At the same time, in 2024, the EU's organic processing sector included 88,977 certified processors, reflecting an advanced level of development of organic value chains at the EU level. Processing represents the essential link between organic agricultural production and the consumer market, with the distribution of this indicator indicating the extent of industrial integration and the ability of member states to to create added value in the organic sector (Map 5).



Map 5. Organic processors across EU member states, 2024
Source: Map created from own analysis of FiBL statistical data (2026), visualized with www.datawrapper.de [22].

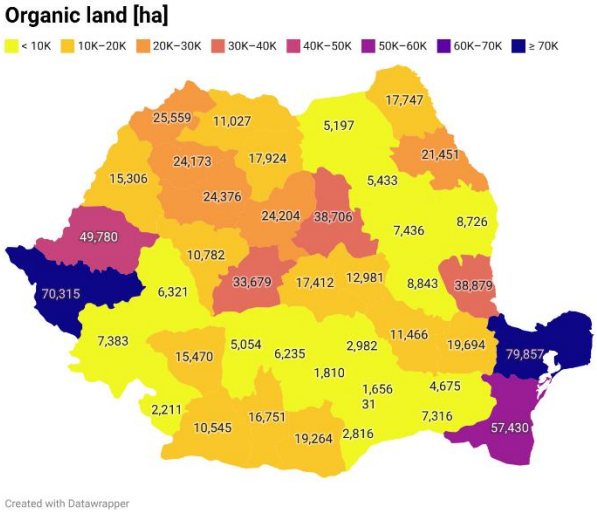
In the case of Romania, the low level of processing (275 processors), relative to the existing area and number of producers, suggests a structure predominantly oriented toward the export of raw materials, with limited added value.

Average per capita consumption of organic products in the European Union reached €110, with eight member states exceeding the threshold of €100 per capita. Denmark ranks first, with €373 per capita, followed by Austria with €292 per capita, indicating a strong integration of organic products into national consumption patterns. These indicator reflects the capacity of domestic markets to sustain organic production and illustrates the extent to which organic products are embedded in consumer behavior. Data for 2024 reveal significant disparities across member states, with values ranging from as little as €2 per person to more than €370 per person, show substantial differences in purchasing power, consumer preferences, and market development (Map 6).



Map 6. Organic per capita consumption [€/person] across EU member states, 2024
Source: Map created from own analysis of FiBL statistical data (2026), visualized with www.datawrapper.de [22].

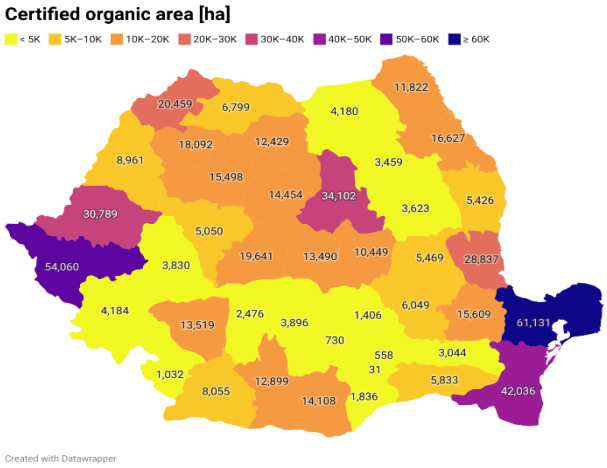
However, an important limitation concerns the availability and timeliness of data. In official statistical publications, several member states have not reported updated figures for many years. Consequently, it is difficult to obtain an accurate and up-to-date assessment of the actual role of organic products in consumer preferences and of the financial effort allocated per capita to organic consumption.
Romania, as a member state of the European Union, stands out for its high ecological potential but with a still limited organic agriculture sector. Although the country has a relatively large agricultural area, only slightly over 780,000 hectares are registered under the organic system. Analysis by county shows significant differences in the distribution of areas and producers, reflecting the concentration of the sector in favorable regions and its underdevelopment areas or regions with fragmented land (Map 7).
The highest values are recorded in counties such as Tulcea (79,857 ha), Timiș (70,315 ha), Constanța (57,430 ha), and Arad (49,780 ha), indicating a concentration of organic production in the western and south-eastern parts of the country.



Map 7. Distribution of organic land across Romanian counties, 2024 [ha]
Source: Map created from own analysis of MARD statistical data, visualized with www.datawrapper.de [22].

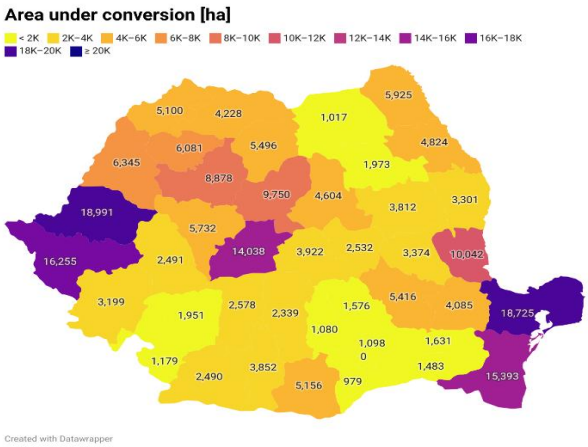
This is followed by counties with intermediate values, such as Sibiu (33,679 ha), Harghita (38,706 ha), Galați (38,879 ha), Satu Mare (25,559 ha), and Cluj (24,376 ha).
At the opposite end are counties with a very low presence of organic agriculture, such as Ilfov (1,656), Dâmbovița (1,810), and Giurgiu (2,816), suggesting that in these areas the sector is nearly non-existent and mainly oriented toward other forms of agriculture.

Analyzing the data on certified organic areas and areas under conversion by county in Romania reveals several important trends regarding the dynamics and structure of organic agriculture (Map 8).



Map 8. Distribution of certified organic land across Romanian counties, 2024 [ha]
Source: Map created from own analysis of MARD statistical data, visualized with www.datawrapper.de [22].

The largest certified areas are found in counties such as Tulcea (61,131 ha), Timiș (54,060 ha), Constanța (42,036 ha), and Harghita (34,102 ha). Additionally, counties like Satu Mare (20,459 ha), Sălaj (18,092 ha), and Galați (28,837 ha) have significant areas, indicating the development of organic farming across a broader range of regions, particularly in Transylvania and Moldova.

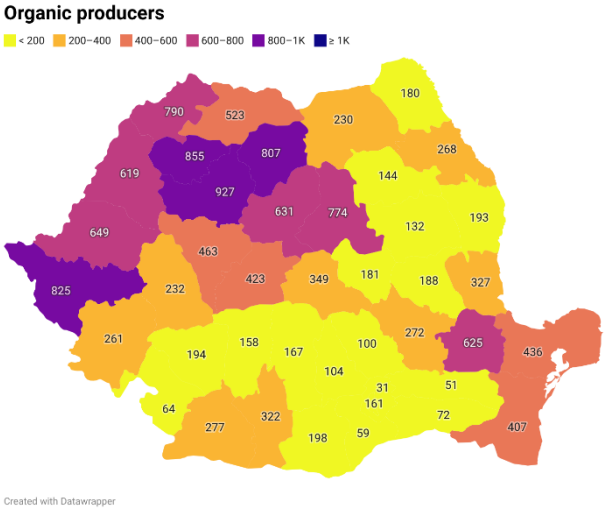


Map 9. Distribution of area under conversion across Romanian counties, 2024 [ha]
Source: Map created from own analysis of MARD statistical data, visualized with www.datawrapper.de [22].

The analysis of areas under conversion shows that counties such as Arad (18,991 ha), Tulcea (18,725 ha), and Timiș (16,255 ha) continue to invest in expanding their organic areas, indicating a trend of growth and consolidation in the sector (Map 9).

Comparing areas under conversion with certified areas reveals that most counties with large organic sectors have a high ratio of certified to conversion area, indicating that the sector is already consolidated. In counties with smaller values, conversion represents a significant proportion of the total, suggesting the early stages of organic development.

The data on organic agricultural producers by county show that the sector is concentrated in regions with strong organic agricultural traditions. Counties such as Cluj (927 producers), Sălaj (855), Harghita (774), Satu Mare (790), and Timiș (825) have the highest number of producers, indicating a strong presence of organic farmers and the potential for developing local production and marketing networks (Map 10).



Map 10. Distribution of organic producers across Romanian counties, 2024 [ha]
Source: Map created from own analysis of MARD statistical data, visualized with www.datawrapper.de [22].

In contrast, urban or fragmented-land counties, such as Ilfov (31 producers), Dâmbovița (104), and Giurgiu (59), have very few producers, reflecting challenges in developing organic agriculture. This distribution highlights a clear regional pattern, with producers concentrated in the west, north-west, and certain areas of central and

eastern Romania, while urban areas and counties with small or fragmented land remain marginal in the organic sector.

Building on the analysis of regional distribution and producer concentration, it is essential to examine the structure of organic land use in Romania to understand the dominant production systems and the potential for sectoral growth.

In 2024, the total area under organic farming amounted to 781,397 ha, representing a sector with significant potential, yet still modest relative to the country's overall agricultural area. The largest share corresponds to permanent pastures and meadows (294,183 ha), reflecting a focus on livestock production and natural resource conservation. Among arable crops, cereals (176,059 ha) dominate, followed by green harvested crops (162,702 ha) and industrial crops (104,085 ha), whereas dried legumes and protein crops (13,421 ha) and other arable crops (2,915 ha) occupy limited areas, indicating low diversification. Permanent crops, including orchards, vineyards, berry shrubs, and nut trees (21,942 ha), constitute a moderate share, while the areas planted with fresh vegetables and strawberries (1,837 ha) and tuber and root crops (481 ha) remain minimal, highlighting underdeveloped production for direct consumption.

CONCLUSIONS

The data presented in this study indicate that organic agriculture at the European Union level is largely concentrated in the south-western member states, which have a strong tradition in organic farming and the infrastructure required for the sector, such as Germany, France, Italy, and Austria.

In this context, Romania is at a moderate stage of development. Although the country has a relatively large agricultural area and a considerable number of producers, processing and per capita consumption of organic products remain low, suggesting that the sector is still largely oriented toward raw material exports with limited integration into value-added supply chains and consumer markets. Organic agriculture in Romania is highly regionally concentrated, with the highest production and number of producers in counties such as Tulcea, Timiș, Constanța, Arad, Cluj, and Sălaj.

The sector is dominated by pastures and meadows (38%) and cereals (23%), whereas vegetables, tuber crops, and permanent crops occupy much smaller areas, indicating substantial untapped potential for diversification and increased domestic consumption.

Despite these prospects, regional disparities, low processing capacity, and limited per capita consumption remain key challenges, emphasizing the need for targeted policies, investments in processing infrastructure, and promotion of organic products to fully integrate Romania into the European organic market.

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COMPARISON OF AGRICULTURAL MODELS UNDER DIFFERENT INSTITUTIONAL FRAMEWORKS: FORECAST OF THE TRADE BALANCE IN BULGARIA AND TURKEY UNTIL 2030

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Abstract

This study presents a comparative analysis of two agricultural models—those of Bulgaria and Turkey—developing within different institutional frameworks and policy approaches. While Bulgaria operates under a liberalized agricultural policy harmonized with the European Union, Turkey applies protectionist measures and autonomous state intervention in the sector. The aim of the study is to assess how these differences affect the agricultural trade balance by analyzing the role of two structural factors: the size of arable land and the number of researchers. Methodologically, the research is based on a comparative analysis of both indicators and agricultural policies, multiple linear regression, and trend extrapolation using data for the period 2000–2025, with forecasts extending to 2030. The results indicate that in both countries the analyzed factors exert a statistically significant impact on the agricultural trade balance. The Turkey's agricultural economy demonstrating greater structural stability of the agricultural trade balance. The scenarios for the period 2026–2030 suggest low dynamics trends. The study provides an empirical basis for formulating targeted agricultural policies aligned with the institutional context.

Key words**:** *agricultural trade balance, institutional frameworks, multiple linear regression, trend extrapolation, Bulgaria and Turkey*

INTRODUCTION

The dynamic nature of the global economic environment requires a strong capacity for adaptation to shocks generated by both internal and external factors. The period after 2019 has been characterized by economic force majeure circumstances that have adversely affected the global economy. These developments necessitate a reassessment of existing adaptation mechanisms and the search for new analytical and adaptive models under conditions of heightened instability. The main challenges arising from the imposition of a new trade order are primarily related to changes in supply channels for goods and services, which initially led to disruptions in food security and subsequently to income constraints on both the demand and supply sides. Consequently, conducting comparative analyses of economies with different structural characteristics is essential for understanding contemporary economic processes. The linking element between economies is international trade; therefore, the starting point of the present analysis is the trade balance. The trade balance functions as an aggregate indicator of agricultural exports and imports, reflecting both the degree of external dependence and the competitiveness of the agricultural sector. In the context of food security, a negative balance may signal economic vulnerability to external shocks such as global crises, military conflicts, and supply chain disruptions which can impair access to essential food resources and compromise the resilience of the agricultural system.

To achieve the objectives of the analysis, two neighboring economies Bulgaria and Turkey are examined. Despite sharing a common historical background, these countries have evolved under different institutional conditions: Bulgaria is a member of the European Union and pursues an active, liberalized trade policy, whereas Turkey applies protectionist measures affecting imports and exports. In addition, two indicators are employed: land (directly linked to agricultural production and representing a

fundamental natural resource) and the number of researchers across all sectors of the economy, reflecting the potential for generating and implementing innovations aimed at process optimization and the realization of economies of scale.

The existing academic literature emphasizes that agricultural trade is particularly sensitive to global shocks, including production disruptions, climate change, and geopolitical conflicts. According to Ferguson and Gars (2020) [7], international agricultural trade exhibits relatively low elasticity in response to production shocks, which constrains the ability of standard models to accurately forecast trade flows under sudden changes in production conditions. The literature highlights the need for analytical approaches that account for the structural characteristics of agricultural systems and their dynamic behavior.

In addition, the OECD (2020) [18] notes that existing models for assessing agricultural resilience prove insufficiently flexible to respond rapidly to crisis situations, underscoring the need for new analytical tools. In the post-2021 context marked by the COVID-19 pandemic, inflationary pressures, and disruptions in supply chains, this need becomes particularly critical, as traditional econometric relationships lose stability and predictive reliability.

According to Ginn (2024) [9], agricultural price shocks exert a stronger macroeconomic impact than production fluctuations, especially under conditions of global instability. This necessitates a reconsideration of methodological approaches and the inclusion of indicators that capture economic reality from an alternative perspective, such as the production capacity and research and development potential of the agricultural sector.

Wang et al. (2023) [26] demonstrate that global agricultural trade functions as a stabilizing mechanism, linking production and consumption regions within a resilient network. This role is particularly important for the economic resilience of import-dependent countries, as trade compensates for domestic deficits and mitigates the effects of regional production fluctuations.

In this context, the number of researchers and the size of arable land can be regarded as structural determinants of the trade balance, particularly when analyzed from a comparative perspective. The present study contributes to this academic debate by proposing an econometric model that assesses the impact of two key structural indicators on the agricultural trade balance. The comparison between Bulgaria, a Member State of the European Union and Turkey, a candidate country, makes it possible to examine how differences in the institutional framework related to land use and research capacity affect the sustainability of the agricultural trade balance.

The objective of the present study is to determine whether a statistically significant relationship exists between the size of arable land and the number of researchers, on the one hand, and the agricultural trade balance, on the other. The analysis also includes the development of trade balance scenarios up to 2030, all else being equal, with the aim of identifying sustainable patterns and formulating agricultural policy recommendations under conditions of economic uncertainty.

MATERIALS AND METHODS

The study employs a set of comparative, regression-based, and forecasting methods using trend extrapolation, applied on an indicator-based principle.

Comparative analysis is used to demonstrate the effects of implemented policies in two different types of agricultural systems: one fully liberalized (Bulgaria) and one of a mixed type (Turkey). These systems are assessed through the results of the agricultural trade balance (USD), the total number of researchers across all economic sectors, and the size of arable land measured in hectares over the period 2000–2025. The analysis relies on data from widely recognized and authoritative sources, including FAOSTAT, Eurostat, the National Statistical Institute of Bulgaria (NSI), and TurkStat (Turkey).

Comparative analysis is widely applied in contemporary academic literature: Masih et al. (2017) [17]; Yerankin et al. (2023) [27]; Sarkar et al. (2024) [22]; Castillo-Díaz et al. (2024) [5]; Yi et al. (2024) [28]; Chiorean et al. (2025) [6]; Ghilencea et al. (2025) [8]; Kabadzhova (2025) [14] etc.

Regression analysis is applied to identify relationships and interactions among the set of indicators within the agricultural systems of Bulgaria and Turkey. The relationship between arable land, the total number of researchers, and the agricultural trade balance treated as the dependent (outcome) variable is modelled.

Regression models are widely used in contemporary academic research literature: Ujjainia et al. (2020 [25]; Amoozad-Khalili et al. (2020) [2]; Benkraiem et al. (2021) [4]; Pinkovestskaia et al. (2022) [21]; Zomchak & Starchevska (2022) [30]; Tanklevska, et al. (2023) [24]; Herman (2024) [11]; Zhang et al. (2024) [29]; Chiorean et al. (2025) [6]; Ghilencea et al. (2025) [8] etc.

The presented study develops two econometric models to assess the impact on the trade balance. The analysis is conducted through the following steps:

(1) $$Y=\Sigma f\ (x1;\ x2;\ \dots\ ni=0xn)$$

where, x1, x2, …, xn represent the determining factors of the trade balance, and yyy denotes the outcome of their combined effect. The constructed econometric model is a multiple linear regression of the following form:

(2) $$yi= \beta0 + \beta1xi + \beta2xi,2 +\dots\ \beta\ xki, k +\epsilon i$$

We use xk to denote the number of explanatory variables, y as the dependent variable, and k to represent the number of predictor variables, implying a total of (k+1) regression parameters, where β0,β1,…,βk are linear coefficients.

One of the most widely applied forecasting approaches is linear and multiple regression, as it allows for modelling relationships among variables and evaluating the magnitude of their effects (Gujarati & Porter, 2009) [10]. In the literature review, vector autoregression (VAR) is applied to forecast agricultural prices (Allen, 1994) [1], while seasonal climate forecasts (SCF) are used for risk management in agricultural production (Parton et al., 2019) [20]. ARIMA models are well-established tools for time-series forecasting (Opara et al., 2025) [19].

Trend extrapolation is applied to derive values under nonlinear dynamics and long-term economic cycles (Kobylin et al., 2023) [15]. Qualitative methods such as the Delphi technique (Linstone & Turoff, 2011) [16] and scenario planning (Schoemaker, 2020) [23] complement quantitative approaches through expert assessments. Stochastic methods, including Monte Carlo simulations (Hu et al., 2020) [12] and DSGE models (Zhu et al., 2025) [31], are used for risk assessment and macroeconomic forecasting. Beia et al. (2025) [3] apply time-series analysis, exponential smoothing (ETS), linear trend analysis, and statistical error evaluation based on long-term FAOSTAT data to forecast honey production in Romania and the European Union.

In this reaearch, the values of the agricultural trade balance, arable land, and the number of researchers across sectors for the period 2022–2025 were forecast using trend extrapolation (Ivanov, 2024) [13]. The same methodology was applied to forecast the values of the agricultural trade balance up to 2030.

The method is based on the analysis of variations in historical data and the derivation of trend steps that reflect the dynamics of the observed processes. By incorporating a time-progressive component and a structured segmentation of the time series, trend extrapolation enables the generation of projected values ceteris paribus, while preserving the internal logic and stability of the model. This approach is particularly suitable for forecasting in contexts characterized by limited data availability and the need for reliable scenarios of future development. The method is implemented through the following steps:

$$\mathrm{VARY_t} = (\mathrm{Y_t} - \overline{\mathrm{Y_{AV}}}) \quad (1)$$

$$Y_{t+1} = \overline{\mu_{VARY}} + \frac{(TrS_{AV} + TrS_{AV2})}{2} * \sqrt{(n_{t+1} - n_t} \quad (2)$$

$$TrS_{AV} = \frac{AV2_{VARY2} - AV1_{VARY1}}{(n_t+1)/_2} \quad (3)$$

$$TrS_{AV2} = \frac{AV2.2_{VARY2.2} - AV2.1_{VARY2.1}}{(n2_t+1)/_2} \quad (4)$$

The core elements in modelling based on the trend of variations involve the derivation of the trend step (TrS). The indicators used in modelling through the trend of variations (Ivanov, 2024) [13] include the overall mean of variations for the entire observed period ((μ_VARY)¯) and the trend step (〖TrS〗 _AV), which is calculated once for the entire period and separately for the second half of the time series. In Equations (3) and (4), the derived variations (〖VARY〗 _t) for the observed historical period are sequentially divided into two major subperiods (〖AV2〗 _(VARY2) and 〖AV1〗 _VARY1), with the second subperiod further divided, using the median, into two additional segments (〖 AV2.2 〗 _VARY2.2 and 〖 AV2.1 〗 _VARY2.1 In Equation (2), which presents the derivation of the future projected value of the dependent variable (Y_(t+1)), a temporal component is also included, defined as the square root of the time sequence—specifically (nt+1 – 2022, nt+2 – 2023 year, etc.).

In this way, temporal progression is embedded into the trend model.

The main assumptions underlying the application of this algorithm for modelling future values of the indicators are that, for various reasons, they can be expressed as functions of their respective trends, represented through variation-based trend steps, calculated both for the entire period and, additionally, for the second half of the historical data series. It should be noted that future modelling based on the trend of variations exhibits decreasing accuracy and reliability over time, with an acceptable ratio being at least three historical years used to derive one projected year (Ivanov, 2024) [13].

RESULTS AND DISCUSSIONS

In order to better understand the context in which the agricultural trade balance is formed, the present study includes a comparative analysis of the agricultural policies of Bulgaria and Turkey.

The analysis covers the period 2000–2025, with a particular focus on differences in strategic priorities, the degree of integration into international trade mechanisms, and the dynamics of public investment in agricultural research.

These factors are essential for interpreting the regression results and for assessing the resilience of agricultural trade.

The coparative characteristics of agricultural policy in Bulgaria and Turkey are presnted in Table 1.

Econometric Analysis of the Trade Balance in Bulgaria

The results of the multiple linear regression analysis (Table 2) indicate a strong and statistically significant relationship between the size of arable land and the number of researchers across sectors and the agricultural trade balance.

The obtained value of the coefficient of multiple determination ($R^2 = 0.98$) indicates that 98% of the variation in the trade balance can be explained by changes in the two independent variables, confirming the high explanatory power of the model.

Both coefficients: arable land ($\beta = 47.90$) and number of researchers ($\beta = 6.87$), are statistically significant at the $p < 0.001$ level, with narrow confidence intervals, indicating the stability of the estimates. This implies that an increase in arable land by one unit leads, on average, to an increase in the trade balance by 47.90 units, while each additional

researcher is associated with an average increase of 6.87 units.

Table 1. Characteristics of agricultural policy in Bulgaria and Turkey

Bulgaria	Turkey
-Member State of the European Union; -Open-type developing economy (classified as a high-income country according to the World Bank classification for 2025); -Harmonization of agricultural policy with that of the European Union and compliance with the Treaty on the Functioning of the European Union (TFEU); -Support for the agricultural sector through national and European subsidies; -Agricultural policy objectives similar to those of Turkey (competitiveness, environmental protection, support for rural areas, and promotion of knowledge and innovation); -Shared food sovereignty within the European Union; -Shared research and scientific base with the European Union; -Absence of state intervention in the agricultural sector with respect to agricultural product prices; -Absence of import bans based on the type of agricultural products; -Liberal policy regarding land acquisition by foreign citizens; -Policy aimed at increasing imports and exports in order to expand international trade relations; -Free trade zones within the European Union (free movement of people, goods, and capital).	-Not a member of the European Union; -Developing economy of a mixed type (classified as an upper-middle-income country according to the World Bank classification); -Independent state agricultural policy with autonomous decision-making; -Support for the agricultural sector through national public funding; -Agricultural policy objectives similar to those of Bulgaria (competitiveness, environmental protection, support for rural areas, and promotion of knowledge and innovation); -National food sovereignty; -Independent research and scientific base; -State intervention in the agricultural sector with respect to agricultural product prices; -Import bans depending on the type of agricultural products; -Protectionist policy regarding land acquisition by foreign citizens; -Policy aimed at reducing imports and increasing exports through protection of domestic production; -Customs union with the European Union covering industrial goods and processed agricultural products only.

Source: Author's own analysis based on data from the Ministry of Agriculture of Turkey, the Ministry of Agriculture of Bulgaria, and Eurostat [32, 33, 34].

Table 2. Regression analysis in Bulgaria for the period 2000–2025

Regression Statistics	
Multiple R	0,99
R Square	0,98
Adjusted R Square	0,98
Standard Error	4035,35
Observations	26,00

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2,00	22473566491,75	11236783245,87	690,05	0,00
Residual	23,00	374533755,33	16284076,32		
Total	25,00	22848100247,08			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	18519596,04	19865,50	932,25	0,00
Arable land	47,90	6,21	7,71	0,00
Total number of researchers across sectors	6,87	0,23	29,38	0,00

Significance level: α=0.05
Source: own research.

The value of the F-statistic (F = 690.05) and the zero value of Significance F further confirm that the model is statistically significant.

Econometric Analysis of the Trade Balance in Turkey

The regression model for Turkey (Table 3) demonstrates a high degree of explanatory

power, with the coefficient of multiple determination ($R^2 = 0.89$) indicating that 89% of the variation in the agricultural trade balance can be explained by changes in the size of arable land and the number of researchers across sectors. Both coefficients—arable land ($\beta = 79.96$) and number of researchers ($\beta = 6.65$)—are statistically significant ($p < 0.01$), confirming their impact on the trade balance. The higher value of the coefficient for arable land compared to the Bulgarian model suggests that production capacity exerts a more pronounced effect on trade performance in Turkey. The value of the F-statistic ($F = 89.80$) confirms the overall significance of the model, while the standard error (73,057.22) is acceptable relative to the scale of the values.

Table 3. Regression analysis in Turkey for the period 2000–2025

Regression Statistics	
Multiple R	0,94
R Square	0,89
Adjusted R Square	0,88
Standard Error	73057,22
Observations	26,00

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2,00	958579966882,55	479289983441,28	89,80	0,00
Residual	23,00	122759235207,12	5337358052,48		
Total	25,00	1081339202089,67			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	37040653,10	636893,57	58,16	0,00
Arable land	79,96	26,87	2,98	0,01
Total number of researchers across sectors	6,65	0,88	7,57	0,00

Significance level: α=0.05
Source**:** own research.

Trend extrapolation and derivation of forecast values for the agricultural trade balance in Bulgaria and Turkey up to 2030

During the period 2026–2030, the agricultural trade balance in Bulgaria demonstrates a high degree of stability, with differences between the baseline, optimistic, and pessimistic scenarios remaining below 0.25%. The baseline scenario increases by 0.013% over the five-year period, while the optimistic and pessimistic scenarios deviate by +0.12% and −0.011%, respectively, relative to the baseline in 2030. These results are valid in equal conditions, that is, assuming that environmental factors remain unchanged and the projected values stay within the specified bounds (Fig. 1).

During the period 2026–2030, the agricultural trade balance in Turkey is also characterized by stability, with differences between the baseline, optimistic, and pessimistic scenarios remaining below 0.2%.

The baseline scenario increases by 0.05% over the five-year period, while the optimistic scenario is 0.095% higher and the pessimistic scenario 0.12% lower than the baseline in 2030 (Fig. 2).

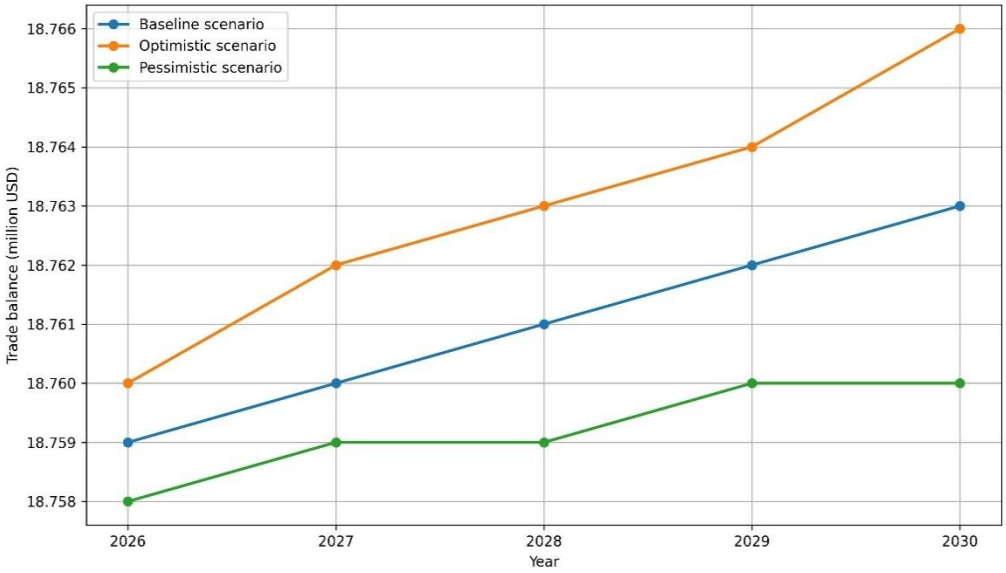

Fig. 1. Scenario-based values of the agricultural trade balance in Bulgaria up to 2030.
Source: Own design and calculation.

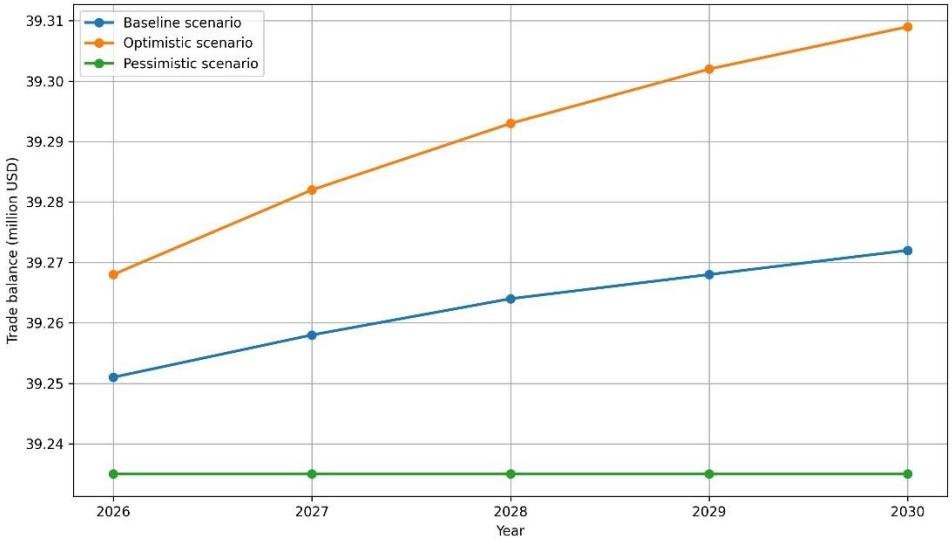

Fig. 2. Scenario-based values of the agricultural trade balance in Turkey up to 2030
Source: Own design and calculation.

CONCLUSIONS

The results of the present study confirm that arable land and research capacity are key structural determinants of the agricultural trade balance in both Bulgaria and Turkey.
A comparison of the regression coefficients indicates that Turkey demonstrating greater structural stability of the agricultural trade balance.
The scenarios up to 2030 highlight the need for targeted policies aligned with the structural characteristics of each economy, with the aim of enhancing the resilience and competitiveness of agricultural trade.

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STRUCTURAL DIFFERENCES IN THE FACTOR IMPACT ON AGRICULTURAL YIELDS IN THE EUROPEAN UNION

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Abstract

The objective of this study is to identify and evaluate the main factors that determine agricultural yields in the Member States of the European Union, as well as to highlight the differences in their influence across individual countries. The methodological approach employs factor analysis and multiple regression to assess the strength and interrelationships between the dependent variable, and three key factors: arable land, central government expenditure, and net entrepreneurial income. The regression model confirms a strong positive relationship between arable land area and yields, whereas subsidies and income exhibit a weak positive effect. The study underscores the structural differences within the EU's agricultural systems and provides a foundation for the development of differentiated policy measures tailored to the specific characteristics of individual economies, aimed at balancing economic incentives and enhancing the efficiency of agricultural production.

Key words**:** *structural differences, European Union, multiply regression, factor analysis*

INTRODUCTION

Over recent decades, agriculture in the European Union (EU) has evolved under the influence of dynamic economic processes, successive reforms of the Common Agricultural Policy, and increasing sustainability requirements (Eurostat, 2024) [6]. These transformations have revealed pronounced disparities among EU Member States with respect to the sector's production potential, farm income performance, access to resources, and the role of government support in ensuring agricultural sustainability. These differences can be examined through key indicators, including gross agricultural output, utilised agricultural area, government expenditure on agriculture, and net entrepreneurial income within the sector.

Notwithstanding the presence of a shared conceptual framework underpinning a common agricultural policy, the agricultural sectors across the European Union continue to display substantial heterogeneity. The identification and analysis of these structural disparities are crucial for a comprehensive understanding of agricultural dynamics within the EU, as well as for the formulation of policy instruments that effectively reflect the distinct structural and economic conditions of individual Member States.

Drawing on the work of Kneafsey et al. (2013) [12], agricultural systems within the European Union can be described as markedly heterogeneous, reflecting wide variations in production structures, marketing channels, and socio-economic environments. A report by the European Commission further conceptualizes this diversity by classifying Member States into three broad meta-regions—the North, the South, and the New Member States—which differ substantially in terms of farm structures, levels of market integration, production specialization, and reliance on public support. In a significant number of EU countries, public support constitutes a key determinant of the economic viability of agricultural holdings. Consequently, the Common Agricultural Policy generates differentiated impacts across

Member States, shaped by their specific production characteristics and economic contexts. Empirical evidence indicates that EU policy instruments, including direct payments and rural development measures such as support for short supply chains, exhibit heterogeneous effectiveness across regions.

The analysis of the national strategic plans of EU Member States shows that, although the common framework establishes shared environmental and social ambitions, their actual implementation inevitably relies on differentiated instruments and financial mechanisms tailored to diverse production structures, environmental conditions, and socio-economic contexts (Mezzacapo, 2024) [15].

A synthesis of recent academic literature underscores the uneven development of the agricultural sector across European Union Member States, driven by economic, institutional, and structural heterogeneity. Empirical studies demonstrate that production capacity, access to resources, levels of market integration, and reliance on public support evolve along divergent trajectories rather than following a uniform pattern. As a result, the effectiveness of Common Agricultural Policy instruments varies considerably across countries, highlighting the necessity for differentiated policy approaches aimed at safeguarding the long-term sustainability of the sector (Herman, 2025 [10]; Klein et al., 2022 [11]; Mozdzen et al., 2024 [17]). While the Common Agricultural Policy provides a shared strategic orientation, its effective implementation requires national-level adaptations that reflect specific production systems, environmental constraints, and socio-economic circumstances. This, in turn, emphasizes the need for robust analytical frameworks to support the coherent alignment of national policies within the unified European agricultural policy system.

In this context, the present study aims to identify and evaluate the main factors determining Gross Production Value in the countries of the European Union and to highlight differences in their influence across Member States, thereby enabling their grouping and the formulation of appropriate adaptive policy approaches.

MATERIALS AND METHODS

The study employs three main statistical approaches: comparative analysis, multiple regression, and factor analysis. Multiple regression enables the assessment of the influence of several independent variables, including the size of utilised agricultural area, government expenditure, and net entrepreneurial income from agriculture, on the gross production value of the sector. The second stage involves the application of Principal Component Analysis (PCA) to reduce dimensionality and identify latent factors that summarize the key relationships among the indicators. This approach makes it possible not only to confirm the significance of individual variables but also to reveal the structural organization of the data, thereby providing a basis for the typologization of countries and the formulation of differentiated agricultural policies.

Comparative Analysis

The comparative analysis is a widely applied approach in economic science (Zeytoon-Nejad, 2025 [23]; Moller et al., 2026 [16]; Amin & Zaher, 2026 [1]; Kostov et al., 2025 [14]; Toth et al., 2025 [22]), used to assess the similarities and differences between two or more economic systems and their inherent processes. The comparative method in the current study has been adapted in the form of a comparative analysis of EU countries. Data from globally recognized sources such as FAOSTAT & EUROSTAT in EU were utilized.

Econometric analysis

The econometric analysis is a widely applied approach in economic science (Amrahov et al., 2022 [2]; Burghelea et al., 2015 [3]; Georgieva, 2025 [8]; Georgescu et al., 2025 [7]; Kopeva et al., 2013 [13]; Nguyen et al., 2021 [18]; Severini & Biagini, 2020 [20]; Petrov et al., 2026 [19]).

Multiple regression was applied to determine the relationships among variables and the direction of their effects.

$$yi = \beta 0 + \beta 1xi + \beta 2xi,2 + \cdots \beta\, xki,k + \epsilon i \quad \ldots\ldots\ldots\

has the strongest impact on production value, exhibiting a positive and statistically significant relationship. The corresponding R^2 values indicate substantial explanatory power of the estimated model.

G2: Countries in which utilised agricultural area represents the primary explanatory factor. This group can be further disaggregated into two subcategories: countries exhibiting a positive association with the dependent variable (Belgium and Lithuania) and those displaying a negative relationship (Austria, France, Greece, Ireland, Malta, Portugal, Slovenia, and Spain). Collectively, these countries account for 37.04% of European Union Member States.

G3: Countries in which net entrepreneurial income constitutes the dominant explanatory factor. This group also represents 37.04% of European Union Member States and includes Croatia, Denmark, Estonia, Finland, Germany, Ireland, Luxembourg, Slovakia, Spain, and Sweden. Within this group, the net income index exerts the strongest influence on production value, with the relationship being positive and directly proportional.

G4: Countries without a clearly dominant factor or with limited model explanatory power. This residual group comprises Hungary, Latvia, Poland, and Romania, accounting for 14.81% of European Union Member States.

In these cases, none of the explanatory variables emerges as a consistently dominant determinant, and the overall explanatory capacity of the estimated models remains comparatively weak.

Across the European Union, government expenditure on agriculture exerts the most pronounced positive impact on gross production value in the largest share of Member States. Specifically, it constitutes a positively stimulating factor in nine out of twenty-seven countries—namely Bulgaria, Cyprus, Czechia, Italy, Finland, Luxembourg, Austria, Belgium, and Croatia. The outcomes of the multiple regression analysis underscore the central role of public support as a key driver of gross agricultural productivity at the Member State level.

Factor Analysis

The correlation matrix for the European Union Member States confirms a positive relationship between gross production value and land use (r =0.894), as well as between gross production value and government expenditure on agriculture (r = 0.919). The results indicate that higher levels of production are associated with more intensive use of agricultural resources and greater public expenditure. Another finding is the positive relationship between land use and government expenditure (r=0.743). No statistically significant correlation was identified between the net income index and the other variables, suggesting its relative independence from the examined factors.

The calculation of eigenvalues and eigenvectors indicates how much variation is explained by each component and the direction of each component in the multidimensional space (Figure 1, Figure 2, Table 2).

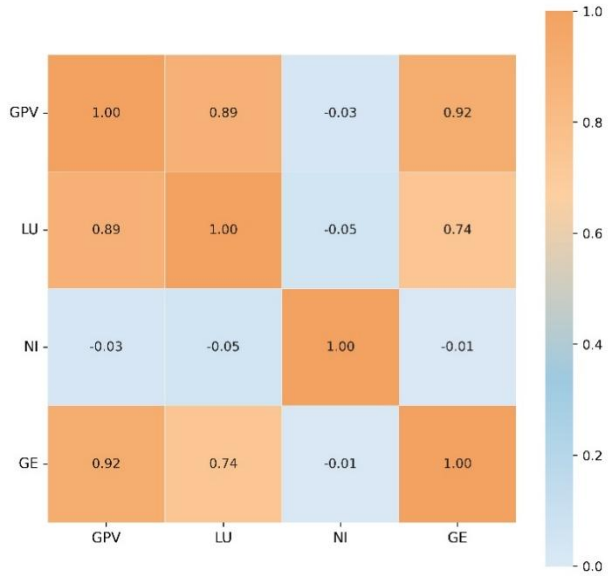

Fig. 1. Correlation matrix (heatmap) for the period 2015-2025
Source: Own research.

The component loading matrix reveals the structure of the principal components. The first component (PC1), interpreted as "Production Capacity" is characterized by high positive loadings for gross production value (0.57), government expenditure (0.63), and land use (0.52), indicating that it summarizes the scale and intensity of production and fiscal activity. The second component (PC2), labelled "Income

Efficiency" is dominated almost entirely by the net income index (0.99), with minimal loadings for the remaining variables, indicating its relative independence from the resource and production characteristics represented in the first component.

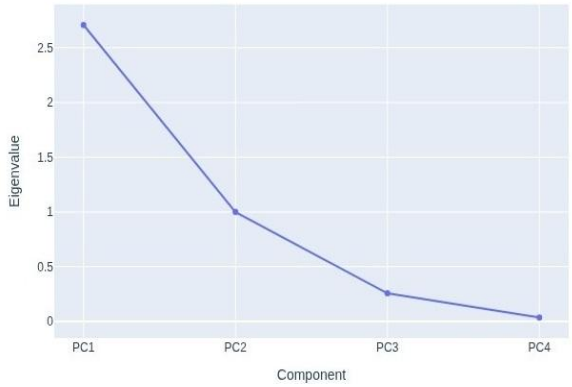

Fig. 2. Eigenvalues of the principal components
Source: Own research.

Table 2. Component loading matrix

Variable	PC1	PC2
Gross Production Value	0.57	0.05
Government Expenditure	0.63	–0.02
Land use	0.52	0.07
Net Income	–0.03	0.99

Source: Own research.

Table 3. Grouping by PC1 and PC2 and recommendations for differentiated policies

Group	Country	Policy recommendation
G1: High PC1, Low PC2	France, Italy, Spain, Germany, Poland, the Netherlands	Diversification of income sources and stimulation of innovation; promotion of digitalization, improved access to finance, and modernization.
G2: High PC2, Low PC1	Slovakia, Ireland, Luxembourg	Land consolidation, investment in infrastructure, and improved market access; support for scaling up entrepreneurial potential.
G3: Low PC1, Low PC2	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, Greece, Latvia, Lithuania, Malta, Portugal, Romania, Slovenia, Sweden	Comprehensive interventions: increasing public support (subsidies and infrastructure), programmes for developing entrepreneurial skills, and integration of small farms into market supply chains.

Source: Own research.

The obtained results provide a basis for grouping EU countries according to the first and second components, which in turn supports the formulation of differentiated policies for sectoral support (Table 3).

CONCLUSIONS

The conducted analysis indicates that the influence of public expenditure, the size of utilised agricultural area, and net entrepreneurial income on the gross production value of agriculture in European Union countries is not uniform. In a substantial group of Member States, including Bulgaria, Cyprus, Czechia, Italy, Finland, Luxembourg, Austria, Belgium, and Croatia, government expenditure on agriculture plays a leading role, exerting a positive and statistically significant effect.

A further substantial group of countries is characterized by utilised agricultural area as the prevailing determinant of production value. In Belgium and Lithuania, this variable exhibits a positive association with production value, whereas a negative relationship is observed in Austria, France, Greece, Ireland, Malta, Portugal, Slovenia, and Spain. In another set of countries—namely Croatia, Denmark, Estonia, Finland, Germany, Ireland, Luxembourg, Slovakia, Spain, and Sweden—net entrepreneurial income emerges as the most influential factor, displaying a direct and proportional relationship with production value. By contrast, in Hungary, Latvia, Poland, and Romania, no single indicator can be identified as a clearly dominant determinant.

These findings indicate that a universal model of adaptation to the European Union does not exist and that the Common Agricultural Policy should not be viewed as a uniform mechanism for successful integration, as each country possesses specific characteristics that must be reflected in its national policy framework. Factor analysis complements these results, with the first principal component highlighting the importance of public expenditure and the second emphasizing the role of income efficiency. Together, they explain nearly all variation in

the data, confirming that sustainable agricultural development in the European Union requires differentiated policies aligned with the specific factor profile of each Member State.

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AGRICULTURAL INTEGRATION AND LAND OWNERSHIP CONSOLIDATION IN BULGARIA

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Abstract

This article examines the evolution of agricultural integration and land consolidation in Bulgaria, from post-communist land restitution to the dominance of large agro-holdings under the EU's Common Agricultural Policy, emphasizing the tension between efficiency and social equity. After 1989, land fragmentation produced over two million co-owned parcels, causing high transaction costs. Later, market forces and Common Agricultural Policy incentives drove consolidation, creating structural imbalances and marginalizing smallholders. Using theories of vertical integration, property rights, cooperation, hybrid governance, and the antitrust paradox, the study applies retrospective and structural analysis supported by land-use indicators. By 2021, only five land trusts (1.6% of entities) controlled 87% of arable land, while cooperatives and family farms declined. Hybrid organizational forms expanded but often obscured ownership and deepened inequality. By 2025, nearly 88% of arable land is expected to qualify for EU subsidies, reinforcing capital-intensive farming. The article concludes that reforms prioritize efficiency but intensify concentration, exclusion, and reduced adaptability, requiring policies that support structural diversity and inclusive governance.

Key words**:** *integration, agricultural cooperation, associations, agricultural lands, consolidation*

INTRODUCTION

The provided literature delves into the intricate dynamics of agricultural integration and farmland ownership consolidation in Bulgaria, tracing its evolution through organizational transitions, regulatory shifts, and socio-economic change. From early cooperative traditions and centralized collectivization to post-1989 restitution efforts, the sector underwent a dramatic restructuring characterized first by extreme fragmentation of land and later by rapid reconsolidation of ownership. This dual process - initial atomization followed by concentration - has produced an agrarian landscape dominated by large-scale agroholdings, entities which have disproportionately benefited from European Union agricultural frameworks, while small-scale producers face increasing marginalization and declining institutional representation.

Beyond the historical and policy dimensions, this transformation raises fundamental theoretical challenges. The transition from fragmented ownership to consolidated control reflects tensions between economic efficiency and social equity - a central problem in agrarian organizational theory. Fragmentation, though rooted in restorative justice, imposed high transaction costs and undermined coordination, investment, and scalability. The later drive toward consolidation, incentivized by market forces and the Common Agricultural Policy (CAP) instruments, has generated structural asymmetries in access to resources and governance capacity.

These developments have also led to the proliferation of hybrid organizational models blending private, corporate, and collective elements, often resulting in legal opacity and institutional misalignment. Such structures illustrate how integration at the operational level can be coupled with disintegration at the socio-territorial level, reflecting a broader theoretical paradox: efforts to optimize production and governance may

simultaneously erode pluralism, resilience, and inclusive access to land.

By synthesizing organizational, economic, and institutional theory, this article offers a multidimensional analysis of Bulgarian agricultural transformation. It argues for the necessity of policy frameworks that go beyond economic consolidation and explicitly support organizational diversity, equity in land access, and sectoral sustainability within the broader European agrarian context.

Objective of the Article. This article aims to critically analyze the dual transformation of Bulgaria's agricultural sector - from fragmented land ownership following post-socialist restitution to the growing consolidation and integration of agrarian structures. By applying organizational and economic theory, the study explores how institutional legacies, market mechanisms, and policy frameworks interact to shape land governance, production models, and social equity. The goal is to illuminate the risks and opportunities inherent in this trajectory, and to advocate for policy solutions that balance efficiency with pluralism and sustainable access to agricultural resources.

Theoretical Framework on Agricultural Integration based on Agricultural Land Ownership

Governance and integration. This article draws upon foundational organizational and economic theories to examine firm boundary decisions and interorganizational design. The theory of vertical integration, as articulated by Williamson (1975) [26], serves as a core lens, emphasizing asset specificity and transaction cost minimization as drivers for internalizing operations. Complementing this, the governance structure perspective (Grossman & Hart, 1986; Hart & Moore, 1990) [10, 11] highlights how ownership rights influence the allocation of residual control, shaping efficient contractual arrangements.

Cooperation theory, especially rooted in the relational view of strategic alliances (Dyer & Singh, 1998) [7], introduces a nuanced understanding of value creation beyond market or hierarchy. It emphasizes inter-firm trust, information sharing, and joint investment mechanisms, offering explanatory depth to non-traditional firm structures. Finally, hybrid structure theory bridges the dichotomy between integration and market transactions (Ménard, 2004) [14], positioning networks, franchising, and alliances as governance forms that embed both coordination and flexibility.

By inter-traveling these theories, the framework enables a multidimensional analysis of organizational design decisions under varying institutional and strategic contingencies.

Cooperatives and Associations: Sarov (2021) [21] offer an in-depth investigation into agricultural integration in Bulgaria, placing land ownership at the center of their analysis. Their study reveals how shifts in land use policy and organizational structure – shaped by historical, legal, and economic factors – have influenced the transition from cooperative models to modern associations. Agricultural cooperatives are traditionally viewed as collective organizations formed to overcome market failures and resource fragmentation among small producers (Olson, 1965) [18]. They enable economies of scale, reduce transaction costs, and enhance bargaining power (Sexton, 1986) [22]. Others outline the condition of the Bulgarian agricultural sector, marked by high intensity, rapid dynamics, growing complexity, and instability, along with a decline in gross agrarian output (Stoeva & Dirimanova, 2023) [24]. In other research, the impact of the economic activities of Almería's cooperatives on the economy was highlighted, and a set of measures for improving landscaping in Spain was made (Chiurciu et al., 2020) [4].

Also, in Bulgaria, scenarios for development of arable land and other indicators by 2030 were made (Gandeva & Ivanov, 2025) [8]. In Bulgaria, cooperatives historically played a central role in consolidating land and labor, especially during the early and mid-20th century.

Integration theory in agriculture - both vertical and horizontal - explores how producers align across the value chain to improve efficiency and competitiveness. Vertical integration links production with processing and distribution, while horizontal integration consolidates

similar operations to achieve scale (Cook & Iliopoulos, 2000) [5].

In post-socialist contexts, integration has been driven by land restitution and EU policy incentives, often resulting in hybrid organizational forms (Bachev, 2018) [2].

Other studies review features of land-rental transactions in domestic agriculture and propose a method for evaluating how Ukraine's agricultural land-rental relations will develop in the future by identifying their connections to key influencing factors (Stupen et al., 2018) [25].

Associations, as voluntary producer organizations, represent a modern evolution of cooperative principles. They are designed to facilitate joint access to subsidies, markets, and technical services, but often lack the formal governance structures of traditional cooperatives (Ministry of Agriculture and Food, 2015) [16]. Their emergence reflects a shift toward flexible, network-based integration, especially in fragmented land systems.

The interplay between these three concepts reveals a continuum: cooperatives provide the foundational logic of collective action; integration theory explains the structural alignment of resources; and associations embody adaptive responses to legal and economic pressures.

Hybrid organizations increasingly blend these elements, creating complex governance models that challenge traditional boundaries (Nikolov et al., 2023; Zheleva & Delcheva, 2023) [17, 27].

Cooperatives and Fragmented Land Systems. In the post-liberation period, Bulgarian agriculture remained fragmented, prompting the emergence of cooperatives as instruments of collective resource management. By the mid-20th century, cooperatives accounted for nearly 70% of national agricultural turnover (Atanasova-Todorova & Lulcheva, 2005) [1]. Their role in improving productivity and market access has been widely studied (Sarov, 2021, Doitchinova et al., 2005) [21, 6].

Others looked into the prospects for agricultural cooperative growth through 2030, it was found that the forecast indicated that by 2030, there would be 13.1 times fewer agricultural cooperatives, a 1.5-fold decrease in the area of agricultural land, and a significant increase in profits relative to losses (Shelenko et al., 2022) [23].

During the communist era (1944–1989), collectivization led to the nationalization of land, restructuring it into large agro-industrial complexes (TKZS and APK).

This horizontal integration model promoted scale economies but diminished individual autonomy (Bachev, 2018) [2].

Structuralism and Antitrust Paradox: The CAP of the European Union promotes resource consolidation and organizational integration through mechanisms that prioritize efficiency – mainly via product structure optimization and economies of scale. According to the Chicago School, this focus on efficiency can undermine competition, a tension known as the "antitrust paradox" (Bork, 1978; Posner, 1978) [3, 19].

Harvard-based scholars suggest that efficiency can lead to the "leverage effect," whereby dominant actors may exert influence across related markets, potentially resulting in discriminatory practices (Robinson, 1933) [20]. Glick (2019) [9] critically examines the conflict between integration and competition, while Hovenkamp (2010) [12] explores how transaction cost economics shapes antitrust analysis. These perspectives raise important questions about whether efficiency-driven agricultural policies might come at the expense of fair competition.

In this context, the purpose of this study is to analyse the evolution of agricultural integration and land consolidation in Bulgaria, from post-communist land restitution to the dominance of large agro-holdings under the EU's Common Agricultural Policy, pointing out the tension between efficiency and social equity.

MATERIALS AND METHODS

Conceptual Diagram Description: This conceptual diagram (Figure 1) presents a historical timeline that traces the evolution of agricultural integration and land ownership structures in Bulgaria across four distinct periods, each characterized by transformative

socio-political and economic shifts. Horizontally, the diagram unfolds chronologically from the post-liberation era through the communist regime, the transition period following 1989, and the current phase marked by EU integration and projected developments until 2025.

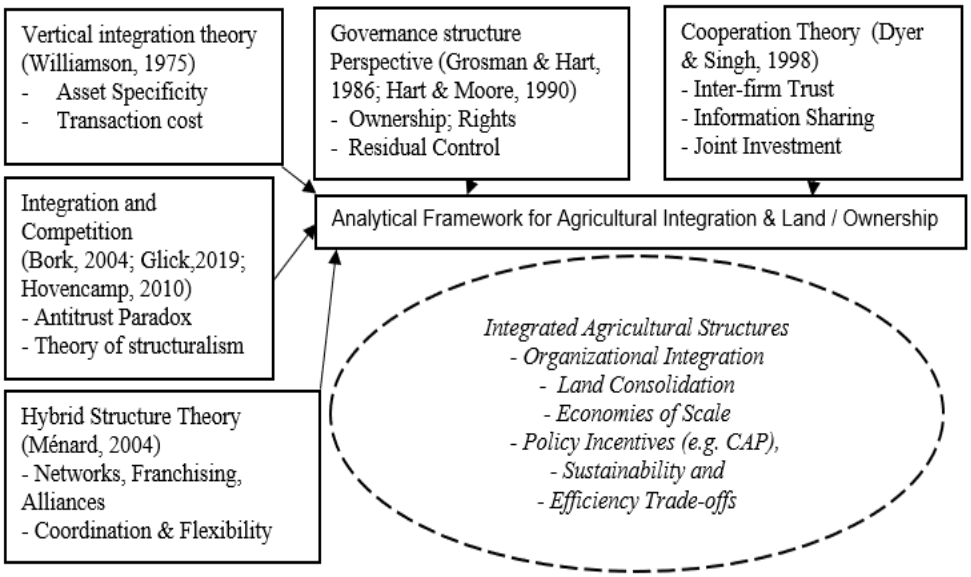

Fig. 1. Conceptual representation of this analytical framework
Source: Own research.

Vertically, the diagram is structured into four thematic "lanes" representing interconnected dimensions:

a)Land Ownership Patterns:

- Early 20th-century and post-restitution fragmentation;
- Land collectivization and nationalization during the socialist period;
- Recent consolidation and concentration trends, notably after EU accession.

b)Dominant Organizational Forms:

- Agricultural cooperatives in the early 20th century, later declining in prevalence;
- Agro-industrial complexes (TKZS, APK) during the communist period;
- Transitional-era associations and restructured cooperatives;
- Emerging land management trusts and hybrid agribusiness entities in the contemporary landscape.

c)Driving Forces and Policies:

- Early needs for collectivization and responses to market failures;
- Centralized planning and state control under socialism;
- Post-1989 restitution legislation and democratization efforts;
- EU CAP and increasing market pressure.

d)Key Outcomes and Consequences:

Economies of scale coupled with reduced individual autonomy. High transaction costs and inefficiencies in land utilization. Exclusionary dynamics disadvantaging small-scale farmers and limiting organizational diversity. Rising legal complexity and resource asymmetries within the sector.

Arrows interlinking these lanes illustrate causal relationships and feedback loops. For instance, restitution leads to land fragmentation, which in turn incentivizes consolidation - a process further reinforced by CAP incentives. The diagram thus captures the layered interplay of historical legacies, policy frameworks, and economic imperatives that have shaped Bulgaria's agricultural sector.

The study employs a discretely structured analysis to examine the internal relationships between policy mechanisms and economic outcomes. A comparative analytical method is also applied to highlight differences and similarities across regulatory frameworks and national implementations. Furthermore, a retrospective analysis is utilized to process and interpret historical data, enabling a deeper understanding of the evolving impact of

agricultural policies over time.

The study's empirical data comes from 110 contracts, which were procedures for the transfer and defense of agricultural land rights. The information was gathered from Bulgaria's regions. 43 of the transactions are for purchase and sale, 37 are for rent, 25 were other legal forms, and 5 were legal issues pertaining to agricultural property. The legal information systems lex.bg and CIELA provided the information on the legal acts.

RESULTS AND DISCUSSIONS

The Land Underpinning Agricultural Organization

Agricultural land has long dictated the organizational trajectory of Bulgaria's rural economy. In the post-Ottoman era, land was highly fragmented among smallholders, prompting the emergence of cooperatives that aimed to consolidate production and improve market access. By the mid-20th century, these cooperatives managed approximately 70% of cultivated land.

During the communist period (1944–1989), the state restructured land ownership through enforced collectivization, transforming private plots into centralized agro-industrial complexes. This horizontal integration model aimed to generate scale economies but eroded individual agency in land stewardship.

The post-communist transition reversed this centralization. Land restitution laws enacted after 1989 returned property to former owners, often creating highly fragmented ownership structures. Over 2 million parcels emerged, some split among up to 20 co-owners, drastically increasing transaction costs and complicating productive use.

Associations and Pressures of Land Consolidation

The post-1989 restitution policy reversed collectivization, resulting in the restoration of land to its pre-socialist owners. Consequently, over 2 million parcels re-emerged, many with multiple co-owners, significantly raising transaction costs and impeding effective land utilization.

To manage this fragmentation, modern agricultural associations emerged, particularly in the early 2000s, aiming to pool resources and enhance subsidy access (Ministry of Agriculture and Food, 2015) [16]. However, legal ambiguities and coordination costs limited their scalability (Agri.bg, 2015).

Efforts to reintroduce cooperatives and establish farmer associations in the early 2000s sought to mitigate fragmentation by pooling resources. However, many new entities struggled under ambiguous legal conditions and high coordination expenses.

Land consolidation accelerated between 2007 and 2021. The number of land trusts fell from 67 to 5, with these few entities acquiring control over 87% of Bulgaria's arable land – despite representing only 1.6% of agricultural organizations. This trend reduced smallholders' access to productive land and sidelined them from key value chains.

Legislative Impact on Land Use

The Bulgarian constitution supports free association, while EU alignment since accession in 2007 has promoted individual efficiency. This legal context facilitates land consolidation, reinforcing competitive advantage for larger entities.

Laws such as the EU Common Market Organization Act (2013) and the Competition Protection Act (2008) regulate national-level market dominance. However, they remain insufficient to curb regional monopolization or to safeguard land access for smaller producers.

Hybrid associations – multi-stakeholder organizations involving legal, financial, and administrative actors – often obscure asset acquisitions. This structure shifts indirect legal and transactional costs toward less-resourced stakeholders, amplifying inequalities in land access.

Hybrid Governance and Land Concentration

Hybrid organizations – combining private, public, and collective governance – have grown in prevalence, often obscuring ownership arrangements and transferring indirect costs to small stakeholders (Nikolov et al., 2023) [17]. Bachev (2018) [2] argues that hybrid governance models significantly influence sustainability, especially in fragmented agricultural systems.

Between 2007 and 2021, the number of land trusts decreased from 67 to 5, while their control over arable land increased to 87%, despite representing just 1.6% of registered agricultural entities. This concentration poses risks to inclusivity and long-term sectoral resilience.

Empirical Analysis of the Implications for Land-Based Organizations in Agriculture

Figure 2 presents trend lines depicting five categories of agricultural entities in Bulgaria: Agricultural Cooperatives, Agricultural Production Cooperatives/Associations, Mixed-Type Agricultural Associations, Agricultural Holdings (Farms), and Land Management Trusts. The data reflect structural transformations in the sector over two decades, marked by consolidation, hybridization, and vertical integration.

The number of Agricultural Cooperatives declined markedly from 1,156 in 2007 to only 128 active listings by 2025, highlighting processes of organizational consolidation and market exit. Similarly, Agricultural Production Cooperatives and Associations, which were most numerous during the post-socialist restructuring (~3,268 in 1998), experienced a pronounced contraction by 2020, consistent with broader shifts away from collectivized models and toward individualized enterprise structures.

In contrast, Mixed-Type Agricultural Associations, incorporating multifunctional roles (e.g., production, processing, advisory), emerged more recently. Their modest increase – from 11 entities in 2024 to 14 in 2025 – illustrates a growing trend toward hybrid governance and integrated value-chain participation (Bachev, 2018; Nikolov et al., 2023) [2, 17].

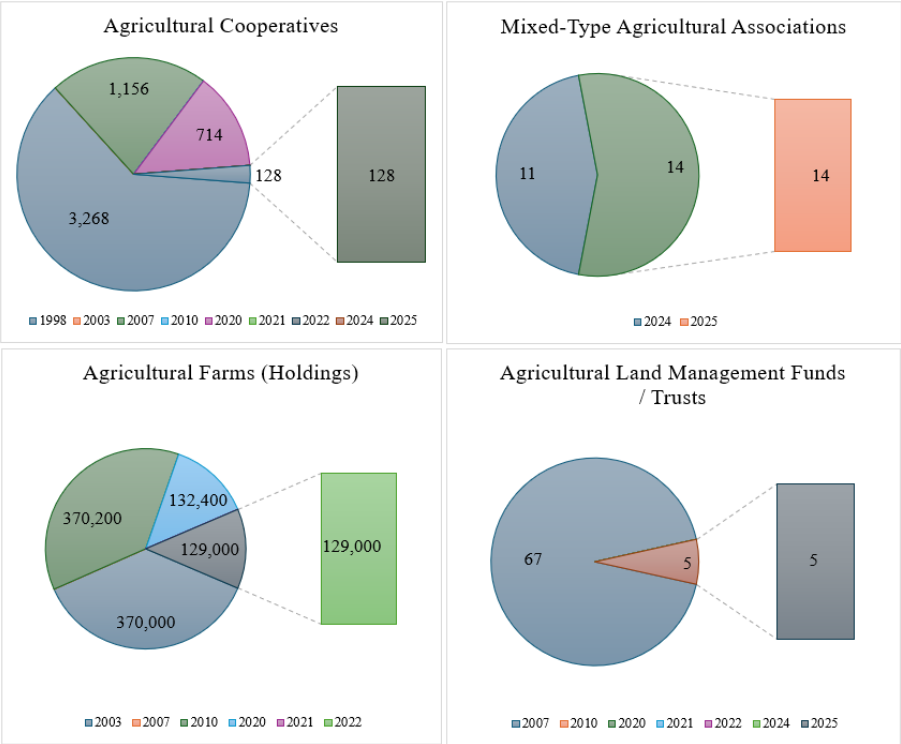

Fig. 2. Evolution of key agricultural organizational forms in Bulgaria (1998–2025)
Source: Own research.

The number of Agricultural Holdings (Farms) fell sharply after 2010, declining from ~370,000 to ~132,400 by 2022. This reduction signifies a concentration of agricultural land and a transition toward fewer, larger farms – a phenomenon driven by competitive pressures, land acquisition mechanisms, and resource consolidation (NSI, 2023) [28].

The convergence of integration and consolidation has intensified exclusionary dynamics within land-based agriculture.

Smallholders face growing barriers to entry as resource chains become increasingly closed and capital-intensive. While legal frameworks promote integration, they offer limited institutional safeguards for micro-level agricultural actors. The overall decline in organizational diversity, coupled with rising transaction intensity, signals a transfer of control over land and production to a smaller set of dominant entities – challenging Bulgaria's agricultural sector's resilience, equity, and adaptability.

Fragmented ownership, unclear contractual arrangements, and highly concentrated asset distribution weaken coordination, raise adaptation costs, and destabilize long-term sectoral viability.

Common Agricultural Policy, Land Consolidation and Land Concentration

The rules of the CAP and underlying economic doctrine – when transposed into the Bulgarian context – have promoted efficiency through organizational integration and land consolidation. However, these mechanisms may cause distortions in market competition due to several factors:

A. Conflicting objectives within EU primary law.

B. Agricultural subsidy and financing regulations.

C. Rules governing integration of production organizations and processes.

D. Legal framework for land consolidation.

E. Indirect support mechanisms favoring large-scale agricultural entities.

Article 39(a) and (c) of the Treaty on the Functioning of the European Union (TFEU) places a strong emphasis on improving efficiency, often at the expense of ensuring market stability. This imbalance has contributed to the development of highly concentrated market structures and relies on the questionable assumption that gains in efficiency automatically benefit consumers. In reality, subsidies tied to land concentration tend to encourage behavior focused on securing financial advantage rather than improving production outcomes. The expected consumer benefits do not always materialize, revealing a mismatch between theoretical expectations and actual outcomes within the framework of the CAP. In the Bulgarian context, subsidies linked to the accumulation of agricultural land have frequently distorted perceptions of what constitutes efficiency and has enabled uncontrolled land acquisition. This has contributed to patterns of large-scale land appropriation, often to the benefit of a small number of powerful actors. As a result, market competition, particularly at the local level, has been weakened.

Although producer organizations are subject to rules regarding pricing practices and membership standards, there are no comparable mechanisms to ensure fair and equitable access to essential production resources, such as land. In some cases, the internal governance of these organizations is used to advance individual or group interests, undermining collective representation and the equitable distribution of benefits. When agricultural resources are fragmented, transaction and production costs rise, prompting CAP-driven consolidation to pursue economies of scale. However, this frequently results in market concentration. National legislation contributes to this problem by substituting market mechanisms with administrative procedures, such as:

•Replacing market actors with administrative bodies;

•Shifting from complete contracts (sales) to incomplete ones (leases, land use);

•Substituting transparency with formal procedures that exacerbate information asymmetry.

These developments have led to fewer small farmers and an increase in large enterprises. Ultimately, the number of market participants has declined, suggesting that existing consolidation rules cultivate bilateral market dynamics.

In Bulgaria, legislation allows large trusts to acquire and manage land domestically and abroad.

These entities benefit from tax advantages and sectoral diversification, which may constitute indirect support. Trusts often expand their activity to include both agriculture and industry.

Further local advantages arise through the consolidation procedure under Article 37(c) of the Agricultural Land Ownership and Use Act (LOUAL, 1991).

It mandates owners or users to declare cultivation of land, and failure to do so results in loss of access for one year.

This legislative-induced information asymmetry facilitates non-market advantages, shifting resources toward large-scale producers.

In Bulgaria, this dynamic has been particularly pronounced following the country's accession to the European Union in 2007, which introduced new market pressures and policy incentives under the CAP.

Initially, the post-communist land restitution process in the 1990s led to extreme fragmentation. Millions of small plots were returned to pre-collectivization owners or their heirs, resulting in a dispersed ownership structure.

According to Kopeva & Noev (2002) [13], the average size of land holdings dropped significantly, with many parcels under 0.5 hectares. By 2000, over 10 million land estates existed, with an average size of just 0.64 ha.

However, after 2007, a gradual consolidation trend emerged. Market mechanisms, leasing practices, and institutional reforms facilitated the aggregation of land into fewer hands. Mihailova et al. (2022) [15] note that the number of individual landowners declined, while the share of land operated by large agricultural enterprises and cooperatives increased.

This shift was reinforced by CAP subsidies, which favored scale and formalized operations, incentivizing land concentration.

By the early 2020s, the structure of Bulgarian agriculture had polarized: a small number of large farms controlled a significant portion of arable land, while many smallholders either exited the sector or leased their plots.

This evolution reflects a broader European pattern, where land consolidation is both a response to and a driver of structural transformation in rural economies.

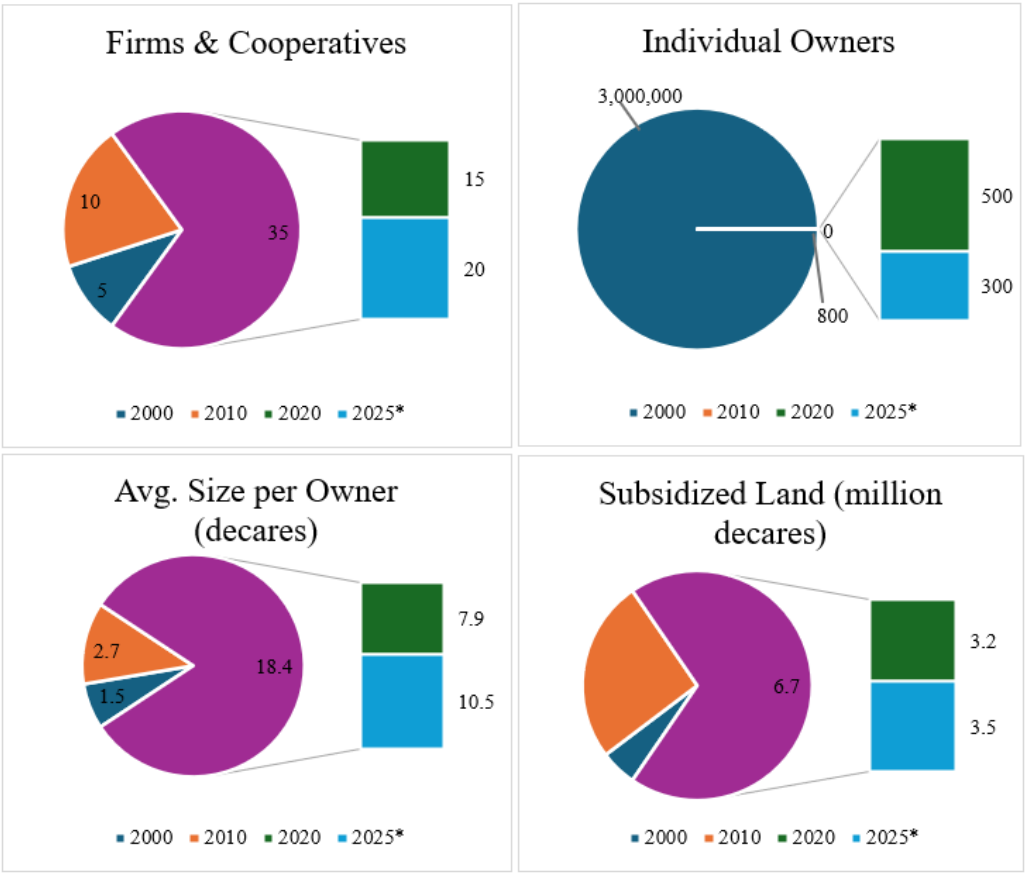

Fig. 3. Evolution of Agricultural Land Ownership in Bulgaria (2000–2025)
Source: Own research.

Figure 3 shows that between 2000 and 2025, Bulgaria experienced a marked transformation in the structure of agricultural land ownership. In 2000, the country had approximately 3 million individual landowners, each holding on average 1.5 decares.

Corporate ownership was minimal, with fewer than 5,000 firms and cooperatives involved in landholding.

By 2010, the number of individual owners had halved to around 1.5 million, while corporate entities increased to 10,000. The average landholding per owner rose to 2.7 decares, reflecting early signs of consolidation through leasing and informal aggregation. In 2020, the trend accelerated: individual owners dropped to 500,000, and corporate entities reached 15,000.

The average landholding per owner climbed to 7.9 decares, and large-scale operators began to dominate the landscape. Over 65% of agricultural land was now leased, and the top 5% of owners controlled more than 50% of arable land.

By 2025, projections suggest fewer than 300,000 individual owners remain, while corporate and cooperative entities exceed 20,000.

The average landholding per owner surpasses 10.5 decares, and corporate farms routinely manage areas exceeding 1,000 decares.

This reflects a deep structural shift toward capital-intensive agriculture, driven by EU policy incentives and the pursuit of economies of scale.

Between 2000 and 2025, the amount of subsidized agricultural land in Bulgaria grew substantially – from just 0.5 million decares to an estimated 3.5 million. This expansion meant that by 2025, nearly 88% of arable land was eligible for EU support, reflecting the dominance of formalized, large-scale farming.

Agricultural Land Analysis in the Context of New Institutional Economics

Figure 4 presents a scatter plot that shows how two key variables relate to each other: Time in Contract (TimeCon), measured in minutes, is displayed on the horizontal axis, and Number of Transactions in Contract (NTCon) appears on the vertical axis.

The plot is divided into three colored zones, each representing a distinct type of contractual arrangement based on where the data points cluster. The green area represents hybrid contracts. These points are located in the upper-right part of the graph, which means they involve both longer durations and a higher number of transactions. This pattern suggests complex, long-term relationships that require frequent interactions between parties.

The red area indicates market contracts. These are found in the middle section of the plot, showing moderate contract lengths and average transaction counts. This implies more flexible, transactional relationships that are less demanding in terms of coordination.

The blue area shows hierarchical contracts, clustered in the lower-left corner. These contracts involve shorter durations and fewer transactions, pointing to more structured, possibly centrally controlled arrangements that require minimal exchange. This visual division helps to clearly distinguish between different forms of governance by showing how much time and interaction each type of contract typically involves. When we look at how TimeCon and NTCon have changed over the years, we can see some important trends in how agricultural operations are evolving.

The variable TimeCon, which likely reflects both human labor and the use of machinery, shows a general upward trend over time. This suggests that agricultural activities are becoming more intensive – either because the areas under cultivation are expanding, interventions are more frequent, or machines are being used more heavily.

At the same time, NTCon – which probably indicates the number of treatments or interventions like fertilization, pesticide use, or irrigation – also shows an overall increase, although with some fluctuations. These ups and downs may be the result of seasonal changes, shifts in the types of crops being grown, or adjustments made in response to weather conditions, market forces, or other pressures.

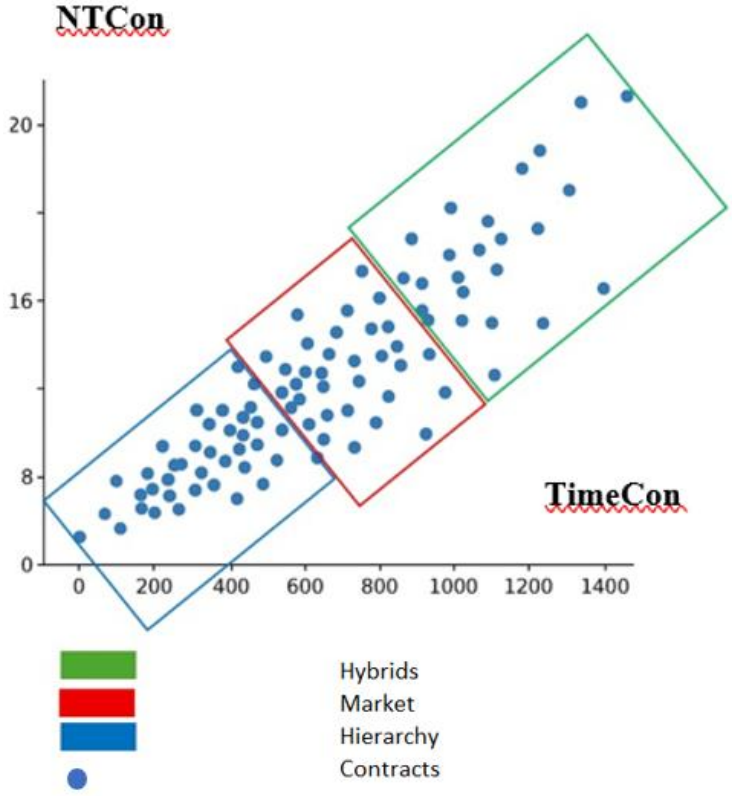

Fig. 4. Time in Contract (TimeCon - min) and Number of Transactions in Contract (NTCon)
Source: Own research.

One noticeable pattern is the sharp increase in both TimeCon and NTCon in 2019 and 2020. This could point to a move toward more input-intensive farming, possibly driven by new technologies, rising market expectations, or policy incentives. Looking at how TimeCon and NTCon rise together gives us insight into how farming practices are changing. When both variables increase at the same time, it suggests that farming is becoming more operationally intensive – meaning more labor and more inputs are being used. If this increase in effort and input is matched by higher yields, better quality, or more profit, then it may be a sign that the investment is paying off. However, if input use keeps rising but output stays the same or declines, that could be a warning sign of inefficiency or overuse of resources. For that reason, it's important to look more closely at productivity metrics. Only by comparing inputs and outputs can we understand whether this intensification of agriculture is sustainable and economically sound in the long term.

Discussion

Following the political transformation of 1989, Bulgarian agriculture entered a phase of profound restructuring, marked by tensions between fragmented land restitution and the growing concentration of land assets. This evolution is not merely institutional – it exemplifies how the interaction between legal regimes, economic incentives, and policy frameworks shapes agrarian structures with far-reaching socio-economic consequences.

Land fragmentation – stemming from post-socialist restitution policies – serves as a textbook example of elevated transaction costs and diminished efficiency under hyper-divided ownership. In theory, this impedes governance, investment flows, and scalability – each of which is crucial for sustainable agricultural development.

The subsequent wave of land consolidation, particularly after Bulgaria accedes to the European Union, reveals how market dynamics and external policy instruments, such as the CAP, can exacerbate structural inequality. Large agricultural enterprises, although streamlined in terms of organization, embody a broader theoretical challenge:

asymmetry in resource access and institutional support. Here, integration paradoxically generates competition-related distortions – enhancing productivity while weakening prospects for social and territorial inclusion.

Moreover, the emergence of hybrid governance structures – blending private, corporate, and collective elements – demonstrates how legal ambiguity and ownership complexity can incur hidden economic costs and foster social exclusion. This signals institutional dissonance, where theoretical and doctrinal logic clashes with local land management traditions and farming practices, generating multifaceted challenges for farmers and the agricultural sector.

The Bulgarian agrarian model underscores how historical legacies, ensuing regulatory decisions, and doctrinal economic pressure – often originating from supranational policies – create structural vulnerability. The core theoretical tension lies in balancing integration and consolidation with market efficiency, since while integration may optimize individual productivity, it simultaneously threatens sectoral competition, social resilience, and organizational diversity.

CONCLUSIONS

Land ownership constitutes a fundamental structural axis in the process of agricultural integration. In the Bulgarian context, this integration is inextricably shaped by the land ownership model. Although legislative reforms aim to expedite both vertical and horizontal integration, they frequently overlook the structural disparities stemming from land concentration. Dominant land trusts are able to externalize the costs associated with integration processes, which leads to the systematic exclusion of small-scale farming units. As a result, there exists an inverse correlation between increased transactional activity and organizational diversity, ultimately undermining the market adaptability of remaining participants.

Furthermore, the implementation of hybrid organizational models amplifies legal complexity and intensifies resource asymmetry. This reinforces the market dominance of capital-intensive enterprises while simultaneously marginalizing labor-intensive farming structures. To ensure long-term sectoral sustainability, future policy measures must balance individual efficiency objectives with regulatory safeguards that integrate land into the pool of resources whose misallocation could trigger market distortions.

Despite the intent of Bulgarian legislation to accelerate agricultural integration, the process remains critically influenced by land ownership dynamics. The concentration of land assets among a limited number of dominant actors restricts access for smallholders and compromises equitable participation within market mechanisms.

To foster inclusive agricultural development, legal reform must facilitate a balanced interaction between efficiency-driven consolidation and mechanisms ensuring fair land access, organizational diversity, and the resilience of smaller-scale entities.

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AGRICULTURAL CONTRACTS: GOVERNANCE, HYBRID STRUCTURES, COSTS AND DIGITAL TRANSFORMATION

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Abstract

This study examines the governance of agricultural contracts in Bulgaria (Plovdiv, Sofia, and Varna) within the EU transition framework, applying the lens of New Institutional Economics (NIE) to assess the effects of digitalization and property rights allocation on transaction costs. Using Comparative Institutional Analysis and Discrete Structural Analysis (DSA), the research evaluates 10,121 documents, semi-structured stakeholder interviews, and administrative procedures through the "one body–one actor" heuristic, distinguishing ex ante and ex post contractual phases. The findings reveal an explosive post-2015 expansion of hybrid contractual forms. A central contribution is the identification of a "paradox of digital transformation" (PDT): technological advancement does not automatically reduce transaction costs but often redistributes or even increases them due to institutional complexity and uneven digital literacy. Hybrid governance structures reallocate opportunistic behaviour toward a broader range of intermediaries (lawyers, notaries, and banks), while contract processing time increases with transaction intensity. Geographic location and farmers' digital adaptability remain key determinants of service accessibility and governance effectiveness. The study concludes by proposing adaptive governance strategies that balance innovation with the structural realities of a transitioning economy.

Key words**:** *agricultural contracts, governance structures, hybrid forms, digital transformation, NIE*

INTRODUCTION

The scientific challenge lies in addressing the problem of increasing complexity within the governance structure and the emergence of the digital transformation, like culture changed the human evolution [33]. Although digital platforms have the potential to reduce transaction costs, their effectiveness depends on the adaptability of users of digital services in agriculture (farmers and related organizations); consequently, overall costs may even increase. Furthermore, the hybrid contractual forms increasingly employed in agriculture having experienced explosive growth over the past two decades do not eliminate opportunistic behaviour but rather redistribute some of its negative effects among an expanding range of institutional actors specialized in the transformed processes.

The objective of this article is to examine the governance of agricultural contracts in Bulgaria (with a focus on the regions of Plovdiv, Sofia, and Varna) within the context of the ongoing transition in the European Union, through the lens of the analysis of different contractual forms, governance structures, and digitalization, assessed as outcomes of the allocation of property rights and the levels of transaction costs.

To achieve this objective, the study addresses the following tasks:•Identification and classification of contractual forms in Bulgarian agriculture according to the logic of NIE into three principal structures: markets, hierarchies, and hybrids.

•Analysis of institutional actors, distinguishing between primary actors (resource owners) and supporting actors (intermediaries such as banks, notaries, and lawyers), including their spatial specialization.

•Assessment of the impact of digital transformation on the speed of contract execution, transparency, and transaction monitoring.

•Examination of the relationship between contract processing time and transaction intensity in order to delineate the administrative complexity associated with different types of contracts. •Formulation of

guidelines for an adaptive governance structure in agriculture that balances overall efficiency with digital integration under the conditions of a transitional economy.

MATERIALS AND METHODS

The research methodology is multi-layered and combines classical and contemporary approaches within the framework of NIE, integrating comparative institutional analysis, structural contract analysis, and quantitative measurement of transaction costs. The analytical framework brings together normative legal-economic evaluation, empirical quantitative analysis, and qualitative structuring of contractual relations in order to explain the interaction between the allocation of property rights, institutional mechanisms, and digital transformation.

Research Approaches. The study adopts a dual methodological approach, including:

•Comparative Institutional Analysis – applied for the normative legal-economic evaluation of agricultural contracts and the comparison of alternative governance structures.

•DSA – used to segment contracts into two principal phases: ex ante (prior to conclusion) and ex post (after execution) (Georgiev & Roycheva, 2017) [20].

This approach enables simultaneous examination of the institutional environment, the internal logic of contractual relations, and their temporal dynamics.

Specific Research Methods. Heuristic principle "one body–one actor" – organizations are classified by legal form, and institutional participants are assigned specific roles: agents, actors, or arbitrators.

•Retrospective comparative analysis – contracts are assessed within a three-year post-execution window in order to trace property rights transfers and enforcement mechanisms.

•Semi-structured interviews – conducted with stakeholders to evaluate the allocation of property rights and the dynamics among participants.

•Process-oriented approach – applied to visualize and analyse sequences of administrative procedures and the roles of institutional actors (e.g., in the registration of agricultural producers or the conclusion of insurance contracts).

Transaction Cost Analysis. Transaction costs are evaluated through a combined quantitative and qualitative framework based on a distinction between:

•Objective indicators – taxes, notary fees, administrative payments, and other formalized property rights and transaction costs (Allen, 1991) [2].

•Subjective factors – opportunistic behaviour, adaptation costs, and information asymmetry (Benham & Benham, 2000; Benham et al., 2004) [6, 7].

This two-component structure allows for a more precise assessment of institutional efficiency and the comparative burden of different contractual forms.

Empirical Base and Scope. The empirical base comprises a dataset of 10,121 documents—including notarial acts, court rulings, cadastral maps, and inheritance certificates—covering 35 administrative procedures and 108 contract types. Special emphasis is placed on land tenure agreements under Article 37c of the Agricultural Land Ownership and Use Act (LOUAL), as well as on digital and hybrid contractual forms accessed through the legal information systems Lex.bg and Apis.

The territorial scope includes the regions of Plovdiv, Sofia, and Varna, tracing the development of institutional actors over the period 1994–2023. Both national legal and administrative databases and international statistical sources are utilized.

Quantitative and Visual Analysis. The study employs:

•Graphical trend analysis, illustrating the dynamics and "explosive growth" of hybrid contracts relative to hierarchical structures;

•Scatter plots to examine the relationship between contract processing time and the number of transactions, enabling the identification of gradients of administrative complexity.

The methodological framework integrates institutional analysis, spatial determinants (location theory see Alonso, 1964) [3], and empirically measurable indicators of transaction costs in order to explain how

digitalization and new contractual forms transform governance structures and efficiency in the agricultural sector.

RESULTS AND DISCUSSIONS

Governance structure and Agricultural Contracts – theoretical perspective.

This study is grounded in NIE, which conceptualizes contracts as embedded governance structures regulating exchanges beyond price mechanisms (Georgiev, 2024; Bachev, 2023) [19, 4]. Central to NIE is property rights theory, viewing rights as institutional arrangements that coordinate behaviour and reduce uncertainty (North, 1990; Alchian, 1969; Demsetz, 1967) [30, 1, 13]. While classical thinkers emphasized private ownership (Mill, 1869; Kurer, 1989) [28, 24], modern approaches highlight collective governance and hybrid models, especially in agriculture where shared resources require institutionalized cooperation (Ostrom, 1994; Shivakoti et al., 2019) [31, 35].

The boundaries of economic organization were first theorized by Coase (1937) [11] and Cheung (1983) [8], laying the foundation for NIE. The NIE integrates legal forms into three governance structures—hierarchies, markets, and hybrids—as outlined by Williamson (1996) [42].

From a transaction cost perspective, property rights help internalize externalities (Coase, 1960) [12], and hybrid organizational forms emerge to manage bounded rationality and opportunism (Williamson, 1981) [41]. In agricultural contracting, governance must balance public and private interests, often hindered by bureaucratic inefficiencies and informational asymmetries (Moe, 1984; Posner, 2003; Stigler & Becker, 1974) [29, 32, 37]. The NIE distinguishes between market actors and institutional intermediaries—some reduce enforcement costs (Jensen & Meckling, 1976) [22], while others engage in rent-seeking and distort resource allocation (Stiglitz, 2010) [39]. Such dynamics are evident in subsidy manipulation and land rights disputes (Stiglitz, 1974) [38].

Djankov et al. (2002) [14] provide a conceptual explanation of "entry costs." This framework enables the analysis of different organizational forms within a unified format and allows them to be evaluated as a single governance structure in the sense articulated by Williamson (1996) [42].

Digitalization introduces new governance tools that may reduce transaction costs and opportunism (Georgieva, 2023) [21], though their effectiveness depends on institutional adaptability (North, 1990) [30]. Agricultural contracts operate within layered governance systems shaped by evolving property rights and institutional complexity. Tne NIE provides a robust lens to assess these dynamics, while also exposing inefficiencies that call for reform and digital innovation (Galanter, 1981; Ciocan et al, 2025) [18, 10].

The relationship between locational theory and the NIE reflects a convergence between spatial determinants of economic behavior and institutional mechanisms governing coordination and risk. Classical models, from Johann Heinrich von Thünen's distance-based land rent theory [40] to William Alonso's bid-rent model [3], show how transport costs and accessibility shape resource allocation. Institutional theory, particularly Transaction Cost Economics, stresses that coordination depends on uncertainty, opportunism, and governance structures—not only prices.

As Ménard and Shirley (2022) [26] argue, mobility costs should not be equated with transaction costs, though they often interact by affecting information, monitoring, and enforcement. Integrating von Thünen's (1826) [40] insights into an institutional framework highlight how spatial constraints shape governance design, bargaining power, and institutional risk. Even in technological transformation, where digital tools modify coordination (Sheikh & Berényi, 2023) [34], spatial frictions remain decisive, as unequal access and geographic fragmentation can amplify or reduce transaction costs. Embedding locational frictions within institutional theory thus offers a more realistic explanation of how governance and technology jointly shape economic outcomes.

Governance Structure in EU Agriculture: Contractual Forms and Trends

Market contracts in agriculture reflect the classical features of exchange, taking the form of familiar legal instruments such as sales agreements or lease arrangements. Participants include buyers, sellers, tenants, and landlords, but within the framework of NIE this set expands to encompass actors who sustain market processes—banks, notaries, and administrative bodies. This broadening represents a horizontal extension of the contractual domain.

Hierarchies correspond to the classical structure of firms and administrative units. In NIE terms, these relationships follow a principal–agent logic, producing a vertically ordered governance structure. Agricultural enterprises organized on a non capital basis and operating in the context of the "farm" are typical representatives. Similar hierarchical contracts characterize processes within state structures, where interactions occur between an administrative unit and the addressee of an administrative act. This model can be extended to the state level, with a central agricultural authority (e.g., a Ministry of Agriculture) on one side and economic agents and organizations on the other, engaging in exchanges of rights within quasi markets for administrative services and related activities (Bachev & Ivanov, 2024) [5].

Hybrid contracts arise from the blending of functions—private and public, human and machine, technological and institutional—or from the interaction between market and hierarchical forms. Franchise arrangements for agricultural trademarks, as well as organizations uniting firms and public administration to protect geographical indications or products with specific origin, are typical examples. Hybrid forms also include contracts integrating human–machine interaction, particularly digital hubs and platforms in agriculture, where coordination occurs simultaneously along horizontal and vertical dimensions. Such systems require both coordination and autonomy of sub processes, which together form a unified governance structure within a larger organization.

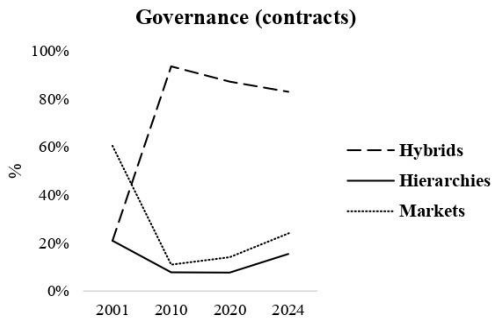

Fig. 1. Trends of Contractual Forms % in EU agriculture (2000-2024)

Source: Own Research based on Eurostat (2022, 2024, 2026); Joint Research Centre (2025); Ciaian, Kancs & Swinnen (2010) [15, 16, 17, 23, 9].

Figure 1 is complete and clearly illustrates the percentage growth across the three types of agricultural contracts in the EU for the period 2000–2024:

-Market contracts — a stable and accelerating upward trend, particularly after 2010.

-Hierarchical contracts — a gradual decline, reflecting consolidation and the exit of small farms.

-Hybrid contracts — explosive growth, especially after 2015, driven by digitalization and emerging organizational forms.

The chart shows a pronounced rise in hybrid governance models, indicating increasing complexity and interdependence among farmers, institutions, and digital platforms. Following the launch of the Green Deal, this trend continues, though with a less pronounced rate of increase. The number of firms declines, suggesting an expansion in operational scale. At the same time, the number of agricultural transactions continues to grow, signalling a shift toward more multilayered governance shaped by digitalization, specialization, and a proliferation of diverse transaction types—some of which are difficult to distinguish from contracts that constitute hybrid institutional arrangements.

Forms in Agricultural Contracts in Bulgaria

Table 1 presents various forms of agricultural contracts, categorized by legal structure and transaction type. For instance, a cooperative is both an organizational and legal entity, while a Sole Trader (ST) may blur the boundary between individual and corporate structures.

Hybrid contracts, though market-based, often involve hierarchical elements (Șomîcu & Vladu, 2025; Mihailova, 2024) [36, 27].

A land sale, for example, typically requires multiple documents, introducing levels of complexity that reflect hierarchical governance within otherwise market-driven transactions. In corporate agricultural entities, legal actions related to registration are increasingly mediated through AI enabled platforms that operate as mechanisms for allocating property rights, thereby classifying these arrangements as hybrid.

Their analysis requires dual methodological treatment and clear institutional role definition to distinguish bilateral exchanges from internal transactions.

Table 1 presents examples of agricultural contractual formS and regimes in NIE.

Table 1. Examples of Agricultural Contractual Forms and Regimes in NIE

Hierarchies	Market Contracts	Hybrids
Administrative procedures	***Sale of agricultural land***	***Technological, franchise hybrids, and mixed forms***
Farmer registration	Land and Lease Agreements	Public registries
Allocation of Subsidies	Partition of agricultural land	Digital hubs (AI-based systems)
Process for the allocation of Document issuance	Loans (secured by agricultural land)	Geographic indication and quality certification organizations
Process for the Licensing (pesticide use)	Agricultural insurance contracts	Organizations under Regulation 1308/2013[1]
Agricultural enterprises, registration modes	Employment contracts	Agreements under Art. 37c LOUAL for land consolidation;
	Inheritance (by law or will)	Special investment companies (land management)
Sole traders, LTDs, agricultural associations, cooperatives, joint-stock companies		Court disputes over land ownership

Source: Regulation (EU) No 1308/2013 of the European Parliament and of the Council of 17 December 2013 establishing a common organisation of the markets in agricultural products [44] and repealing Regulations No 922/72, 234/79, 1037/2001 and 1234/2007 [45].
Source: Own Research.

Contract participants fall into two categories: (a) Primary actors — resource owners holding transferable or protected property rights.

(b) Supporting actors — facilitators of rights transfer, including buyers, sellers, and tenants. Contracts are enforced by institutional intermediaries—market institutions (exchanges, brokers), public agencies (registries, notaries), and arbitration bodies—whose functions span compliance and enforcement. As participation expands, contractual complexity increases, driving specialization among actors (Ménard, 2022) [25].

Table 2 summarizes the main institutional actors across contractual forms, grouped by governance structure—hierarchies, market contracts, and hybrids. It shows how farmers, public agencies, financial institutions, and legal professionals coordinate across domains such as registration, land deals, insurance, employment, and digital platforms. Relevant legislation—such as Regulation 1308/2013, which establishes a Common Market Organization (CMO) for agricultural products, the Farmers Assistant Act (FAA), and LOUAL (covering land ownership and use)—provides the legal backdrop.

This classification reflects a theoretical duality between contractual forms and economic entities: for example, cooperatives may function simultaneously as firms and collective arrangements.

Ultimately, this structural framework highlights the diversity of institutional participants in agricultural contracting, spanning regulatory bodies and market-based intermediaries. It emphasizes the need to understand contractual governance as a layered interaction between formal rules, transaction types, and actor roles.

Table 2. Contractual Forms and Institutional Actors

Contractual Form	Institutional Actors
Hierarchies	
Farmer registration	Applicants: Individuals, Legal Entities, Trade Registry, Tax Authorities, National Social Security Institute, Banks
Subsidies (FAA)	Applicants: Farmers, Agricultural Fund, Banks
Licensing (pesticide use)	Applicants: Farmers, Regulatory Agency, Banks
Agricultural enterprises	Applicants: Individual or legal entities, lawyers, notaries, banks
Market Contracts	
Sale of agricultural land	Buyers, sellers, tenants, landlords, registry agencies, cadastral offices, local tax authorities, lawyers, banks
Lease agreements	Farmers, landlords, and financial institutions
Agricultural insurance	Farmers, insurance companies, brokers, banks
Employment contracts	Employers, workers, labor unions, labor inspectorates, banks
Hybrids	
Public registries	Entities are listed in a hybrid environment.
Digital hubs	Platforms facilitating coordination: Scientific institutions, public bodies, individual and group agricultural producers
Quality schemes	Ministry of Agriculture, farmers, and consulting organizations
Regulation 1308/2013 Organizations	Farmers, agricultural traders, and regulatory bodies
Land consolidation (Art. 37c LOUAL)	Local agricultural offices, municipal authorities, regional governors, lawyers, banks
Court disputes over land	Courts, plaintiffs, defendants, public authorities, expert witnesses

Source: Own Research.

Process-based approach to analysing of agricultural contract

Initiation and Administrative Registration as an Agricultural Producer

Figure 2 presents a structured overview of the initial registration process for agricultural enterprises in Bulgaria.

It delineates the sequence of administrative procedures and the institutional actors involved, including commercial registries, tax authorities, and commercial banks.

The process of registering an agricultural enterprise in Bulgaria is institutionally and administratively complex, involving a sequence of legal interactions with various regulatory bodies.

Both natural and legal persons initiate their status as agricultural producers by submitting documents attesting to ownership or lease of No. 3 (29.01.1999) and the Agricultural Producer Support Act.

Legal entities must additionally provide a certificate of legal status from the Commercial Register and a BULSTAT identification card, establishing formal identity.

Registration begins with the completion of a survey form, which is submitted to the Municipal Agricultural Office (MAO) or the Regional Agricultural Office (RAO).

Once production commences, the process continues through the National Revenue Agency (NRA), the National Social Security Institute (NSI), and VAT registration where applicable—procedures that reflect a multi-layered interaction between business and institutional ecosystems.

Agricultural enterprises (firms): sole traders, limited liability companies, cooperatives

Figure 3 illustrates the legal and institutional pathways for establishing agricultural firms as cooperatives or limited liability companies (LLCs), emphasizing the roles of farmers, legal professionals, notaries, and administrators in defining ownership, management, and compliance.

Figure 3 also clarifies the actions that both natural persons and legal entities must undertake in order to navigate the legal, financial, and bureaucratic requirements associated with establishing a new agricultural business entity. The registration of agricultural producers as commercial entities is governed by provisions in the Commercial Act, the Cooperatives Act, and the Trade

Register Act, alongside a broader regulatory framework that includes the Social Security Code, the Accounting Act, and the Corporate Taxation Act, among others. This layered legal structure reflects the institutional complexity of agricultural entrepreneurship and the necessity for coordinated inter-agency registration procedures.

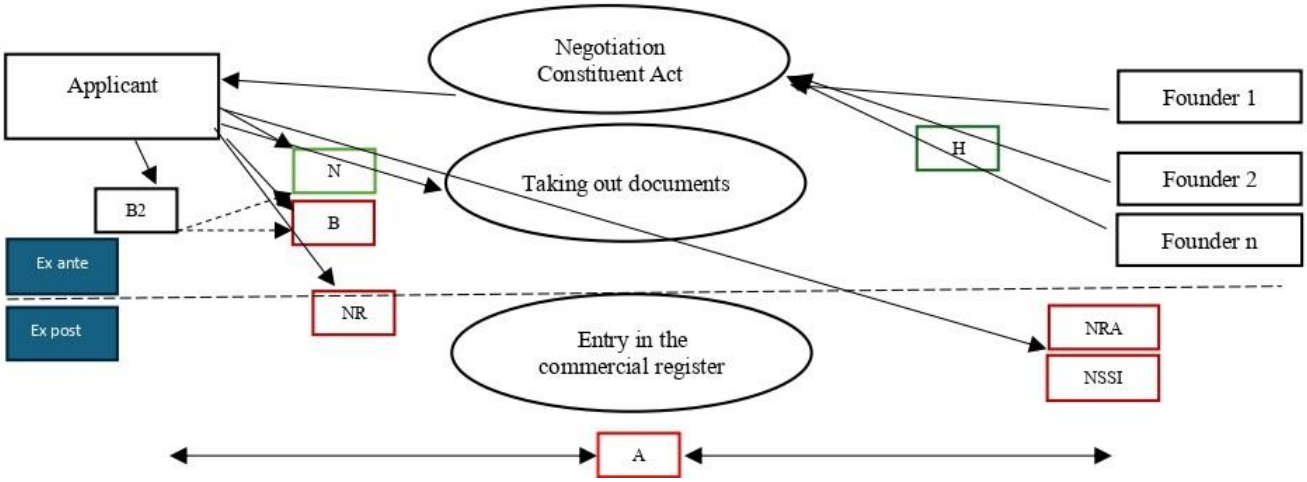

Fig. 2. Agricultural Business Start-Up (Initial Registration)
Source: Own Research.

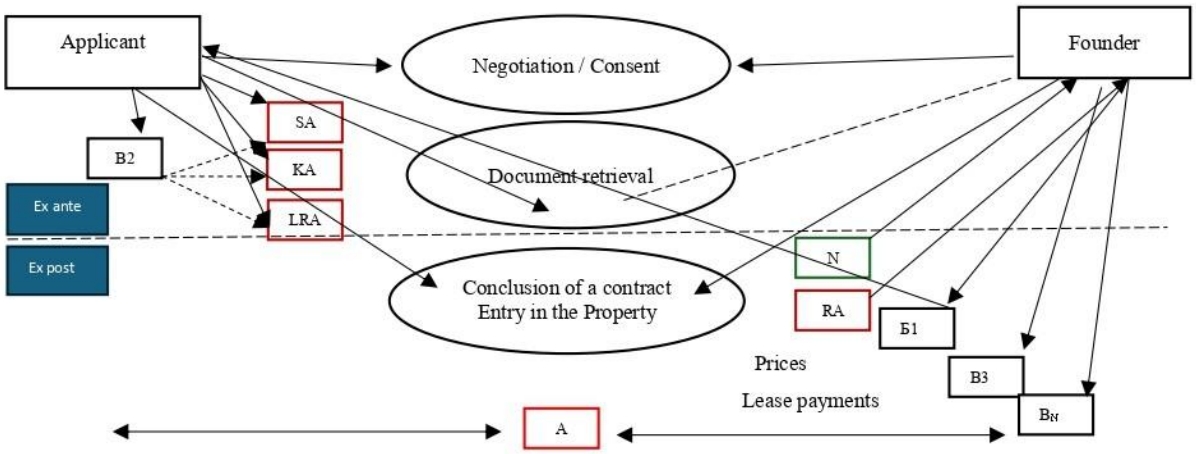

Fig. 3. Agricultural Firms-Cooperatives and LLCs
Source: Own Research.

From the perspective of NIE, the registration process embodies the logic of a classical, complete hierarchical contract. It formalizes property rights and organizational legitimacy—prerequisites for accessing financial mechanisms such as EU agricultural subsidies.The procedural rigidity and defined steps affirm the embeddedness of governance within bureaucratic structures, consistent with the NIE view of contracts as institutionalized instruments of coordination and control. For LLCs, founding partners agree on core elements—name, capital, internal structure, and business scope—formalized through a Company Agreement.

Documentation is submitted to a bank and the Registry Agency (RA), followed by registrations with the NRA, NII, and VAT system, where applicable.Under the NIE framework, cooperative contracts are viewed as neo-classical, incomplete, and embedded in hierarchical structures. Property rights are allocated based on residual functions (e.g., decision-making, dividends), while transaction costs are assessed across formation, operation, and dissolution phases—highlighting institutional inefficiencies and NIE's emphasis on governance in economic coordination.

Purchase-Sale and Lease of Agricultural Land and Buildings

Figure 4 illustrates the institutional architecture of land transactions, distinguishing private, public, and mixed-function actors via border-coded designations. It marks two thresholds: the ex ante/ex post phases and the transition from contract initiation to execution.

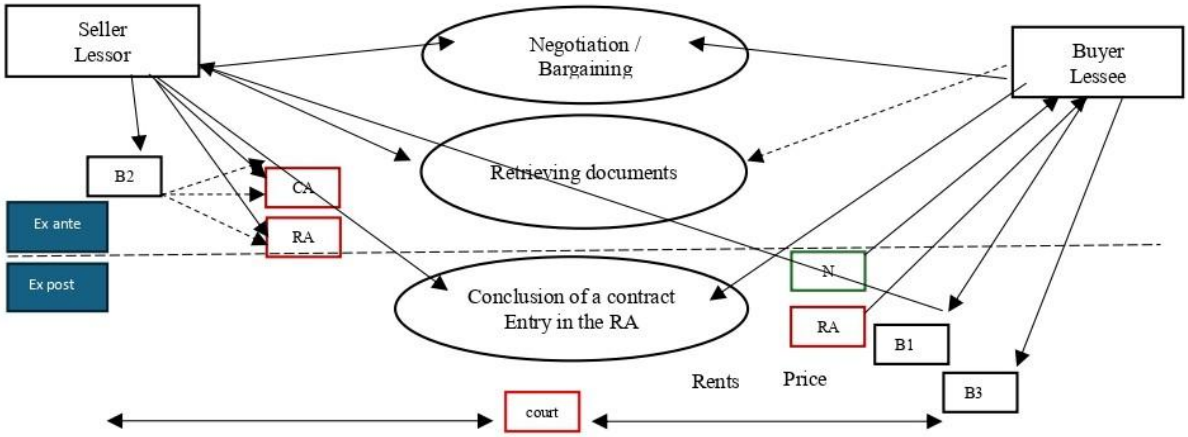

Fig. 4. Land Purchase-Sale and Lease Transactions
Source: Own Research.

The schematic captures legal, financial, and administrative dimensions of sale and lease agreements, highlighting the roles of buyers, sellers, tenants, landlords, and institutions such as registries and banks.The transfer of agricultural real estate in Bulgaria is regulated by multiple legal acts, including the Agricultural Land Ownership and Use Act, Property Act, and Obligations and Contracts Act. Standard sale contracts typically involve land, buildings, equipment, and produce, while share transfers in agricultural enterprises remain legally atypical. Legally, land sales are bilateral, reciprocal, and consensual, formalized through multilateral procedures. Commodity-based transactions, however, often lack formalization. Within the NIE framework, land purchase agreements are viewed as neo-classical, complete contracts with clearly defined terms and minimal ambiguity.

A key distinction exists between land leasing (arenda) and rental. Leasing entails stricter formalities—requiring notarized, registered agreements—which support long-term investment and offer stronger legal protection for lessees. These contracts are governed by the Land Lease Act and related statutes. While leases involving land and buildings are common, equipment leasing remains legally marginal. Like sales, leases are bilateral and consensual, but land leases are consistently formal and multilateral in execution. Within the NIE framework, leasing contracts are considered incomplete, generating transaction costs through property rights transfer, protection, and exposure to opportunism. These inefficiencies reflect deeper asymmetries and institutional challenges in agricultural land tenure. Contract finalization varies: sale agreements transfer rights upon registration, while leases remain active over multi-year periods. Property rights are categorized by function—alienation, possession, income generation, protection, and liquidation. Choosing the appropriate contractual structure involves assessing organizational design, cost efficiency, liquidity, and risk mitigation. In some cases, risk redistribution among parties aligns governance with production realities.

Agricultural Insurance Contracts

Figure 5 models the agricultural property insurance process, highlighting how rights and risks are functionally distributed among institutional actors based on coverage scope and risk intensity. The figure portrays the interrelations between: a. Farmers, who seek to mitigate operational risk; b. Insurance companies, responsible for underwriting and

compensation; c. Insurance brokers, acting as intermediaries; g. Banks, involved in financing and risk assessment processes.

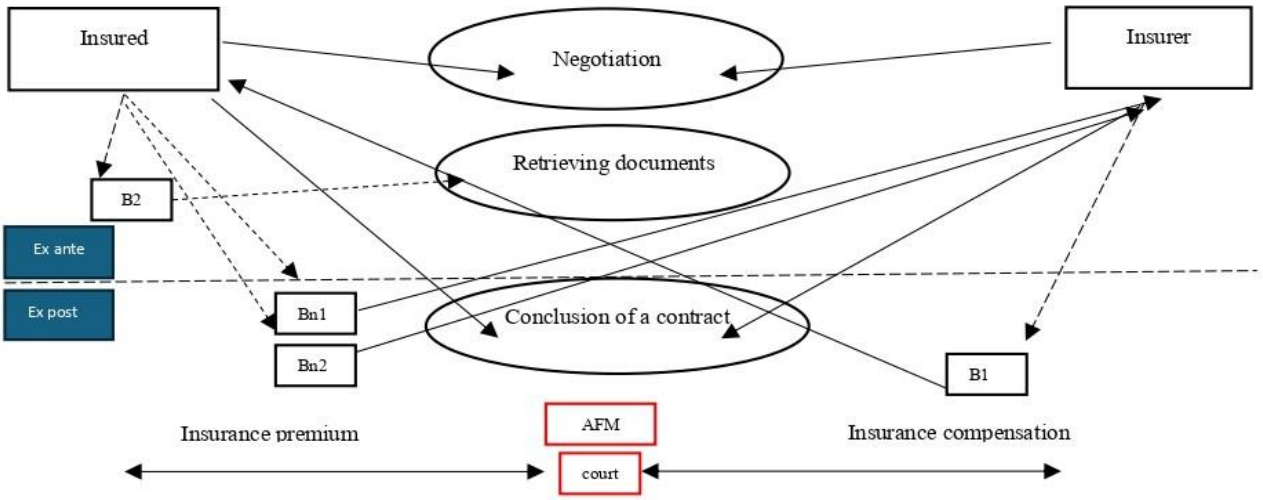

Fig. 5. Agricultural Property Insurance Contract
Source: Own Research.

Agricultural insurance in Bulgaria operates under the provisions of the Insurance Code, which defines such contracts as bilateral, reciprocal, formal, and aleatory in nature. These contracts inherently involve risk-sharing mechanisms, where one party (the insurer) guarantees compensation for potential agricultural losses contingent on uncertain future events. From the standpoint of NIE, agricultural insurance contracts are categorized as neo-classical yet incomplete. The incompleteness stems from the challenge of fully specifying all contingencies and outcomes in advance, given the volatility inherent in agricultural production. Key transaction costs in agricultural insurance include property rights protection, transfer, and monitoring. These reflect the institutional mechanisms necessary to enforce contracts and protect stakeholder interests in dynamic environments.

The schematic outlines key stages including risk evaluation, coverage negotiation, contract finalization, and asset protection, underscoring the multifaceted role of financial and administrative institutions in shaping agricultural resilience.Despite the theoretical aim of insurance to minimize transaction costs, empirical evidence suggests a contrary trend. Rising costs are often attributed to the redistribution of property rights, whereby contractual ambiguities and enforcement complexities hinder cost efficiency. This reflects the broader NIE concern with institutional limitations in managing economic transactions under uncertainty.

Employment Contracts: Permanent, Temporary, and Collective Agreements

Figure 6 categorizes participants by their role in the legal and administrative formation of labor agreements, outlining procedural steps such as compliance verification, occupational safety enforcement, and financial accountability. Property rights are allocated based on risk protection and opportunism levels, shaping both enforceability and sustainability of contracts. That presents agricultural labor relations in Bulgaria, governed by the Labor Code, Occupational Safety Act, and Social Security Code. Employment contracts are bilateral, formal, and consensual, embedding mutual obligations. Within the NIE framework, they are classified as behavioral and incomplete due to informational asymmetries and limited contingency coverage. Key transaction costs include: a. Monitoring expenditures; b. Negotiation efforts; c. Transfer and protection of rights; g. Adaptation expenses due to technological and seasonal shifts.

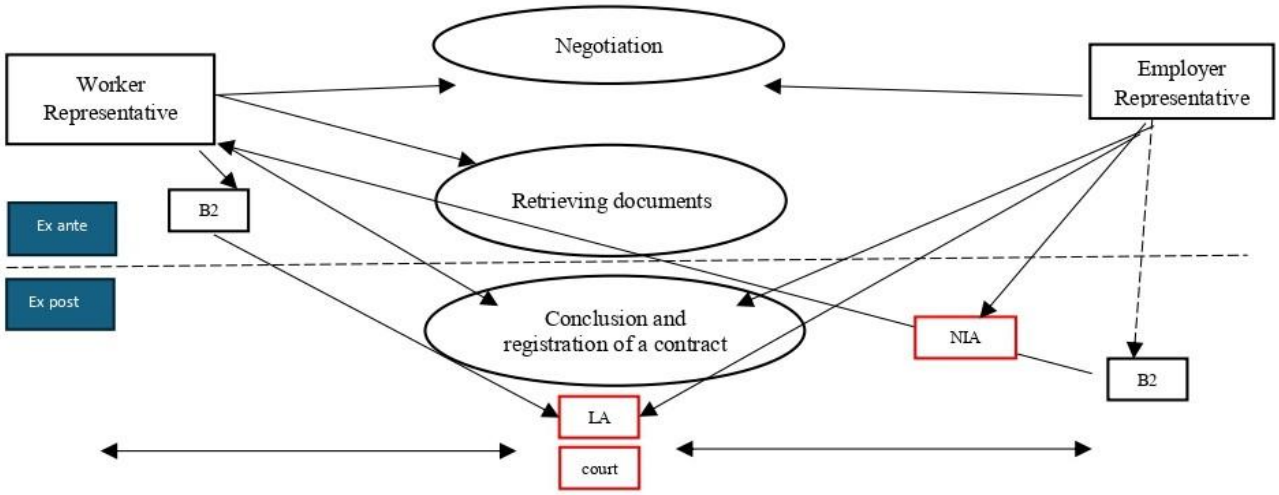

Fig. 6. Employment contracts in agriculture
Source: Own Research.

Agricultural production's seasonality and technological specificity create tensions between short-term and long-term employment, increasing contractual complexity and administrative burden. In family-based farming, informal labor is common and functionally efficient but lacks institutional oversight. Formal labor relations often involve collective bargaining, where unions and employer representatives negotiate wages, conditions, and protections—reinforcing the behavioral nature of contracts.

The figure depicts the contractual and institutional landscape of agricultural labor. It visualizes the roles and interactions among: a. Employers and workers; b. Labor unions and inspectorates; c. Financial institutions (e.g., banks). Figure 6 categorizes participants by their role in the legal and administrative formation of labor agreements, outlining procedural steps such as compliance verification, occupational safety enforcement, and financial accountability. Property rights are allocated based on risk protection and opportunism levels, shaping both enforceability and sustainability of contracts. Despite technological advances in mechanization and digital monitoring—expected to lower labor-related transaction costs—empirical data reveal a paradox: administrative burdens and monitoring duties are redistributed across participants, increasing overall costs.

This finding questions the NIE assumption that innovation automatically improves institutional efficiency and instead underscores the importance of sound contract design and regulatory coherence. Modern agricultural insurance contracts seek to reduce production costs through mechanization and digitalization. Although these tools decrease monitoring costs, changes in the allocation of property rights often shift part of the costs to other actors, thereby reducing the net efficiency gains. Labor contracts in agriculture remain behavioral and incomplete, as emphasized by NIE, and are regulated by the Labor Code, the Occupational Safety Act, and the Social Security Code. Transaction costs stem from monitoring, negotiation, transfer and protection of rights, and contractual adaptation. The sector's seasonality and technological specificity create tensions between short-term and long-term employment, increasing contractual complexity and raising enforcement and implementation costs.

Contractual Agreements Under Article 37c of the LOUAL

Land governance operates within an extensive regulatory framework that includes the Agricultural Land Ownership and Use Act (LOUAL), the Property Act, the Obligations and Contracts Act, the Municipal Property Act, and the State Property Act. Together, these laws establish a multilayered system for regulating property relations and contractual

arrangements. Central to this framework is Article 37c of the LOUAL, which introduces a hybrid land-redistribution mechanism combining market negotiation with administrative allocation based on hierarchical decision-making within agricultural enterprises. The process concludes with the issuance of a final land distribution map by the Regional Governor, formalizing the reconfigured property rights. This sequence integrates administrative procedures, contractual obligations, and institutional coordination, reflecting Bulgaria's approach to structured land-use governance.

Figure 7 presents a concise, analytically structured depiction of the legal and institutional processes governing the use and redistribution of agricultural land in Bulgaria.

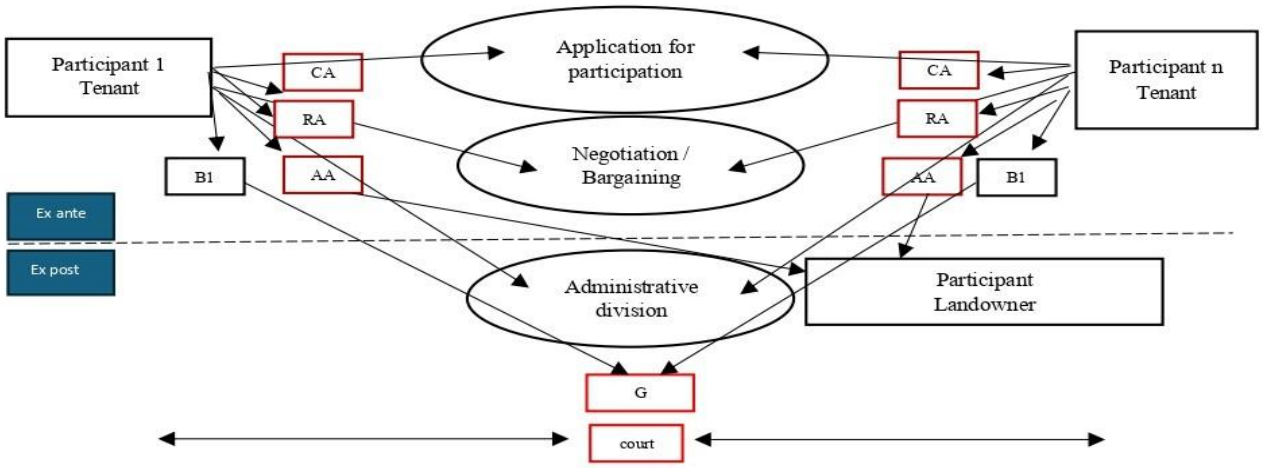

Fig. 7. The procedure under Article 37c of the LOUAL
Source: Own Research.

Figure 7 highlights the roles of agricultural enterprises, municipal and regional agricultural offices, municipal administrations, regional governors, and legal and financial intermediaries. The process begins with internal decisions by agricultural firms to participate in coordinated land-use or consolidation schemes. Upon registration with the Agricultural Office, firms gain access to information on unclaimed parcels (Articles 69–71, LOUAL), initiating formal institutional engagement. Subsequent negotiations with landowners determine the allocation of parcels; when no agreement is reached, authorities redistribute undeclared land through formal lease contracts, with rents set according to regional market averages. This mechanism exemplifies hybrid governance, blending state coordination with market-based valuation.

Institutionally, the resulting allocation of property rights reduces exposure to operational risk while balancing administrative authority and market bargaining. Although Art. 37c contracts are designed to promote coordinated land use and reduce inefficiencies, empirical evidence indicates that they often redistribute rather than eliminate opportunism. Incentives are reshaped within institutional constraints, sometimes lowering administrative fees without reducing overall transaction costs. These arrangements represent a hybrid governance form—an attempt to align market mechanisms with state regulation—yet in practice they frequently enable strategic behavior and shift transaction costs among stakeholders, challenging the assumption that institutional design alone ensures efficiency.

Agricultural Associations Under Regulation 1308/2013 [44]

The establishment process is similar to corporate structures, but functions as a representative body protecting members' rights against producers in other sectors. This protection is facilitated through institutional partnerships with state bodies (The Ministry of Agriculture and Food - MAF) [46] (Fig. 8).

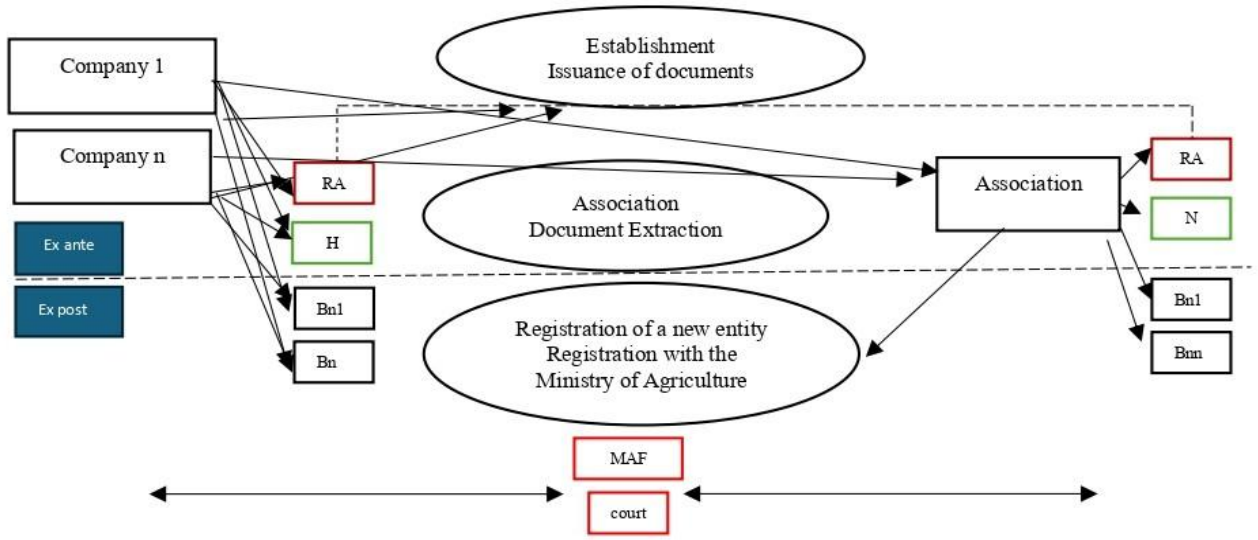

Fig. 8. Association Formation Under Regulation 1308/2013
Source: [44, 46].

The association maintains private sector interests while balancing interactions with market and non-market hierarchies.Associations are organizations established to protect property rights through collective action. However, they also enable the concentration and redistribution of these rights to a limited group of representatives. While individual costs for this group remain low, they are high for other members.

Consequently, overall transaction costs tend to increase in the long term. Modern agricultural contracts reflect a complex interplay between property rights, governance structures, and institutional actors. These actors can play dual roles: some reduce monitoring and enforcement costs, while others act as rent-seekers, extracting value and inefficiently reallocating transaction costs. The rising number of participants in agricultural agreements has spurred an increase in institutional intermediaries, intensifying competition over property rights distribution. Data reveal a marked rise in the number of lawyers, banks, and notaries—particularly in Sofia—signaling the growing complexity and specialization in agricultural transactions. Agricultural Associations Under Regulation 1308/2013 [44]: Classified as hybrid and incomplete contracts. Transaction costs are evaluated via residual property rights and monitoring expenses. Although they safeguard rights through collective action, they may concentrate and redistribute these rights among a limited group of representatives, leading to an increase in long-term transaction costs.

Teritorial allocations and agricultural contracts

Administrative actors

Territorial organization in agriculture critically supports contractual processes by shaping institutional capacity—much like neo-classical factors such as producer distribution affect supply. Yet, spatial density does not inherently raise individual transaction costs. Coordinated mechanisms, including integrated institutional functions and digital platforms, can absorb complexity and facilitate scalable exchanges. Digitally-enabled alternatives streamline procedures, reducing burdens on individual actors. However, the expansion of institutional participants—lawyers, notaries, banks, and intermediaries—drives up administrative fees, often borne by property rights holders. This institutional growth has increased both transaction costs and the complexity of contractual pathways across the sector. Figure 9 illustrates the evolution of institutional actors in agricultural governance across Varna, Plovdiv, and Sofia from 1994 to 2023.

Varna	1994 - 2023	
Office of Agriculture	1994	2023
Cadastre	12	11
Notaries	1	1
Lawyers	207	1020
Banks	13	13
Intermediaries	88	151

Sofia	1994 - 2023	
Office of Agriculture	1994	2023
Cadastre	12	11
Notaries	1	1
Lawyers	524	5130
Banks	13	13
Intermediaries	22	56

Plovdiv	1994 - 2023	
Office of Agriculture Service	1994	2023
Cadastre	12	11
Notaries	30	65
Lawyers	303	1146
Banks	18	18
Intermediaries	19	35

Fig. 9. Distribution of actors in BG (agricultural regions: Plovdiv, Sofia, Varna 2000-2023)
Source: Own Research.

The data show significant growth in the number of lawyers—exceeding 5,000 in Sofia alone by 2023—as well as a steady expansion of notaries, banks, and, more recently, specialized intermediaries. This distribution of actors reflects core market supply dynamics: as administrative capacity becomes strained, delays in securing documentation increase, amplifying transaction burdens. Sofia's concentration of legal and financial infrastructure underscores its central role in the institutional landscape. These patterns reveal both regional disparities in service provision and a broader trend toward institutional expansion and complexity nationwide.

Digital transformation offers a potential remedy by reducing the need for physical transactions. Online platforms can streamline interactions, lowering costs related to travel, paperwork, and in-person coordination.

However, the effectiveness of such solutions still hinges on the geographic accessibility of service centers—an ongoing barrier for many rights holders facing distance and mobility constraints.

The PDT

Highly digitized contract forms do not always lead to lower transaction costs. Figure 10 presents a scatter plot comparing transaction volume with total processing time across several types of agricultural contracts, including land sales, leases, insurance agreements, labor contracts, and legal disputes. The figure visualizes how the number of transactions unfolds relative to contract duration for the previously described contractual forms. The length of the contracting process and the frequency of transactions are closely linked to opportunistic behavior among property-rights holders, which in turn shapes the magnitude of transaction costs. The scatter plot illustrates the relationship between Time per Contract (horizontal axis) and Number of Transactions (vertical axis), with each point representing a distinct contractual form. The distribution reveals a predominantly positive and approximately linear association: contract types requiring longer processing times tend to generate a higher number of transactions.

The configuration follows an upward-sloping trajectory, indicating a systematic relationship between processing time and transaction frequency. Contractual categories occupy distinct positions defined by these two dimensions, forming a gradient of administrative complexity—from streamlined arrangements with limited follow-up to resource-intensive regimes requiring prolonged engagement and frequent interaction. Contracts with short processing times and low activity (e.g., Registration of Agricultural Producer, Fumigation Procedure, Firm LTD) reflect simplified procedures and minimal obligations. An intermediate cluster (Cooperation, Digital Platform, Association) combines moderate duration and transactional

intensity, suggesting higher coordination and regulatory requirements.

Lease, Organization P-1308/2013, and Sale occupy the upper range, characterized by extended cycles and substantial activity. At the extreme, Quality Scheme, Procedure Art. 37c LOUAL, and Ownership Dispute (Litigation) display the longest durations and highest transaction counts, indicating complex legal or regulatory oversight (Fig. 10).

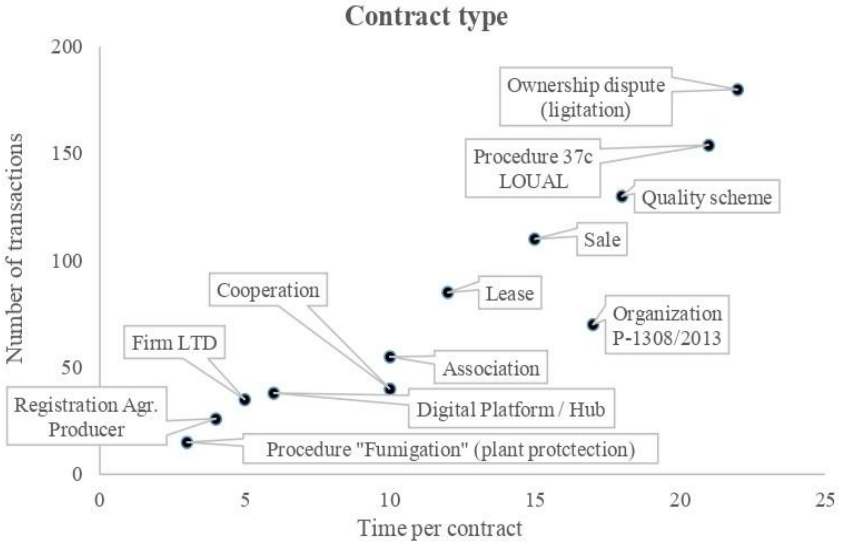

Fig. 10. Average Number of Transactions and Average Time Across Contract Types
Source: Own Research.

Overall, contractual complexity appears multidimensional and clustered rather than linear.

The strong positive association suggests that institutional and procedural complexity jointly increases both duration and transactional intensity. Digitalization adds nuance: initiation-type contracts show low costs and short duration, yet long-term efficiency depends on users' adaptive capacity and institutional competence.

Hybrid or weakly digitalized forms (e.g., litigation, R-1308/2013 organizations) retain high transaction costs, while even digitally integrated contracts (tenancy, sale) continue to generate substantial costs.

This indicates that digitalization alone has not significantly reduced total contractual costs, as enforcement and rights-protection mechanisms remain the dominant cost component.

Figure 11 presents a bar chart that maps the relationship between transaction volume and processing time across various types of agricultural contracts types—land sales, leases, insurance, labor agreements, and legal disputes—by transaction frequency and processing time, offering insight into procedural complexity and institutional involvement.

The data show no definitive evidence that market-based contracts incur higher costs than hybrid alternatives. Instead, hybrid structures may foster opportunistic behavior, especially where enforcement mechanisms are weak, influencing performance outcomes. These findings highlight the need to assess both contract form and institutional context when evaluating efficiency and cost distribution.

Property rights, increasingly viewed as instruments of resource control, add layers of complexity to hybrid arrangements, where overlapping market and institutional mechanisms shape governance.

Transaction costs arise from both objective factors—taxes, registration, notarial fees—and subjective ones such as opportunism and adaptation. As demand for specialization grows, so does the number of intermediaries and arbitrators, increasing transaction volume and administrative load.

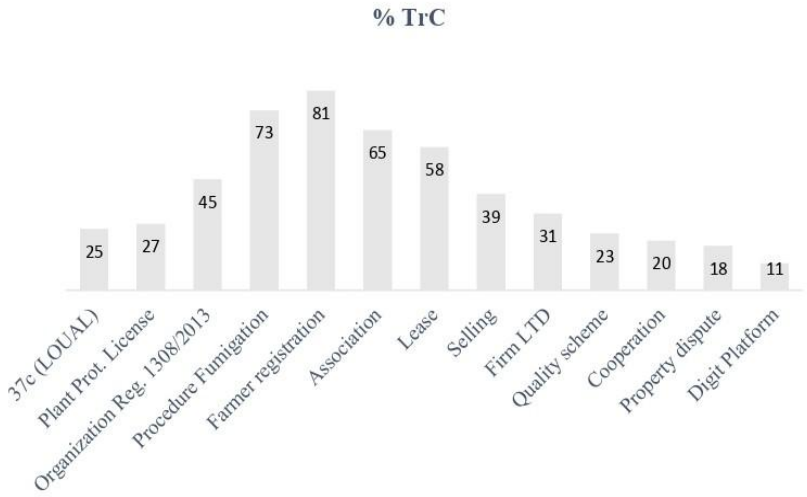

Fig. 11. Market Fees Distributions as a Percentage of Total Transaction Costs
Source: Own Research.

The study formulates the following preliminary conclusions regarding the level and structure of transaction costs across different types of contracts: Land-related contracts (lease and sale), as well as insurance and labor contracts, generate higher transaction costs due to the need for standardization and internalization of transactions within organizational frameworks. These costs include tax and insurance assessments, notarial and legal services, registration fees, and related administrative expenses. In this context, market-based forms are associated with lower risk and, correspondingly, lower levels of transaction costs (Yap et al, 2025) [44].

Procedures under Art. 37c of LOUAL and R-1308/2013 exhibit a hybrid character. However, the involvement of multiple actors with differentiated functions contributes to relatively high transaction costs Legal disputes and specialized contracts involve unpredictable costs, often linked to unforeseen losses, risk mitigation, expert assessments, legal consultations, state fees, and related expenditures. These largely reflect opportunistic costs. Hybrid governance forms may reduce some of these costs—for example, mediation integrates functions of different actors within a single procedural framework. Conversely, digital platforms may increase transaction costs due to difficulties in standardizing transactions.

Administrative procedures and hierarchical organizations are subject to a high degree of digitalization, which positively affects the reduction of transaction costs.

Digital organizations (hubs and platforms), as inherently hybrid forms, have the potential to substantially reduce costs through synergies between human and machine labor. At the same time, they may generate increased institutional barriers related to technological rights and access to technology.

CONCLUSIONS

A. *Explosive growth of hybrid structures*. A major trend is the marked expansion of hybrid contractual arrangements that combine elements of market exchange and hierarchy, particularly after 2015. These forms emerge from intensified digitalization and the growing need for coordination between private actors and public administration. At the same time, classical hierarchical structures (such as small farms) decline due to consolidation processes.

B. *The PDT*. The most significant—and somewhat counterintuitive—finding is that digital transformation does not automatically reduce transaction costs. Although online platforms can accelerate processes and enhance transparency, their effectiveness depends critically on how well the technology adapts to the users of digital services. Among agricultural actors with low digital literacy

(e.g., older landowners and resource holders), technological solutions may even increase overall costs.

C. *Redistribution rather than elimination of opportunism.* The study demonstrates that hybrid contracts and institutional reforms (such as the procedures under Art. 37c of the Agricultural Land Ownership and Use Act) do not eliminate opportunistic behavior; they merely redistribute rights among a larger number of participants with different specializations in agricultural labor markets.

Such structures often create conditions for "hidden gains" captured by intermediaries, administrative units, or institutional arbiters (lawyers, notaries, judges) who, under the guise of risk reduction, accumulate rights for personal benefit.

D. *Rising role and costs of intermediaries*. There is a substantial expansion in the range of institutional intermediaries—lawyers, notaries, banks, and specialized agents. Data indicate a dramatic increase in their numbers (especially in major centers such as Sofia, Plovdiv, and Varna). While this supports specialization, it also raises administrative burdens and market fees for rights holders.

E. *Linear relationship between time and transactions.* A direct dependency is observed: contracts requiring longer processing times generate a higher number of transactions. The most resource-intensive and complex regimes involve judicial disputes over property, quality schemes, and procedures for land-use consolidation.

F. *The spatial factor as an institutional driver*. Contrary to some theoretical models, the study emphasizes that geographic location is not merely a logistical variable but a key institutional determinant. Spatial distribution directly affects mobility costs and service accessibility, shaping the effectiveness of governance over agricultural property rights, including those related to institutional risk.

G. The *governance of agricultural contracts* is a complex, multilayered process in which the institutional design of the governance structure is shaped both by the pace of technological innovation and by the degree to which technology is adapted to the needs of farmers and their communities. Digitalization and the proliferation of hybrid contracts do not necessarily reduce transaction costs. Institutional alternatives must therefore be evaluated across both short-term and long-term horizons.

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INSTITUTIONAL CHALLENGES AND FRAUD RISKS IN THE MANAGEMENT OF FUNDS FOR RURAL DEVELOPMENT

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Abstract

The aim of this study is to analyze institutional challenges and fraud risks in the management of funds allocated for rural development in the Republic of Moldova, in the context of increasing access to national, European, and international financial resources. The research is exploratory in nature and relies on qualitative methods, including documentary analysis of the relevant legal framework, examination of reports issued by audit and control institutions, and a comparative review of selected European Union practices. The analysis identifies key fraud typologies affecting fund management, such as document falsification, fictitious projects, non-compliance with eligibility criteria, overstatement of expenditures, and collusion between beneficiaries and public officials. The results reveal significant deficiencies in internal control systems, monitoring procedures, and inter-institutional coordination, which increase exposure to fraud risks and reduce the effectiveness of rural development policies. Limited transparency and insufficient administrative capacity further undermine efficient resource allocation and public trust. The study emphasizes the need to strengthen institutional capacity through digitalization, improved transparency, enhanced cooperation among authorities, and alignment with European standards in fraud prevention, in order to ensure accountability and sustainability.

Key words**:** *rural development, fund management, fraud risks, institutional challenges, public finance, governance, transparency, control mechanisms*

INTRODUCTION

Rural development represents a key priority of public policies aimed at promoting sustainable economic growth, enhancing the competitiveness of the agri-food sector, and reducing socio-economic disparities between regions [12], [15].

Thus, public financial resources allocated to the agricultural sector and rural areas are an essential tool for supporting sustainable development, facilitating the modernization of rural infrastructure, improving the performance of agricultural holdings, and diversifying economic activities specific to non-urban areas. In the Republic of Moldova, the legal framework for the provision of financial support is regulated by Law No. 71/2023 on subsidies in agriculture and rural areas, which establishes the guiding principles of subsidy policy, delineates the responsibilities of the relevant public authorities, and defines the mechanisms for granting financial support. In this context, the National Fund for the Development of Agriculture and Rural Areas is the main budgetary instrument through which support programs and rural development initiatives are implemented. This legislative act regulates the fundamental principles of the subsidy policy, defines the responsibilities of public authorities involved in the administration of financial support mechanisms, and establishes the procedures for granting financial assistance to the agro-industrial sector. According to the provisions of this law, the National Fund for the Development of Agriculture and Rural Areas represents the totality of budgetary resources allocated for the implementation of agricultural subsidy programs and for supporting rural development initiatives [9].

An essential component in preventing potential fraud in the management of public funds is the effective implementation of the regulatory framework governing integrity in the public sector. In this respect, Integrity Law No. 82/2017 establishes the fundamental principles of institutional and professional integrity, promoting transparency,

accountability, and the prevention of corruption-related practices [10]. A crucial element of this regulation is the conflict of interest, which is considered a major risk factor in the public decision-making process. The rules on the disclosure, management, and resolution of conflicts of interest, as well as the rules regarding incompatibilities and restrictions applicable to public officials, are intended to reduce the risk that administrative decisions will be influenced by the personal interests of officials or the interests of third parties. Consequently, these mechanisms contribute to ensuring the impartiality, legality, and transparency of the procedures related to the allocation and monitoring of public funds [10].

Despite the increasing importance of rural development policies, academic research focusing specifically on institutional challenges and fraud risks associated with the management of rural development funds in the Republic of Moldova remains relatively limited. Against this background, the present study aims to examine the main institutional challenges and potential fraud risks related to the management of financial resources allocated to rural development programs. Particular attention is given to the institutional framework and to the control mechanisms involved in the allocation, supervision, and monitoring of these financial resources. Through a systematic analysis of institutional vulnerabilities and relevant administrative practices, this research contributes to the development of theoretical and methodological foundations regarding the integrity and efficiency of public fund management in the field of rural development. [1], [13].

In this context, the paper goal is to analyze institutional challenges and fraud risks in the management of funds allocated for rural development in the Republic of Moldova, in the context of increasing access to national, European, and international financial resources

MATERIALS AND METHODS

In order to conduct an in-depth analysis of the institutional challenges and fraud risks associated with the management of funds allocated to rural development in the Republic of Moldova, this study adopts a specific methodological approach based on a critical review of the regulatory framework and relevant theoretical sources. The primary method used is documentary analysis, which enabled a systematic examination of the legal and institutional framework governing the administration of public financial resources allocated to rural development.

To complement this analysis, the study incorporates an evaluation of the Report on the Management of the National Fund for the Development of Agriculture and Rural Areas, prepared by the Ministry of Agriculture and Food Industry, a document that provides a practical perspective on the mechanisms for allocating and utilizing funds. At the same time, in order to identify types of fraud and highlight institutional vulnerabilities, reports and studies prepared by leading international institutions, such as the European Commission, the European Court of Auditors, and the European Anti-Fraud Office, whose conclusions help shape a comparative perspective and provide a basis for the analysis of risks associated with the management of public funds.

RESULTS AND DISCUSSIONS

In the context of the Republic of Moldova's gradual alignment with European Union standards, strengthening institutional integrity mechanisms within the entities under the Ministry of Agriculture and Food Industry is a fundamental prerequisite for ensuring the efficient, transparent, and accountable management of financial resources allocated to rural development (Figure 1). The analysis of institutional challenges and fraud risks therefore requires an integrated approach that combines legal, institutional, and administrative perspectives, highlighting the interdependence between the regulatory framework, institutional capacity, and the effectiveness of control mechanisms.

Fig. 1. Agencies under the Ministry of Agriculture and Food Industry
Source: Author's elaboration based on MAIA institutional structure.

An analysis of the regulatory and institutional framework governing the management of rural development funds in the Republic of Moldova highlights both the importance of these resources for the modernization of rural areas and the existence of institutional vulnerabilities that may increase the risk of fraud in the process of allocating and utilizing public funds. The agricultural subsidy system is regulated by Law No. 71/2023 on subsidies for agriculture and rural areas, which establishes the principles of financial support policy, the mechanisms for granting subsidies, and the responsibilities of the institutions involved in managing funds allocated to the agri-food sector [9].

The National Fund for the Development of Agriculture and Rural Areas (FNDAMR) serves as the primary financial instrument used to support and promote investment in rural areas. According to the Report on the Management of the FNDAMR, the subsidy programs managed through this fund involve a considerable number of beneficiaries and a significant volume of financial resources, which necessitates the implementation of effective mechanisms for controlling and monitoring the use of public funds [11].

In this context, the data analysis reveals the complex and multidimensional nature of rural development, which goes beyond the scope of agricultural activities and involves investments in infrastructure, public services, and the socioeconomic development of local communities. [11], [12], [15].

A relevant example is the LEADER Program, which promotes local development through partnerships between local public authorities, the business community, and civil society. The analyzed data indicate that, between 2022 and 2024, 1,409 projects were implemented through this program, with a total value of over 168.5 million lei, projects focused on renovating educational institutions, developing public spaces, promoting local crafts, preserving cultural heritage, and improving tourism infrastructure and community services. The program is implemented through Local Action Groups (LAGs), established under Law No. 50/2021, and currently there are 54 LAGs registered in the Republic of Moldova, covering approximately 61% of the country's territory and including 513 administrative-territorial units [8], [11].

At the same time, through the Agency for Intervention and Payments in Agriculture (AIPA), support mechanisms have been implemented to promote the development of economic infrastructure in rural areas. Under the advance subsidy mechanism, 31 applications were submitted by local public authorities in 2023, and in 2024, payments were made for the rehabilitation and construction of over 21 km of roads, totaling approximately 67 million lei [11]. These investments underscore the crucial role of public funds in supporting the development of rural communities, while also highlighting the need to strengthen rigorous mechanisms for monitoring and controlling how financial resources are used [13].

In addition to national programs, the development of the agricultural sector is also supported through projects funded by external partners. In this regard, the Consolidated Unit for the Implementation and Monitoring of Agricultural Projects (UCIMPA) [2] plays a key role in implementing projects funded by the World Bank, including the AGGRI Project Agriculture Governance, Growth, and Resilience Investment [16]. This project aims to strengthen the resilience of the agricultural sector, modernize agricultural infrastructure, and improve agricultural risk management systems. The implementation of these projects involves the application of strict standards regarding transparency, auditing, and monitoring of fund usage, thereby contributing to the strengthening of

institutional integrity mechanisms in the public sector.

At the same time, in this context, it is essential to clarify what the term *„external funds" actually entails, which refers to financial and material resources allocated in the form of grants, subsidies, credits, donations, loans, and humanitarian aid from other states, the European Union, or international institutions, organizations, and associations, as well as foreign natural or legal persons, whether guaranteed or contracted by the state, and non-repayable funds"* [3].

However, an analysis of the institutional framework reveals significant challenges in the management of funds allocated for rural development, which can create vulnerabilities and risks of fraud in the process of allocating and utilizing financial resources. The management of public funds involves a complex system of administrative procedures, responsible institutions, and control mechanisms, and any dysfunction in these processes can create conditions conducive to irregularities or fraudulent practices.

Furthermore, the Methodological Guide on Institutional Integrity Assessment, developed by the National Anti-Corruption Center, highlights the multifactorial nature of corruption risks in public institutions, which arise from the interaction between external, organizational, and operational factors. [1].

External factors are primarily associated with imperfections in the regulatory framework or legislative ambiguities that may arise in the regulation of public financing mechanisms. An incomplete, inconsistent, or difficult-to-interpret regulatory framework can create room for discretionary interpretations of the rules and may facilitate the emergence of non-compliant practices in the process of allocating funds [1], [13]. At the same time, organizational factors relate to how public institutions organize their internal operations, including the existence of unclear administrative procedures, the lack of effective internal control mechanisms, or the inappropriate distribution of responsibilities among different institutional structures [7].

Operational factors also refer to the specific manner in which administrative processes are implemented, including procedures for evaluating funding applications, monitoring project implementation, and verifying the use of funds. In situations where these processes are not sufficiently standardized or are carried out predominantly through documentary checks, there is a risk that certain irregularities may not be identified in a timely manner [5].

In the context of managing funds for rural development, such vulnerabilities can facilitate the occurrence of fraud schemes such as the submission of inaccurate documents, the declaration of fictitious investments, or the overestimation of costs for funded projects.

Therefore, the systematic identification and assessment of these risk factors is essential for strengthening institutional integrity and improving fraud prevention mechanisms in the management of public funds. The application of institutional integrity assessment methodologies enables public institutions to identify existing vulnerabilities and adopt preventive measures designed to ensure transparency, accountability, and the efficient use of allocated funds.

Applying these criteria to the management of rural development funds highlights the existence of institutional vulnerabilities, such as the complexity of administrative procedures, limited transparency in the project evaluation process, or insufficient mechanisms for verifying the eligibility of funded investments. These vulnerabilities can facilitate certain types of fraud, such as the falsification of documents submitted with funding applications, the declaration of fictitious investments, or the overestimation of costs for funded projects [4], [5], [6].

This situation is directly linked to the existence of conflicts of interest and the exertion of undue influence on the decision-making process, both of which are particularly significant institutional challenges in the management of public funds. According to the provisions of Law No. 82/2017 on integrity, a conflict of interest arises when a public official's personal interest may influence the impartial exercise of their official duties. In the context of rural funding programs, such situations may arise during the project

evaluation process, in the selection of beneficiaries, or in the monitoring of investment implementation.

Consequently, the international literature confirms that financial support programs for agriculture and rural development may be vulnerable to fraud in situations where control and monitoring mechanisms are not sufficiently developed. Reports from European institutions highlight that subsidy schemes may be exposed to fraud risks such as inaccurate declarations, document manipulation, or conflicts of interest in the fund allocation process [4], [6].

Furthermore, the European Court of Auditors highlights that the effectiveness of fraud prevention measures in the management of agricultural funds is closely dependent on the quality and functionality of internal control systems, as well as on the institutions' ability to adequately identify, assess, and manage the risks associated with funding programs. In this context, the research findings reveal that effective fraud prevention in the administration of funds for rural development requires the adoption of integrated measures aimed at strengthening institutional control mechanisms, developing digital solutions for monitoring funded projects, and implementing appropriate tools for assessing institutional integrity. At the same time, ensuring transparency and accountability in the management of public resources involves preventing conflicts of interest and limiting undue influence on decision-making processes, as these are essential elements of sound financial governance. The relevance and timeliness of the topic under analysis are amplified by the current context of the Republic of Moldova's European integration process, because European integration European integration entails not only the harmonization of the national regulatory framework with the EU acquis, but also the strengthening of institutional mechanisms to prevent and combat fraud affecting the use of public funds. In particular, in the field of agriculture and rural development, European Union member states apply rigorous standards of financial control, transparency, and institutional accountability, designed to protect the Union's financial interests [4], [6]. In this context, strengthening institutional integrity, preventing conflicts of interest, and developing effective mechanisms to monitor the use of funds are essential conditions for aligning the Republic of Moldova with European financial governance practices and for ensuring the efficient and transparent management of resources allocated to rural development.

CONCLUSIONS

The management of rural development funds represents a key instrument for the modernization of rural communities and the development of the agricultural sector in the Republic of Moldova.

The complexity of administrative procedures and the involvement of multiple institutional actors create structural vulnerabilities that may increase exposure to fraud risks in the allocation and use of public funds.

The study shows that the most frequent fraud risks in rural development funding include the submission of falsified documents in funding applications, the declaration of fictitious investments, the overestimation of project costs, and the misuse of financial resources for purposes other than those initially approved.

Institutional analysis indicates that these risks are influenced by several structural factors, including deficiencies in the regulatory framework, complex administrative procedures, insufficiently developed monitoring and control mechanisms, as well as the existence of conflicts of interest or undue influence in decision-making processes [14].

The research also highlights the important role of institutional integrity assessment mechanisms promoted by the National Anti-Corruption Center in identifying institutional vulnerabilities and preventing irregularities in the management of public funds.

The experience of projects implemented through the Consolidated Unit for the Implementation and Monitoring of Agricultural Projects demonstrates the relevance of applying international standards

related to transparency, financial control, and monitoring of public fund utilization [2].

Recent institutional developments also indicate gradual improvements in integrity practices within the public authorities responsible for managing rural development funds.

The Ministry of Agriculture and Food Industry has implemented several institutional instruments aimed at ensuring compliance with integrity standards, including the Register of Conflict of Interest Declarations, the Register of Inadmissible Gifts, the Register of Admissible Gifts, the Register of Disclosures and Warnings, the Register of Improper Influence, and the Register of Institutional Risks.

The implementation of these administrative tools reflects ongoing efforts to strengthen transparency, prevent conflicts of interest, and reduce institutional vulnerabilities associated with the management of public funds.

Strengthening institutional integrity mechanisms and improving fraud prevention tools in the management of rural development funds should remain a strategic priority of public policy. The development of integrated control systems, the expansion of digital monitoring tools, and stronger cooperation between national authorities and international oversight institutions can significantly contribute to reducing fraud risks and increasing transparency in the management of public resources. Promoting a culture of integrity within public institutions is also essential for ensuring responsible and efficient governance of rural development funds, particularly in the context of the Republic of Moldova's European integration process.

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NAVIGATING THE BIOECONOMY PATH: SURVEY INSIGHTS INTO BUSINESS MOTIVATIONS AND BARRIERS ACROSS BULGARIA AND EUROPE

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Abstract

The bioeconomy is increasingly recognized as a key pathway toward sustainable economic transformation in response to environmental pressures and resource constraints. Despite its growing policy relevance, bio-based businesses continue to face significant challenges, particularly in emerging and less mature bioeconomy ecosystems. This paper examines the key motivations, barriers, and enabling factors shaping the development of bio-based enterprises in Bulgaria and across Europe. The study applies a mixed-methods approach, combining a cross-national survey of bio-based businesses conducted between January 2025 and January 2026 with qualitative insights from selected case studies and semi-structured interviews. The survey captures firm-level perspectives on innovation drivers, regulatory and financial constraints, market access, and sustainability-oriented strategies. The findings indicate that environmental commitment and innovation potential are primary motivations for engagement in bio-based activities, while regulatory complexity, limited access to finance, and market uncertainty remain major barriers. Comparative analysis reveals both common challenges across Europe and context-specific constraints affecting Bulgarian firms. This research contributes empirical evidence to ongoing bioeconomy development debates and is part of HORIZON-CL6-2023-ZEROPOLLUTION-01-4.

Key words**:** *bioeconomy, bio-based businesses, development barriers, sustainability, Bulgaria and Europe*

INTRODUCTION

The last few centuries have elevated economic activity to heights that were arguably once unimaginable. Over the past 200 years, a vast portion of the world has experienced unprecedented levels of wealth (Pyka & Prettner, 2017) [11]. The catalyst for this shift was the First Industrial Revolution in Great Britain, occurring between 1750 and 1850 (More, 2000) [5]. While this period propelled the world toward a progressive future, it simultaneously introduced a multitude of global challenges that were neither expected nor could have been foreseen. Overconsumption, the depletion of biological resources, global warming, and climate anomalies represent the legacy we are bequeathing to future generations. (Parsons, Jowell, Erika Veidis, & Israni, 2024) [9] identified three levels of consequences that await us: (a) physical environmental changes causing temperature extremes, hydrological anomalies, and extreme weather events; (b) ecological disruptions in the form of resource deficits, environmental imbalances, and health risks; and (c) socio-political changes leading to economic instability, cultural and social upheaval, migration, and conflict. Unfortunately, the process is irreversible, but we can at least attempt to slow it down. All of these have necessitated a crucial change, in which the concept of economic activity has begun to transform from a linear economy - the so-called "take-make-waste economy" (Ellen MacArthur Foundation, 2024) [3], into one where waste becomes a resource for creating new products, known as the "circular economy" (Neves & Marques, 2022) [7]. Scientists and businesses around the world are joining forces (Pyka & Prettner, 2017) [11] in an attempt to implement innovations in production processes that are environmentally sustainable, accessible to consumers, and competitive in the market (Croitoru et al, 2024) [2].

The idea itself is by no means new; its roots can be traced back as far as the Stone Age

(Noriega, Braza, & Petrova, 2025) [8], but its development in recent years has been accelerating rapidly. The term "bio-based technologies" encompasses a set of innovative methods that utilize renewable biological raw materials, including agricultural and food waste streams, as well as marine biomass, for the sustainable production of energy resources and goods (UN report outlines roadmap for advancing bio-based technologies, 2025) [13]. In the twenty-first century, we are faced with the vital question of how to restore the ecological sustainability of economic activities.

The knowledge-based bioeconomy plays a key role in this process of transformation. In 2007, during the German presidency of the EU, the Cologne Paper was presented, outlining the strategic vision for a European knowledge-based bioeconomy (KBBE) by 2030. The initiative was developed under the expert guidance of Christian Patermann, a key figure in EU research policies, a long-standing official responsible for ecology and sustainability, and an architect of the European framework for agricultural research (Kircher, Maurer, & Herzberg, 2022) [4].

According to (Patermann & Aguilar, 2021) [10] the childhood of the bioeconomy is over after more than 15 years, the bioeconomy has reached maturity." The bioeconomic paradigm has gone through stages of intensive development, spreading into countries with vastly different conditions. The result is a diversity of national strategies and initiatives distinguished by their adaptability, allowing for the effective integration of the bioeconomy according to the specific climatic characteristics and socio-political context of each nation.

The term "bioeconomy" (sometimes referred to as "bionomics") is used to describe two distinct areas of study: (a) the economy of biological systems - that is, the ways in which biological organisms and communities utilize scarce resources such as space, time, and sources of sustenance; and (b) the economy of biological resources - the ways in which the economic activities of human societies interact with the dynamics of biological systems. In the context of our study, we refer to an economy focused on the production of products based on biological resources. (Röpke, 2016) [12]. Despite strategic documents, scientific research, and growing interest in the bioeconomy, the practical implementation of these ideas is primarily realized through entrepreneurial activity. It is entrepreneurs who take the risk of transforming scientific discoveries into real products and services, building markets for bio-based solutions, and experimenting with new business models. Therefore, regardless of the multitude of policies and strategies, it is essential to hear the voices of entrepreneurs developing bio-based businesses - their perspectives, the challenges they face, and the opportunities they identify in this dynamically evolving sector.

The present study aims to engage precisely with this practical perspective. It is based on a survey conducted among entrepreneurs and participants in the bio-based economy, with the primary goal of tapping into real business experience to identify key barriers, incentives, and trends in the development of bio-based initiatives, as well as to outline opportunities for more effective sectoral growth in the future.

MATERIALS AND METHODS

The study applies a mixed-methods approach, combining a cross-national survey of bio-based businesses conducted between January 2025 and January 2026 with qualitative insights from selected case studies and semi-structured interviews. The survey consists of 17 closed- and open-ended questions and was targeted at bio-based businesses in Bulgaria and across Europe. This research is part of the LCA4BIO project, funded under HORIZON-CL6-2023-ZEROPOLLUTION-01-4.

The distribution of the survey was carried out via email, telephone, and personal meetings with business representatives. To reach European organizations, we were assisted by other partners in the LCA4BIO project. Despite the systematic approach, the team encountered challenges in data collection, manifested by a relatively high rate of incomplete responses among participants who

had initially confirmed their participation. The survey captures firm-level perspectives on innovation drivers, regulatory and financial constraints, market access, and sustainability-oriented strategies. The findings indicate that environmental commitment and innovation potential are primary motivations for engagement in bio-based activities, while regulatory complexity, limited access to finance, and market uncertainty remain major barriers. Comparative analysis reveals both common challenges across Europe and context-specific constraints affecting Bulgarian firms.

RESULTS AND DISCUSSIONS

The current results are based on the survey "Biobased companies and their development in Europe," which was conducted between January 2025 and January 2026 among European bio-based businesses. The participating companies successfully fall into two of the four main types of bio-based innovations encountered in practice:

(a) Innovation Type I (IT I): Substitute products - involves the introduction of bio-based alternatives (such as PLA or biofuels) that replace fossil-based raw materials in existing value chains, offering the same functions through a fundamentally different renewable source.

(b) Innovation Type II (IT II): new processes - covers technological and organizational improvements in bio-based production, ranging from incremental optimization of existing systems to radical innovations that create entirely new value chains and processing opportunities (e.g., biorefineries for lignocellulosic waste or enzyme-based chemical production).

(c) Innovation Type III (IT III): New Products - encompasses radical innovations that create entirely new markets and value chains through products with previously unknown functionalities, such as engineered organisms for pharmaceutical production or biocompatible implants with antimicrobial properties.

(d) Innovation Type IV (IT IV): New behaviour - involves a change in the way business and consumption are organized, including new business models (such as the circular economy and cascading use of biomass), collaboration between stakeholders, and shifts in consumer attitudes, which together facilitate a systemic transition toward sustainability. (Bröring, Laibach, & Wustmans, 2020) [1].

In the time of report 56.3% of participants originate from Bulgaria, with the remaining 43.8% representing other EU countries. Engagement with the business entities was facilitated through a multi-modal approach, encompassing direct contact via email and telephone, supplemented by networking support from other project stakeholders (Fig. 1).

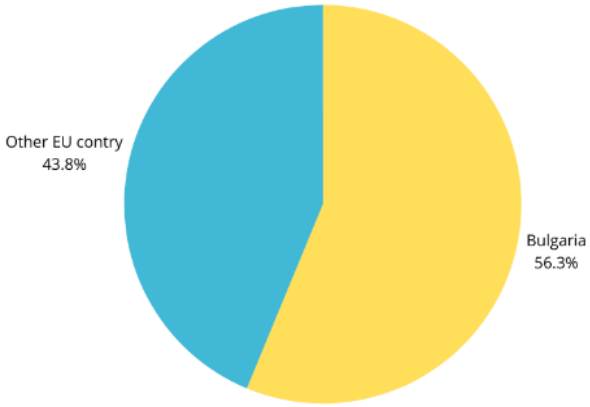

Fig. 1. Distribution of survey participants
Source: Field survey.

The survey among bio-based businesses from Bulgaria and other European countries shows that environmental factors are the most significant for them, accounting for 37.1% of the overall influence. Economic factors are the second most important at 22.9%, while social and political factors carry less weight, at 17.1% and 11.4% respectively. This indicates that despite the importance of the economic and political environments, the primary drivers in this sector are predominantly related to environmental protection (Fig. 2).

The survey results regarding the biological resources used in production reveal a clear dominance of plant-based materials.

Plant resources account for the vast majority of input, representing 93.8% of the total, while animal resources constitute a minimal

share, utilized by only 6.3% of the bio-based businesses. This distribution indicates that the sector's production processes are overwhelmingly reliant on plant-derived raw materials (Fig. 3).

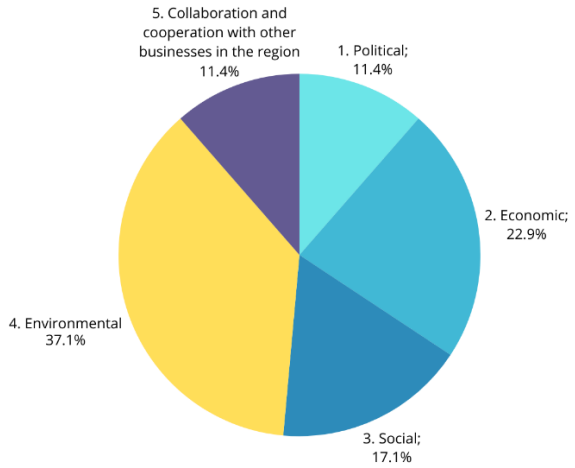

Fig. 2. Key motivations for the establishment of bio-based businesses.
Source: Results from field survey.

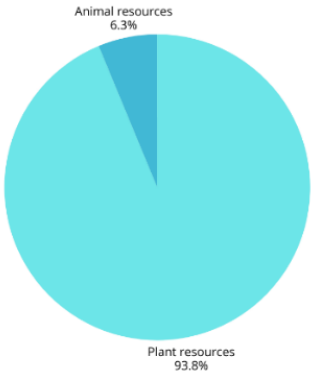

Fig. 3. Types of biological feedstocks utilized in production processes.
Source: Results from field survey.

Based on the pie chart detailing the sectors of the interviewed bio-based businesses, the largest single sector is Construction, accounting for 29.2%. This is closely followed by the Woodworking sector at 25%. The Food industry represents the third largest segment with 20.8%.
Finally, both the Chemical sector and the Other category constitute the smallest, but equal, shares at 12.5% each (Fig. 4).
In summary, the majority of the bio-based companies surveyed operate within the Construction and Woodworking industries, which together represent over half (54.2%) of the respondent pool.

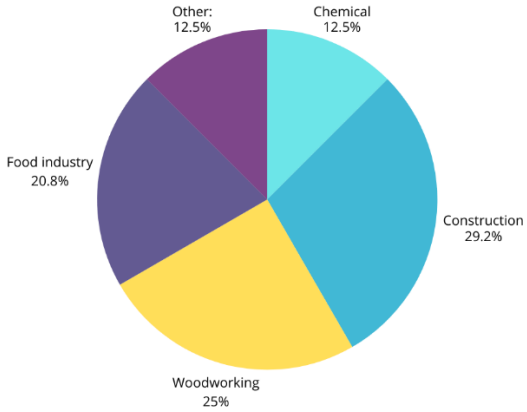

Fig. 4. Distribution of respondents by primary target market sector.
Source: Photovoltaic systems, Packaging, Tourism

In the construction sector, the vast majority of challenges with bio-based materials fall into the 'Other' category, accounting for 71.4% of all reported barriers. These 'other' challenges are predominantly centered around economic viability and production performance, specifically encompassing high costs, pricing competitiveness against fossil-based alternatives, meeting mechanical norms while maintaining a low cost, and the availability of raw materials. By comparison, specific technical challenges such as Recycling complications are far less frequent at 14.3%, while issues concerning Fire safety requirements and Durability represent the smallest shared barriers, each at only 7.1%. Others include:
-Price in our segment
-Cost and availability of bio-based raw materials
-Manufacturing speeds
-Cost
-Meet the same properties as not bio-based materials
-Meeting the mechanical norms at current low cost
-Initial overcosts
-Pricing compared to low cost fossil based raw materials (fi UF-resins)
-Higher cost of this type of materials
-Pollution and natural disasters (Fig. 5).

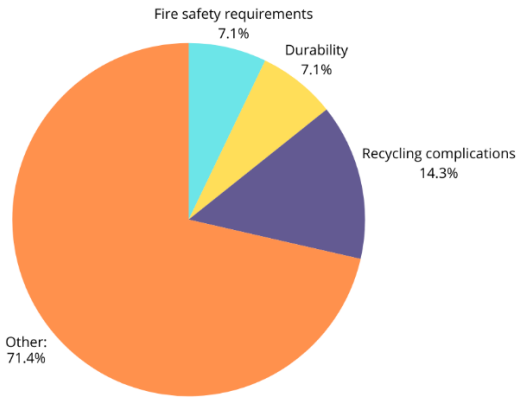

Fig. 5. Main barriers to the implementation of bio-based materials in Construction sectors.
Source: Results from field survey.

The survey indicates that the main technical challenges facing bio-based materials are equally distributed across three major areas, with each segment accounting for 33.3% of the responses: Mechanical properties, Sensitivity to environmental factors, and Other (Fig. 6).

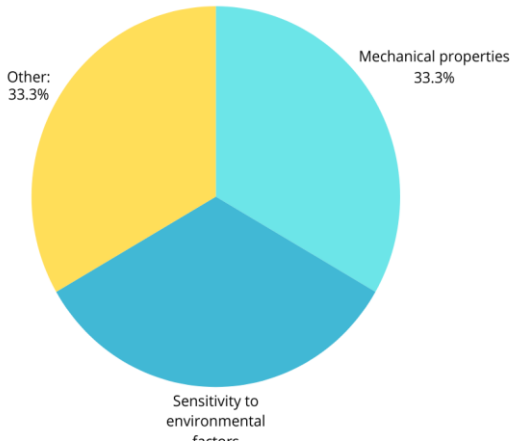

Fig. 6. Primary barriers to the adoption of bio-based materials in the packaging industry.
Source: Results from field survey.

The diverse issues grouped under the 'Other' category highlight specific logistical and production difficulties within the industry.
For example, some companies face infrastructural challenges, as noted by: LAM'ON: "The main challenge for us is the lack of a separate waste stream for bioplastics. This reduces many sales opportunities in Europe due to the inability to recycle or use recycled material."
Other businesses grapple with process optimization, such as Evolve Packaging, which cited "Curing time."

The survey data on the geographical location of bio-based businesses indicates a strong concentration in urban areas. The regionalization applied in the survey is based on the standards for the administrative-territorial division of Bulgaria (in accordance with the data provided by the National Statistical Institute as of December 31, 2024). (Administrative-territorial and territorial division of the Republic of Bulgaria as of 31.12.2024, 2024) [6].
The largest share of activity is conducted in (2) Regional cities (37.5%), followed by (4) Mid-sized cities (30,000 to 100,000 inhabitants) (25%), and the (1) Capital (18.8%) (Fig. 7).
Combined, these three categories account for over 81% of all operations. In contrast, (3) Smaller urban and rural areas—which include villages, small towns, and large cities (100,000 to 200,000 residents) - represent only minor segments of the sector's operational footprint, with (6) Villages accounting for 12.5% of the total.

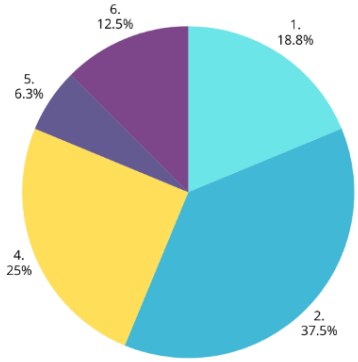

Fig. 7. Geographical scope and primary areas of operation of the surveyed organizations
Source: Results from field survey.

Based on the survey results regarding the intended market for manufactured products, the overwhelming majority of bio-based businesses target both the domestic and international markets. Specifically, 86.7**%** of the companies report their products are intended for Both domestic sales and export. Only a small fraction, 13.3%, focus exclusively on Domestic sales. This data clearly indicates a strong outward-looking, export-oriented business model across the surveyed bio-based sector (Fig. 8).

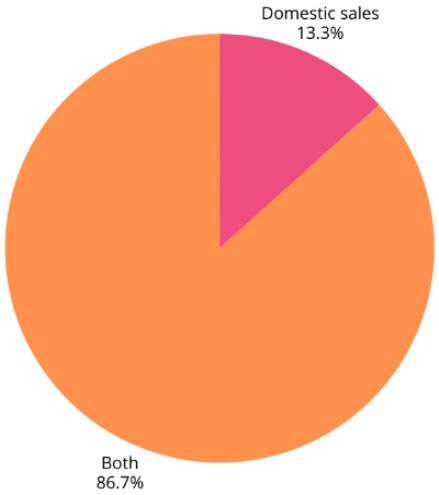

Fig. 8. Market orientation of manufactured bio-based products: domestic and international sales.
Source: Results from field survey.

The data clearly indicates that the majority of products from the surveyed bio-based businesses are aimed at The mass consumer, which accounts for 60% of the target market. The remaining 40% of the output is directed towards a Specific business audience. This distribution suggests that the bio-based sector is significantly focused on developing products for the broad consumer market rather than specialized business-to-business applications (Fig.9).

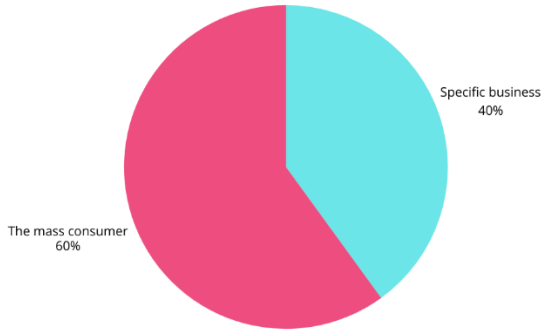

Fig. 9. Distribution of target consumer segments for manufactured bio-based output.
Source: Results from field survey.

The primary challenge faced by bio-based businesses is Economic (30%), which is significantly higher than other factors. Following closely are Market challenges (22%), highlighting difficulties related to pricing, competition, and reaching customers. Social and Technological hurdles account for 14% and 10% respectively. Other issues, including Environmental concerns (4%), Quality of required material (6%), and Availability of necessary resources (4%), make up the remainder of the concerns (Fig. 10).

*For example, some specialized sectors face unique constraints; in oyster production, the main problems are related to logistics, the poor natural conditions in our country for mass production, and a small market.

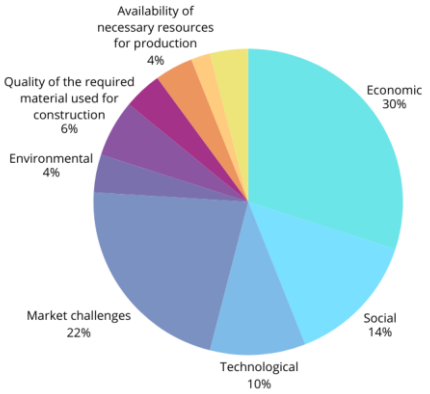

Fig. 10. The main challenges
Source: Results from field survey.

The analysis of challenges in sourcing bio-based materials shows that the primary obstacle is High costs, which impacts 53.8% of the surveyed businesses.

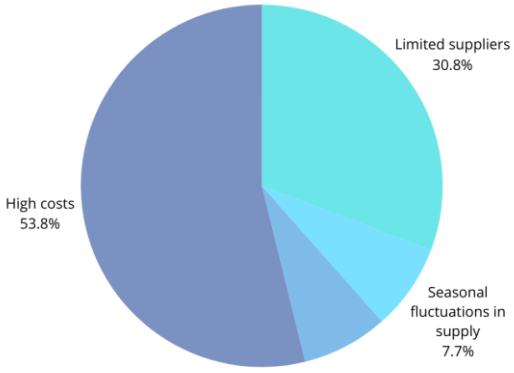

Fig. 11. Key challenges and barriers in the sourcing of bio-based raw materials
Source: Results from field survey.

The secondary major issue is related to supply chain structure, specifically Limited suppliers, cited by 30.8%. Less significant concerns are equally split between Long transportation distances and Seasonal fluctuations in supply, each representing only 7.7% (Fig. 11). This clearly establishes that financial barriers and a

constrained supplier base are the dominant issues for the sector's material sourcing.
75% of the surveyed bio-based businesses did not encounter difficulties related to the regulatory approval or compliance of their bio- based materials. Only 25% indicated that they had faced challenges with regulations (Fig. 12).

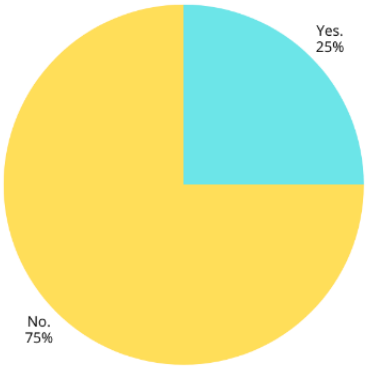

Fig. 12. Regulatory challenges and compliance barriers for bio-based materials in industrial applications
Source: Results from field survey.

A majority of bio-based businesses (60%) conduct environmental assessment studies like LCA or EPDs, a practice driven by customer demand, internal company policy, and the need for rigorous carbon footprint verification (e.g., Sonae Arauco, Covestro). This high engagement rate aligns with the overall finding that Environmental factors are the most significant business driver in the sector (37.1%) (Fig. 13).
Companies utilize these assessments not just for compliance, but also as a critical market tool for sales (Plantics) and to differentiate their products.
-LAM'ON - Yes, we prepare LCA report for each of our products.
-Sonae Arauco - Yes. For all products launched in the market we have a EPD. For any new raw material, we develop a preliminary assessment of carbon footprint impact, as being bio-based doesn't mean always lower impact on sustainability.
-Chimar Hellas S.A. - yes, when mandatory and as a marketing tool
-Plantics - Yes, LCA is critical parameter for sales
-Evertree - Yes, for HgH calculation and GhG inclusion
-Covestro - Yes, is part of company policy and customers ask for it
-Markos-Petrovi Ltd. - Annual laboratory analyses of the product and seawater.

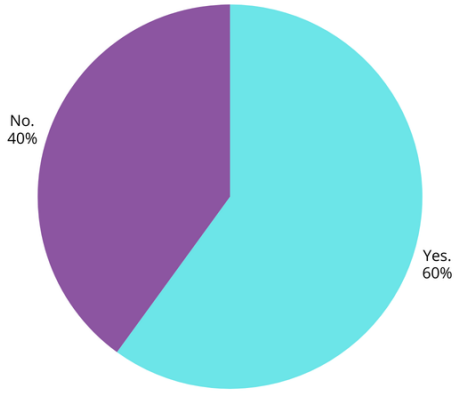

Fig. 13. Prevalence and types of environmental impact assessments (LCA, EPD) conducted for bio-based products
Source: Results from field survey.

Based on the survey data, the perception of substitutability for bio-based products in the market is primarily one of partial replacement. The largest single group, accounting for 43.8%, finds their products to be Somewhat substitutable for existing non-biobased alternatives.

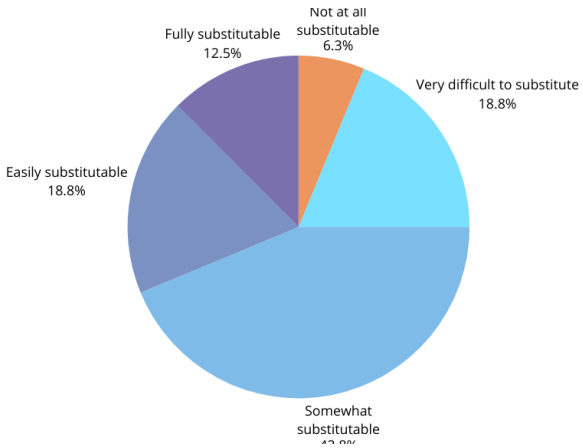

Fig. 14. Market substitutability of bio-based products compared to conventional (non-bio-based) alternatives.
Source: Results from field survey.

The remaining responses are split between those who find substitution Easily substitutable (18.8%) or Fully substitutable (12.5%), and an equal percentage of those who find it Very difficult to substitute (18.8%) (Fig. 14).

Overall, the data suggests that while complete substitution is limited, a significant majority of bio-based products currently serve as a partial alternative to conventional materials.
Based on the survey data comparing the final price of manufactured bio-based products to conventional ones, the vast majority of businesses report a higher cost. A substantial 56.3% of respondents state their price is Higher, but not much, while a significant 25% report it is Significantly higher. Only a small minority of 18.8% indicate their final price is Close to the regular product. In total, over 81% of bio-based products carry a higher price tag than their conventional counterparts (Fig. 15).

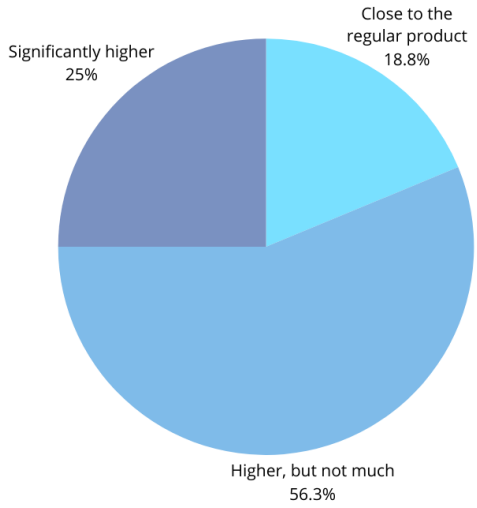

Fig. 15. Comparative pricing analysis
Source: Results from field survey.

When asked whether they encounter barriers to using bio-based products as substitutes for existing conventional alternatives, the consensus among the surveyed companies is that economic and market-related challenges are the principal obstacles, significantly outweighing technical performance issues or regulatory barriers. Firms like Volnut and Sonae explicitly cite the high price and lack of availability of raw materials as major constraints, with Sonae noting that current costs remain far too high compared to fossil-based feedstocks. This is echoed by Covestro, which emphasizes that the transition remains difficult as long as cost control is the dominant market driver, particularly because the price of conventional materials remains "ridiculously" low. Furthermore, systemic issues further complicate market entry; LAM'ON highlights a lack of consumer knowledge, the strong influence of oil and chemical companies, and the absence of dedicated waste streams for bioplastics as critical hurdles. Similar sentiments are shared by others, such as Pokriv za primer, which notes that while their green walls offer environmental benefits, the construction costs are prohibitively expensive. Ultimately, as Plantics suggests, these diverse perspectives converge on a single reality: despite the technical potential of these materials, their widespread adoption is currently stalled by a market framework that continues to favor traditional, cheaper alternatives over sustainable innovation.

CONCLUSIONS

The present report, titled "Navigating the Bioeconomy Path: Survey Insights into Business Motivations and Barriers across Bulgaria and Europe," outlines the complex dynamics of the bio-based sector within the modern European economy. The survey results clearly indicate that the drive toward sustainability and environmental responsibility is the primary motivator for businesses (37.1%), testifying to a profound transformation of values within the industry. However, the transition to a circular bioeconomy remains a significant challenge due to systemic economic barriers with high production costs, price competition against fossil-based alternatives, and a shortage of specific infrastructural solutions.
It is important to note that the present work constitutes a pilot study that lays the foundation for a more in-depth and large-scale analysis of the sector. The data presented is currently being dynamically accumulated and is subject to subsequent supplementation and expansion in order to achieve maximum representativeness and statistical precision.
In this process, we consider it vital and a priority that the voice of entrepreneurs be heard. Their practical perspective is an indispensable source of information that allows for the identification of real operational barriers and opportunities, which often remain

hidden in dry statistics and theoretical models. We believe that the active participation of businesses is the key to transforming this research into a functional tool for strategic decision-making, which will support the more effective transformation of the European economy toward sustainable and circular models.

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WINE TOURISM DEVELOPMENT MODELS: BEST PRACTICES FROM LEADING INTERNATIONAL DESTINATIONS

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Abstract

Wine tourism has become an important component of regional development strategies in wine-producing areas worldwide. This paper consists in a comparative examination of wine tourism development models by analyzing best practices from leading international destinations: Napa Valley (USA), Bordeaux (France), and Tuscany (Italy), while assessing their structural relevance for the Romanian wine region of Dealu Mare. A qualitative comparative approach is applied, structured around four key dimensions: governance, regional branding, tourism infrastructure, and visitor experience. The analysis combines secondary data from international case studies and institutional sources with field observation conducted in Dealu Mare. The findings highlight that mature wine tourism destinations operate as integrated territorial ecosystems characterized by coordinated governance, coherent regional branding, and diversified experiential offers. In contrast, Dealu Mare remains in an early development stage marked by fragmented coordination and limited integration. The study identifies strategic directions that may support the development of wine tourism in the near future.

Key words**:** *wine tourism, destination governance, regional branding, tourism infrastructure, visitor experience*

INTRODUCTION

Wine tourism has evolved from a niche form of rural tourism into a high important component of regional development strategies, particularly in wine-producing territories seeking economic diversification and enhanced destination competitiveness. Wine tourism was defined as visitation to vineyards, wineries, wine festivals for which wine tasting or experiencing the attributes of a wine region are the prime motivating factors [18] [17].

This definition positions wine tourism at the intersection of agriculture, hospitality, and cultural tourism, emphasizing its experiential dimension [6] [11].

Subsequent research expanded this perspective, framing wine tourism as a strategic tool for the development of territorial branding. [11] and [12] argue that wine tourism functions simultaneously as a marketing channel for wineries, a development strategy for rural regions, and a component of destination management. Their work highlights the importance of coordinated regional efforts, emphasizing that competitive wine tourism regions rely on networks of stakeholders rather than isolated producers [2] [10]. Moreover, collaborative governance and cross-sector integration have been shown to enhance destination competitiveness [14] [19].

From the demand-side perspective, [8] demonstrate that wine tourists differ in motivation, involvement, and level of wine knowledge.

This segmentation has direct implications for product design and branding strategies, as destinations must plan experiences to both wine enthusiasts and leisure tourists [6]. Similarly, [26] underline that wine tourism experiences extend beyond tasting activities, incorporating gastronomy, landscape aesthetics, and cultural immersion [28].

Moreover, the integration of wine tourism within broader rural development frameworks has also been emphasized by [15], who note that wine regions often become emblematic of authenticity. [5] introduces the concept of the "wine tourism region" as a geographically defined destination with a significant number of wineries and supporting infrastructure with the purpose of contributing to visitor

attraction [1] [25].

On the other hand, branding have become central theme in more recent literature available in multiple domains. [24] argues that destination branding must communicate a clear value proposition based on unique regional attributes, while [20] stress that destination branding requires alignment between identity, image, and stakeholder communication. In the context of wine regions, this alignment is particularly important, as wine itself becomes a symbolic representation of terroir, heritage, and authenticity [22] [23].

International benchmark destinations illustrate how these theoretical principles translate into practice. Regions such as Napa Valley (USA), Bordeaux (France), and Tuscany (Italy) have developed structured governance mechanisms, strong regional brands [4], and diversified experiential tourism products [7] [12]. According to [7], successful wine tourism destinations integrate public and private actors into collaborative frameworks that enhance innovation, quality control, and marketing effectiveness, contributing to overall destination sustainability [3].

For emerging wine destinations, however, structural challenges remain significant. Fragmented governance, limited infrastructure, and insufficient marketing coordination often lower competitiveness [12] [14].

In Central and Eastern Europe, wine tourism development is frequently constrained by post-transition institutional restructuring and uneven investment patterns [26]. Nonetheless, research indicates that emerging regions can leverage authenticity, indigenous grape varieties, and cultural heritage to position themselves strategically within niche markets [16] [9].

In Romania, wine tourism is increasingly recognized as a complementary economic activity for viticultural regions, yet it remains in a consolidation phase [13]. Studies analysing the evolution of the Romanian wine sector highlight that although wine quality and export performance have improved significantly, the tourism component is still structurally underdeveloped [29] compared to established Western European destinations. The region of Dealu Mare benefit from favourable terroir conditions, improving wine quality, and proximity to major urban markets, particularly Bucharest. However, systematic governance models, coherent regional branding strategies, and integrated tourism infrastructure are still under development, limiting the international competitiveness of Romanian wine destinations [27].

Against this background, this paper examines established wine tourism development models by analysing best practices from leading international destinations and assessing their transferability to emerging contexts. By combining comparative analysis with field research in Dealu Mare, the study aims to identify governance structures, branding strategies, and experiential design principles that can strengthen Romania's wine tourism competitiveness.

MATERIALS AND METHODS

This study consists in a qualitative case study design to identify and compare established wine tourism development models and assess their structural relevance for less developed destinations. Three internationally recognized wine tourism destinations: Napa Valley (USA), Bordeaux (France), and Tuscany (Italy) were selected as benchmark cases based on global brand recognition, structured governance mechanisms, diversified tourism infrastructure, and documented best practices in destination management. Secondary data were collected from peer-reviewed literature, official tourism platforms and reports, and destination marketing materials. These sources were analysed using deductive thematic content analysis structured around four key dimensions derived from wine tourism and destination competitiveness literature: governance, regional branding, tourism infrastructure and visitor experience. For the Dealu Mare case, structured non-participant observation was conducted during field visits in the region and to selected wineries, including participation in guided tours, tasting experiences, and review of

digital communication channels like social media platforms. To operationalize comparison, a qualitative scoring system was applied across the four dimensions, resulting in a composite *Wine Tourism Maturity Index*.
The comparative results were illustrated using a radar chart generated in R to visually compare the four dimensions across destinations.

RESULTS AND DISCUSSIONS

The selection of the four key analytical dimensions derives directly from established wine tourism and destination competitiveness literature, as follow:
-governance
-regional branding
-tourism infrastructure
-visitor experience
Governance represents the institutional backbone of wine tourism destinations, as regional performance depends on the coordination of multiple stakeholders, including wineries, public authorities, and tourism intermediaries [12] [15]. On the other side, regional branding concerns the development of a coherent identity and message that differentiates a destination from others [14] [20], while tourism infrastructure refers to the spatial and functional integration of accessibility, accommodation, gastronomy, and complementary services within the destination ecosystem [5] [21]. Finally, visitor experience design addresses the diversification and structuring of tourism products in response to heterogeneous
visitor motivations and levels of involvement [8]. Together, these four dimensions provide a structured framework for assessing wine tourism development.
In addition to the four core analytical dimensions, several complementary structural indicators were considered to provide contextual depth to the comparative assessment. For instance, the existence of a formal destination management structure reflects the degree of institutional coordination and collective strategic planning, which is central to destination competitiveness [12]. Similarly, digital integration influences visibility, accessibility, and market reach, reinforcing the effectiveness of regional branding and communication strategies [24], while international visibility, in turn, reflects the broader reputation and symbolic positioning of a wine region, which contributes to tourism attractiveness and long-term competitiveness [15].
Therefore, these elements offer additional insight into structural differences between consolidated and emerging wine tourism destinations.

Table 1. Comparative Structural Characteristics of Wine Tourism Destinations

Dimension	Napa Valley	Bordeaux	Tuscany	Dealu Mare
Governance models	Unified public–private partnership	Institutional AOC-based system	Regional consortia and wine routes	Fragmented, emerging coordination
Branding Strategy	Lifestyle and premium positioning	Heritage and classification-based prestige	Landscape and cultural immersion	Winery-focused branding
Infrastructure Density	Very high	High	Very high	Moderate
Experiential Diversification	Luxury tourism, events, wellness	Heritage tourism and cultural assets	Agritourism and gastronomy integration	Limited, tasting centered
Digital Integration	Advanced	Advanced	Strong	Limited
International Visibility	Very High	Extremely High	Very High	Low–Moderate
Destination Management Structure	Strong centralized association	Interprofessional councils	Regional collaborative networks	Not formally consolidated

Source: Own elaboration based on online information.

Further, in order to compare mature and emerging destinations, a qualitative evaluation was conducted across each of these dimensions.

Table 1 presents descriptive structural differences between Napa Valley, Bordeaux, Tuscany, and Dealu Mare. The comparison illustrates that benchmark destinations function as integrated territorial systems characterized by consolidated governance, coherent branding, diversified infrastructure, and advanced experiential portfolios.

In contrast, Dealu Mare shows entrepreneurial dynamism but limited systemic integration.

To provide analytical depth beyond descriptive comparison, a qualitative scoring system was developed. Each destination was evaluated on a 1 to 5 scale across the four dimensions (1 = weak; 5 = highly developed).

Scoring criteria were defined as follows:

-*Governance*: presence of formal destination management structures, stakeholder coordination mechanisms, regulatory coherence, and collaborative promotion.

-*Regional branding*: existence of consistent regional identity, shared communication strategies, terroir positioning, and brand alignment across stakeholders.

-*Infrastructure*: transport accessibility, signage, accommodation, gastronomy integration, and wine route structuring.

-*Visitor experience*: diversification beyond tasting, events and festivals, educational workshops, and immersive design.

The scoring reflects structured qualitative assessment based on:

-publicly available reports and documents,

-official destination marketing materials,

-comparative benchmarking literature,

-and direct observation in Dealu Mare.

Table 2. Destinations comparative key dimensions

Destination	**Governance**	**Branding**	**Infrastructure**	**Experience**	**Total Score (*Maturity Index*)**
Napa Valley	5	5	5	5	20
Bordeaux	5	5	4	4	18
Tuscany	4	5	5	5	19
Dealu Mare	2	2	2	2	8

Source: Own elaboration.

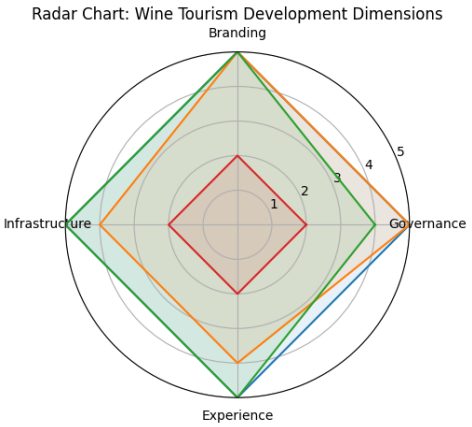

Fig.1. Wine tourism development dimensions (where: blue – Napa Valley, orange – Bordeaux, green – Tuscany, red – Dealu Mare)
Source: Own elaboration.

The composite index reveals clear stratification. Napa Valley achieves the maximum score (20/20), Tuscany scores 19, Bordeaux 18, while Dealu Mare records 8. The 11-point gap relative to benchmark average (19) indicates structural asymmetry rather than incremental difference.

Also, this scoring approach aligns with comparative maturity modeling frequently applied in destination competitiveness research (Getz, 2000; Hall and Mitchell, 2000) [10, 15]. To enhance comparative clarity, the qualitative scores were visualized using a radar chart.

The comparative analysis suggests that leading international wine tourism destinations operate under identifiable development models characterized by structured governance, coherent regional branding, integrated infrastructure systems, and diversified experiential portfolios. While these elements collectively define a consolidated development model, in comparison with less developed regions such as Dealu Mare that reflect an early-stage fragmented development model driven primarily by individual winery initiatives rather than coordinated regional strategy.

Governance

The governance dimension represents the most critical differentiator. The benchmark destinations demonstrate structured coordination mechanisms integrating public and private actors. Napa Valley operates under a coordinated association-based governance model, Bordeaux functions through institutionalized appellation councils that reinforce regulatory and symbolic consistency, while Tuscany integrates consortia and agritourism networks into regional planning frameworks. These findings confirm [12] argument that network-based coordination is central to wine tourism competitiveness.

In contrast, Dealu Mare lacks a consolidated destination management organization, while individual wineries have invested in infrastructure and services, regional coordination remains small represented and event-driven. This fragmentation sustains [18] observation that emerging wine regions frequently struggle with institutional alignment.

Governance therefore functions as the catalytic dimension influencing performance across all other components.

Regional branding

Benchmark destinations demonstrate strong identity coherence rooted in terroir symbolism and heritage. Bordeaux's appellation system reinforces classification-based legitimacy, Tuscany integrates landscape and cultural immersion, while Napa Valley emphasizes innovation and premium lifestyle positioning.

These findings support [24] value proposition model and [20] identity–image alignment theory.

In Dealu Mare, content analysis of winery websites indicates predominantly winery-centered communication focused on tastings and events. Regional storytelling remains underdeveloped, explaining the low branding score (2/5).

Tourism infrastructure

Infrastructure in mature destinations is well developed and closely connected to other tourism services, contributing to a more integrated visitor experience. Accommodation, gastronomy, cultural attractions, and transport connectivity are highly coordinated, confirming [5] cluster model. Dealu Mare benefits from geographical proximity to Bucharest, which reduces accessibility barriers. However, regional signage along the wine route remains inconsistent, while services and accommodation facilities at the winery are present, but rather limited. The main issue in Dealu Mare is not the lack of infrastructure itself, but the limited coordination between existing services.

Visitor experience

Mature destinations offer diversified experiential portfolios including wellness tourism at the wineries, festivals, culinary integration, educational workshops, and museum interpretation. This aligns with [8] segmentation framework highlighting differentiated visitor motivations. In Dealu Mare, wine tasting activities are the main core for the experience. Although recent growth in winery hosted events indicates positive entrepreneurial dynamics, experiential diversification remains limited and insufficiently integrated at regional scale.

In addition to the four core analytical dimensions included in the maturity index, complementary structural indicators were examined to provide contextual depth to the comparative analysis. These include destination management structure, digital integration, and international visibility. Although not independently scored, these elements help explain structural differences observed between mature destinations and Dealu Mare. Firstly, the presence of a formal destination management structure reflects the level of institutional coordination and collective strategic planning, which has been identified as central to wine tourism competitiveness [12]. Also, benchmark destinations operate through consolidated associations or inter-professional councils, whereas Dealu Mare lacks a formally institutionalized coordination body. For instance, in this wine region it is active only one winery association that consists in only a few wineries.

Moreover, digital integration further differentiates mature and emerging regions.

For instance, strong online presence, coordinated digital communication, and accessible booking systems reinforce branding effectiveness and market reach [24]. In contrast, limited digital coordination may constrain visibility and visitor engagement in emerging destinations. Also, international visibility reflects broader recognition and symbolic positioning in global markets. Established wine regions benefit from accumulated reputation and export identity, which enhance tourism attractiveness [15]. Lower international awareness in Dealu Mare suggests that symbolic positioning remains under development.

All the above complementary indicators were analyzed qualitatively and serve to contextualize the structural maturity gaps identified across the four core dimensions.

Field observation in Dealu Mare

Structured non-participant observation conducted during winery visits indicates:

-modern tasting spaces in several wineries,
-improved internal signage for the wineries,
-increasing events and festivals at the winery,
-limited digital presence for booking and tours,
-limited coordination between wineries,
-inconsistent wine route signage,
-absence of unified regional branding.

These findings reinforce the maturity index assessment and validate the scoring methodology.

To summarize, the multidimensional comparative analysis demonstrates that role models destinations display systemic balance across governance, branding, infrastructure, and experience design. For Dealu Mare case, it has been demonstrated a low score across all dimensions. This pattern indicates that the development challenges affect the destination as a whole rather than a single dimension, meaning that the findings are consistent with [11] view that wine tourism destinations function as a comprehensive system, where overall performance depends on coordination across multiple components.

Strategic implications for Dealu Mare

The comparative findings confirm that competitiveness in wine tourism is shaped less by production volume and more by systemic coordination. Successful destinations convert terroir identity and cultural heritage into coherent strategic identity that support diversified tourism.

For Dealu Mare, strategic priorities include:

•Establishing a formal destination management structure,
• Developing a unified regional brand centered on terroir and authenticity,
• Integrating gastronomy, accommodation, and cultural events into structured visitor packages;
• Enhancing digital promotion and coordinated marketing.
• Developing thematic wine routes and annual emblematic events.

The analysis shows that wine tourism development depends on coordinated action at destination level rather than isolated investments by individual wineries. Additionally, clear governance structures and a consistent regional brand are key factors in moving from an emerging stage toward a more mature wine tourism destination.

CONCLUSIONS

This study examined wine tourism development models in three internationally recognized destinations Napa Valley, Bordeaux, and Tuscany, and assessed their structural relevance for the Romanian wine region of Dealu Mare. By operationalizing wine tourism maturity across four key dimensions governance, regional branding, tourism infrastructure, and visitor experience, the research provides a structured framework for evaluating destination competitiveness. This multidimensional perspective is consistent with prior studies emphasizing the importance of coordinated stakeholder networks [12], coherent place branding strategies [24] [20], spatial and service integration [5] [21], and differentiated experiential design [8] in shaping wine tourism performance. Also, the four key dimensions and are closely linked and collectively influence destination performance, while the gap identified between mature destinations and Dealu Mare reflects broader coordination challenges rather than

limitations in wine production quality, supporting [15] observation that institutional alignment plays a central role in wine tourism development. This study contributes to the literature by applying existing theoretical concepts in a structured comparative framework that can be used to assess development patterns in emerging wine regions. The multidimensional assessment approach provides a practical tool for comparing destination performance beyond the Romanian context.

Overall, the results highlight that wine tourism development depends on coordinated action at destination level and a clear regional identity. For the wine regions that are in a development stage, their progress requires stronger institutional coordination and more diversified visitor experiences.

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PLANT RESEARCH CENTERS OF EXCELLENCE AS DRIVERS OF THE EUROPEAN BIOECONOMY AND SOCIO-ECONOMIC DEVELOPMENT

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Abstract

The bioeconomy is a key driver of sustainable regional development, as it fosters innovation and promotes the efficient resource use. The bioeconomy and Centers of Excellence are closely connected, as Centers of Excellence serve as knowledge hubs that advance the bioeconomy while generating positive socio-economic impact and supporting sustainable development at the regional level. The study aims to present a comparative analysis of four European Centers of Excellence specialising in plant research. The survey applies a comparative case study methodology to examine the Centers of Excellence, selected for their scientific impact and involvement in European research frameworks related to the bioeconomy. The findings show that all four centers are catalysts for the development of the bioeconomy by supporting value chains, fostering start-ups and spin-offs, and transferring results into applied solutions in the agro-food industry. In addition, they have a substantial socio-economic impact, related to job creation, investments and the support of innovation-friendly business ecosystems. By promoting collaboration between academia, industry, and public institutions, they contribute to economies that are more resilient and support Europe's transition towards sustainable models.

Key words**:** *sustainability, knowledge transfer, new business models*

INTRODUCTION

The European Commission updated Bioeconomy strategy in 2025 and the new framework is directed towards competitiveness, industrial decarbonization, and resilience. Key elements include scaling up innovation, market leadership for bio-based products, sustainable biomass supply, and strengthening global partnerships [7]. The updated document strongly emphasizes shifting research from laboratories to industrial applications. In addition, the strategy outlines the importance of regional and local approaches alongside with stronger coordination tools.

This institutional framework creates the conditions for interdisciplinary and long-term research, precisely characteristics that are critical for the transformation towards an inclusive bioeconomy. Such transformation is closely linked to the principles of sustainable development, which aim to balance economic growth, environmental protection and social well-being [32]**.** The bioeconomy requires integration between biological sciences, engineering, economics, policy and social sciences, as well as investments in infrastructure and human capital. In this context, the Centers of Excellence (CoEs) have become an important part of European priorities for advancing higher education and research, mainly related to green transformation, innovations and bioeconomy development. CoEs are considered a key driver for improved institutional capability, scientific progress and financial benefits [2]. In addition, CoEs can help bridge the gap by linking academic field and external stakeholders such as industry, policymakers, and public institutions [28].

Number of studies analyse the role of Centres of Excellence in capacity building, interdisciplinary research, funding effects and improvement [11, 12, 13].

The aim of the paper is based on comparative case study analysis of leading European Centres of Excellence in plant science using

multi-dimensional criteria to assess their impact on socio-economic development and the broader advancement of bioeconomy in Europe.

The novelty of the study lies in integrating the analysis of Centres of Excellence within the broader framework of the bioeconomy. While most surveys have examined either the role of research centres or the development of the bioeconomy separately, this study combines both perspectives in a comparative framework.

In addition, the paper contributes by comparing four distinct institutional models and by extending the analysis beyond scientific impact towards socio-economic role, regional development and innovation ecosystems. This multi-dimensional approach provides a more comprehensive understanding of how Centres of Excellence contribute to sustainable development.

MATERIALS AND METHODS

The theoretical foundation of the study is based on a conceptual framework that explains the relationship between Centres of Excellence and bioeconomy development.

The framework positions Centres of Excellence as key actors between knowledge creation, innovation processes and socio-economic impact. The importance of this organization is closely linked to the question how scientific outputs are transformed into solutions.

The conceptual framework illustrates the role of Centres of Excellence as crucial element in the innovation system, transforming scientific knowledge into bioeconomy applications through knowledge and innovation.

The framework highlights the influence of policy environments, funding mechanisms and stakeholder linkages, as well as the socio-economic role and influence.

The survey is based on a comparative case study methodology [9, 31] and is applied to analyse four leading European Centres of Excellence in plant systems biology. They were selected because of their scientific impact, and the scope focused on molecular and systems approaches in plant biology.

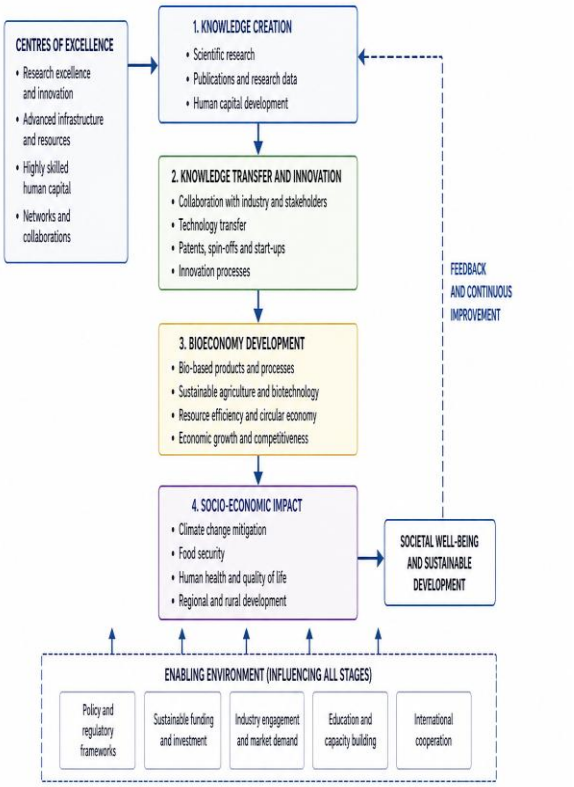

Fig. 1. Relationship between Centres of Excellence and Bioeconomy
Source: Own interpretation based on [1, 2, 7].

The selection of the four Centres of Excellence follows a purposive sampling approach, aimed at ensuring analytical comparability rather than statistical representativeness. The selected cases meet several key criteria: (1) high scientific relevance in plant systems biology; (2) active participation in European research and innovation frameworks, (3) diversity of institutional models, including public research institutes, university-based centres and hybrid public-private structures; and (4) representation of different stages of development, ranging from emerging centres to globally established institutions.

This approach allows for analytical generalization and identification of patterns across different institutional and policy contexts. (Table 1).

It should be noted that the selected centres are not intended to be statistically representative of all Centres of Excellence in Europe. Instead, they are designed to capture the diversity of institutional models, funding structures, and strategic orientations within the European research landscape. This

approach allows for analytical generalization and the identification of broader patterns regarding the role of Centres of Excellence in the development of the bioeconomy.

Table 1. Selected Centres of Excellence

CoE	Country	Founding Year
CPSBB	Bulgaria	2015
JIC	UK	1910
MPI-MP	Germany	1994
VIB-UGent	Belgium	2002

Source: Own survey based on [4, 16, 22, 30].

The methodological framework is adapted from the surveys of [3, 5, 27]. The analysis combines case description with cross-case synthesis [25]. Results are presented in a cross-case comparative matrix, enabling pattern identification and formulation of conclusions.

Data is collected based on a combination of document analysis and secondary sources, including institutional strategies, annual reports, research data, project participation, and policy and funding analysis.

RESULTS AND DISCUSSIONS

CoEs can be viewed as institutional environments designed to foster high-quality research, stimulate innovation, and advance education [17]. The size and scale of CoEs can vary widely [11]. Even though the CoEs are different, they are aligned not only with scientific and technological advancement and progress but as well as with achieving wider societal and policy related objectives [1,18]. CoEs are focused on high potential and innovative fields in science and industry [8, 21]. In addition, some CoEs also have social objectives and serious regional and local impact [18]. Organisational structure of the CoEs, teams, and collaboration are essential [29]. Regarding funding, some studies outline resource resilience and flexibility as drivers for research results [10, 14, 20]. In addition, some authors stated that the funding has a secondary effect, as measured by publications, citations, and human capital development [19, 33]. The OECD report [26] remarks that CoEs with larger budgets are more focused on external cooperation. The funding links positively with interdisciplinary collaboration that directs to opportunities for higher scientific impact and long-term goals [26]. On the other hand, the effect of the fund concentration does not necessarily lead to excellence [18]. Resources, skills, and organisational structure can be considered as key factors in CoEs' development**.**

Based on the methodological framework the CoEs are compared in several direction: (1) institutional focus and bioecomomy relevance (Table 2); (2) funding sources (Table 3); (3) socio-economic role (Table 4).

The Max Planck Institute of Molecular Plant Physiology (MPI-MP), the Centre of Plant Systems Biology and Biotechnology (CPSBB), VIB–UGent Plant Systems Biology Centre and the John Innes Centre (UK) have similarities in some aspects; however, they differ in scale, institutional integration, strategic priorities. The MPIMP is divided into three departments and supplemented by various independent research groups, as well as affiliated university units. Approximately 400 people from over 30 countries work at the institute [22].

As a center of plant biotechnology, VIB-UGent specializes in research and innovation as well as capacity-building and collaborations. Ghent University has over 50,000 students and 15,500 staff, which offers an ecosystem for scientific excellence [30]. The UGent fosters cross-disciplinary collaborations. The international cooperative partnerships in plant biotechnology give the organization a dynamic profile of social responsibility and academic leadership.

The John Innes Centre is a leading UK center of excellence in plant science, known internationally as an independent institute. JIC has spent well over a century making significant contributions to evolutionary scientific knowledge and its many branches, from basic research to practical innovations in agriculture, health, and biotechnology. JIC is organised into over 40 research groups, led by Group Leaders across five departments [16]. The institute is well-known for translating research into widely adopted products and commercial ventures.

Table 2. Comparative matrix based on institutional model, strategic objective and bioeconomy role

Dimension	CPSBB (Bulgaria)	MPI-MP (Germany)	VIB–UGent (Belgium)	John Innes Centre (UK)
Institutional Model	Independent institute, public-private, based on EU projects	Public-funded; Independent under Max Planck Society	Public-funded; Collaboration with Ugent	Public research institute under UKRI/BBSRC
Core Research Focus	Apllied plant biology, Biotechnology Bioinformatics, Metabolomics, Plant breeding, Plant genomics, Plant stress biology, Systems biology,	Apllied plant biology, Biotechnology Bioinformatics, Metabolomics, Plant genomics, Plant stress biology, Computational biology	Apllied biology, Biotechnology Epigenetics Genomics, Metabolomics, Plant biotechnology, Plant breeding, Plant genomics, Plant stress biology, Systems biology	Apllied plant biology, Biotechnology Bioinformatics Crop genetics, plant–microbe interactions, synthetic biology, Plant breeding, Plant genomics, Plant stress biology
Strategic Objectives and main goals	Regional bioeconomy transformation and capacity building	Scientific excellence and fundamental research	Scientific innovation and industry engagement	Food security, agricultural sustainability, crop improvement
Role in Bioeconomy	Focus on plant-based innovations, capacity building in the region	Indirect via fundamental science underpinning bio-based R&D	Integration into bioeconomy via biotech spin-offs and applied projects	Direct impact on sustainable agriculture and plant breeding for bioeconomy
Stage of Development	Emerging and rapidly growing	Mature and globally recognized	Mature and internationally competitive	Long history, high global impact

Source: Own survey based on [4, 6, 15, 16, 22, 23, 30].

CPSBB structure is organized in administrative, technical, and IT units, as well as research and service Departments. The CPSBB Administration manages the administrative and financial management of CPSBB. It also takes care of communication with national and EU authorities and the doctoral program in Biotechnology. Among the huge workload is also the management of many national and international projects, supporting in this way the fundamental and applied research conducted by the CPSBB Departments [4].

Based on the data, it can be concluded that CPSBB is a newly established private independent research center. MPI and John Innes are excellence-based institutes that are independent public institutes, integrated into the national framework presented by the Max Planck Society and CPSBB, respectively. The VIB-UGent is a collaboration between a research institute and a university.

Regarding research focus, all organisations are concentrated in the field of plant biology. CPSBB focuses on biotechnology applications in the context of climate change resilience and bioeconomy.

On the other hand, MPI-MP scientific contributions are directed towards fundamental plant metabolism and systems biology.

John Innes Centre is focused on agricultural sustainability, microbial interactions, and synthetic biology.

In addition, the VIB–UGent scientific field is related to genomics and biotechnology for commercial use. Based on the comparison, it can be outlined that CPSBB orientation is more focused on bioeconomy and technology transfer, while others are with basic and translational research scope.

Regarding the strategic goals, CPSBB is still developing and oriented towards capacity building. On the other hand, MPI-MP's priority is scientific excellence. VIB-UGent, as a collaboration, is concentrated on innovation and industry engagement, while

John Innes focuses on food security and sustainability.

The four Centres of Excellence demonstrate different roles within the bioeconomy development.

CPSBB plays a transformational role in an emerging bioeconomy ecosystem. Its activities are related to plant stress biology, biotechnology that directly support sustainable agriculture and bio-based innovation. In addition, CPSBB contributes to knowledge transfer and the creation of regional innovation networks.

MPI-MPs contribution is primarily indirect. Its emphasis on systems biology, and multi-omics research generates foundational knowledge that creates opportunities for future applications in biotechnology and crop improvement [22]. Although not directly market-oriented, MPI-MP is supplying discoveries, methods, and highly trained researchers.

VIB–UGent presents integrated research and innovation bioeconomy model. By combining academic excellence with industry partnerships and biotechnology spin-offs, it actively implements scientific discoveries into commercial solutions. Its engagement in genomics and synthetic biology helps in bridging laboratory science and industrial biotechnology markets.

The John Innes Centre demonstrates bioeconomy model focused on global challenges such as food security, sustainable agriculture, and crop resilience. Its expertise directly supports the development of climate-resilient crops and sustainable production systems. Through international collaborations, it links fundamental science with real-world agricultural production, highlighting the bioeconomy's social dimension.

In relation to funding, MPI-MP funding sources include the Max Planck Society and are supplemented by EU grants. The Max Planck Society is one of the world's most prestigious and well-funded research organisations, ensuring stable and substantial baseline funding. EU grants add competitive, project-based support, enabling collaborations [24].

CPSBB is linked to EU Teaming projects, national grants, and private funding. The funding relies on EU capacity-building programs to strengthen research excellence [6].

VIB–UGent Funding is a mix of Flemish government, European Research Council (ERC)/H2020, and industry. A substantial public investment from the Flemish government ensures balanced institutional support, while EU funding and industry partnerships support innovation and applied research [30].

John Innes Centre receives core financial support from national funding, EU projects and charities. This reflects research excellence and social impact, as charitable funds often back high-impact science [15, 16].

For the John Innes Centre, publicly available data indicate that government grants constitute the largest share of its budget. In the most recent reporting period, JIC received £33.7 million in government funding, which represents approximately 45.3% of its total income (£74.4 million) [15,16]. Contributions from charitable donors and philanthropic sources are minor. The remaining 54.5% derives from "other income", which includes revenue from, trading operations, investments, and competitive research grants not classified as core government support. This structure highlights JIC's strong reliance on public funding while also demonstrating a significant capacity to attract diverse non-governmental revenue streams through partnerships, scientific services, and externally funded projects.

In contrast, the funding model of VIB-PSB reflects its position within a highly integrated regional research ecosystem in Flanders.

The center receives 70–90% of its resources from public sources, primarily through operational support from the Flemish government and competitive European funding programs such as Horizon 2020 and Horizon Europe.

Industry collaboration accounts for 5–20% of its budget, originating from joint research agreements, technology transfer activities, and targeted innovation partnerships in the biotechnology and agritech sectors.

Philanthropic funding plays only a minor role, estimated at 1–5%, typically supporting specific initiatives rather than core operations. This diversified yet predominantly public model underpins VIB-PSB's dual mission of fundamental research and high-impact innovation [30].

Table 3. Comparison based on funding and scientific influence

Institute	Funding Sources	Global Scientific Relevance
MPI-MP	Federal and regional governments (83%), EU and other project funding (17%)	Top-tier globally in European plant science
CPSBB	Project funding (85%), economic activities and other own sources (15%)	Emerging Southeast European plant science Institute
VIB–UGent	National (Flemish) government (70%), project funding (20%), funding from industry (5%)	Top EU player in plant biotechnology
John Innes Centre	National government funding (45%), project activities (55%), donations (0.2%)	World leader in plant-development science

Source: [4, 6, 15, 16, 23, 24, 30].

The Max Planck Institute of Molecular Plant Physiology presents a third model typical of the Max Planck Society's funding architecture. Approximately 80% or more of the institute's budget comes from public sources, primarily federal and state government allocations. Private sector funding represents an estimated 10–15%. Philanthropic contributions constitute 5–10%, reflecting donor support for scientific advancement, infrastructure, and early-stage research. This structure confirms MPI-MP's strong foundation in public investment, complemented by strategic private-sector partnerships and philanthropic support [23, 25].

Approximately 85% of CPSBB budget comes from competitive project funding—primarily EU programs such as Horizon Europe and national operational programs, reflecting its strong integration into European research networks. The remaining 15% is generated through economic activities and other own sources, including services to local SMEs, training programs, and technology transfer initiatives. This structure highlights both the rapid development of CPSBB and its growing role as a regional driver of scientific capacity, innovation, and economic modernization [4].

The comparison shows different types of funding from public to project-oriented, which reveals the diversity of centres of excellence and the various opportunities for research and innovation in the EU.

The socio-economic role of the institutions is also essential, especially for boosting local economics and contribution for overcoming social challenges at regional level.

The John Innes Centre generates significant socio-economic value through its research, innovation, and educational activities. Over 25 years, JIC's total estimated contribution to the global economy is £54.2 billion, with £5.95 billion accruing to the UK alone. The research return on investment (RoI) is high - 29:1 in the UK and 264:1 globally [15,16]. JIC supports around 881 full-time equivalent jobs in the UK, including direct employment, supply chain, and induced effects. The centre's operations and scientific activities contribute £42.5 million in annual Gross Value Added to the UK economy [16]. Productivity gains arise primarily from agricultural innovations and bioengineering applications that enhance efficiency and sustainability in the agri-food sector. Health-related research contributes £6.3–28.2 billion globally by advancing nutrition, antibiotic resistance solutions, and bio-based materials. JIC's environmental research supports biodiversity, carbon reduction, and sustainable crop production, leading to measurable ecological benefits valued at over £35 million [16]. JIC's training and education programmes generate around £180 million in socio economic value, equipping students and researchers with advanced bioscience and biotechnology skills. These activities strengthen the UK's innovation ecosystem and global research leadership [16]. While the UK gains directly from employment and innovation, more than 80% of JIC's economic

impact occurs internationally, particularly in low- and middle-income countries that benefit from food security, improved crop yields, and environmental resilience. The Centre's international collaborations amplify the global impact of UK-funded science.

Table 4. Comparison based on socio-economic role

Dimensions	CPSBB (Bulgaria)	JIC (UK)	MPI-MP (Germany)	VIB-UGent (Belgium)
Employment Impact	Scientific staff, local construction and service jobs	Scientists, support staff, and spin-off companies	Research staff, supporting industries	Scientists, startup staff, university collaborations
Business Ecosystem Support	Start-up support, public-private projects	Start-up incubator, agri-tech companies	Spin-offs, biotechological collaborations	Incubators, seed funding, VIB bio-accelerator
Education and Skills Development	Research training, EU fellowships	Graduate schools, scientific outreach, technician training	PhD and postdoc programs, student internships	Graduate training, academic-industry programs
Economic Impact	Increased demand for services, skilled worker retention	Tourism, real estate, high-value job creation	Boost to real estate, transport	High-value added jobs, regional biotechnology visibility
Industry Collaboration	Regional agricultural and biotechnology firms	agriculture, biotechnological, pharma firms	partnerships with biotechnological and agricultural firms	agri-food, digital farming, biotechnology
Global Research Integration	Horizon 2020, Horizon Europe	UKRI, EU (pre-Brexit), and global research networks	Max Planck Network, EU projects, international visibility	EU-funded networks, global academic partnerships
Regional impact	Rising innovation hub in Southeastern Europe	Scientific leader of East England	Scientific leader for Golm/Potsdam	Bioeconomy driver for Flanders

Source: Own survey based on Own survey based on [4, 6, 15, 16, 22, 23, 30].

The VIB-UGent Center for Plant Systems Biology generates significant socio-economic value by advancing scientific innovation, strengthening agri-food systems, and enabling industrial competitiveness. At the core, its impact is the contribution to agricultural productivity and climate adaptation. Research in plant development, stress tolerance, gene regulation analysis helps unlock plants' biological potential, leading to improvements in crop productivity, drought resilience, nutrient efficiency. For example, new discoveries about the regulation of root development and the identification of transcription factors that control growth transitions open avenues for creating more climate-resilient crops. Such innovations reduce vulnerability to extreme weather, a driving factor of yield loss and income instability in agriculture. A major driver of PSB's socio-economic impact is its connection to entrepreneurship, industrial partnerships, and regional economic growth [30]. Additionally, PSB contributes to socio-economic development by serving as a training hub for scientific talent. With 19 research groups and 258 staff members, the center plays a key role in educating future experts in plant biology, bioinformatics, genetics, and biotechnology. This enhances the region's human capital, developing skills needed for the green transition, sustainable agriculture, and advanced life sciences research [30]. Over the years, PSB has been the source of several successful biotech spin-offs, including notable examples such as CropDesign and Aphea.Bio, which have become important actors in the agri-tech and green biotechnology sectors. These companies not only translate scientific discoveries into practical agricultural solutions but also stimulate job creation, private investment, and technological competitiveness in Flanders. PSB also plays a key role in the development

of the Ghent Biotech Valley, serving as a leading institution that strengthens the region's position as a European hub for life sciences and sustainable biotechnology.

The Max Planck Institute for Molecular Physiology is part of the broader Max Planck Society (MPG), whose innovation and commercialisation ecosystem generates significant socio-economic impact. The Max Planck Society has produced a strong portfolio of knowledge-based companies, with 200 spin-offs created since 1990, generating approximately 9,500 jobs globally. MPI-MP contributes to this innovation ecosystem by generating foundational molecular and biochemical discoveries that seed new technologies, methods and industrial applications [23]. MPI-MP's research platform is built upon four main pillars: genetic diversity, phenotyping, gauntlets, and biomodeling. Although primarily focused on fundamental science, MPI-MP also advances plant biotechnology. MPI-MP produces highly trained PhDs and postdoctoral researchers who enter academia, biotechnology, pharmaceuticals and medical technology sectors. At the regional level, MPI-MP serves as one of the key institutions in the Potsdam-Golm Science Park, one of Germany's most dynamic innovation clusters [22]. Its presence enhances the park's scientific reputation, attracts investment, strengthens collaboration networks, and generates demand for specialized services. By stimulating innovation, the institute supports the expansion of high-skilled employment and improves the economic competitiveness of the Brandenburg region. The Max Planck Institute of Molecular Plant Physiology (MPI-MP) has played a central role in fostering innovation and entrepreneurship through the creation of several spin-off companies. In its early years, the institute helped establish two major R&D firms – PlantTec and Metanomics, both founded with significant involvement from MPI-MP scientists [22, 23]. In subsequent years, additional spin-offs emerged from the institute's research ecosystem. Together, these spin-offs illustrate the institute's strong capacity for translating fundamental research into commercial innovation and contributing to the regional biotechnology ecosystem. MPI-MP's research platform is built upon four main pillars: genetic diversity, phenotyping, gauntlets, and biomodeling. Although primarily focused on fundamental science, MPI-MP also advances plant biotechnology. MPI-MP produces highly trained PhDs and postdoctoral researchers who enter academia, biotechnology, pharmaceuticals and medical technology sectors.

The Center of Plant Systems Biology and Biotechnology in Bulgaria has emerged as a key scientific institution generating strong socio-economic impact at both regional and national levels. By establishing a modern research infrastructure in Plovdiv, CPSBB creates high-skilled employment opportunities in Southern Bulgaria and significantly contributes to building local scientific capacity.

Through its training programs for young researchers, PhD students, and postdoctoral scientists, the center plays an important role in reducing brain drain and fostering the development of a new generation of specialists in plant biology and biotechnology. CPSBB is also an active driver of innovation. Through participation in EU-funded projects, including Horizon Europe and national operational programs, the center promotes technology transfer and supports the commercialization. Its collaborations with local SMEs in biotechnology and agriculture stimulate the adoption of innovative solutions, creating modern bioeconomy sector in Bulgaria [4, 6].

At the regional level, CPSBB supports economic development in the Plovdiv area. Its presence strengthens the city's role as an emerging innovation hub and enhances Bulgaria's integration into the European Research Area by fostering international partnerships and contributing to European research networks. Through its combined contributions in employment, innovation, regional development, and sustainability, CPSBB plays an increasingly important role in positioning Bulgaria as a competitive participant in European plant science and biotechnology.

The comparative analysis also highlights the significant role of national policy frameworks in shaping the performance and strategic orientation of Centres of Excellence. In countries such as Germany and the United Kingdom, strong and stable public funding systems support long-term scientific excellence and infrastructure development. In contrast, in emerging systems such as Bulgaria, Centres of Excellence rely more heavily on European funding instruments, particularly capacity-building programs.

Regional policy models, as in the case of Belgium, demonstrate how coordinated innovation strategies and public investment can foster strong links between research institutions and industry.

These differences illustrate that national policy environments influence not only funding stability but also the degree of industry collaboration, innovation capacity and overall impact on the bioeconomy.

CONCLUSIONS

Based on the comparative analysis it can be concluded that all four centers contribute significantly to Europe's plant science landscape, though with different scales and missions. JIC and MPI-MP benefit from long-term, stable funding that supports world-class infrastructures and high-impact fundamental research. VIB-UGent has hybrid university–institute model to drive one of Europe's biotech innovation ecosystems, linking academic excellence with industry collaborations. CPSBB, while the youngest, shows rapid development and an important regional role in bioeconomy innovations and technology transfer in Southeast Europe.

These institutional differences reflect national priorities and funding architectures but ultimately create a complementary ecosystem across Europe. MPI-MP and JIC lead in deep scientific discovery, VIB-UGent facilitates commercialization, and CPSBB strengthens capacity and innovation in emerging regions. Together, they advance climate-resilient agriculture, plant biotechnology, and green innovation, reinforcing Europe's leadership in the global bioeconomy.

Based on the findings of the study, several policy implications can be identified.

(1) The establishment of long-term and stable funding mechanisms is crucial for sustaining scientific excellence, enhancing institutional resilience and enabling strategic, forward-looking planning;

(2) There is a clear need for stronger policy incentives to foster collaboration between academia and industry, with a particular focus on improving knowledge transfer, innovation uptake and the commercialization of research results;

(3) Policy frameworks should actively support the development of regional innovation ecosystems by strengthening the alignment with smart specialization strategies and encouraging synergies between research institutions, businesses and public authorities;

(4) Targeted support for emerging Centres of Excellence is essential for reducing regional disparities, enhancing research capacity in less-developed regions and reinforcing the overall competitiveness of the European bioeconomy.

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ENERGY CONSUMPTION OF A SOLAR GREENHOUSE WITH NOCTURNAL THERMAL PROTECTION USING DOUBLE LAYERS COMPARED TO A CONVENTIONAL POLYCARBONATE SOLAR - CASE STUDY: FEBRUARY 2025

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Abstract

This study investigates and compares the thermal performance and net energy efficiency of two types of greenhouse structures during winter conditions: a double-layer greenhouse with nocturnal insulation and active heating, and a conventional polycarbonate greenhouse. Based on hourly measurements collected in February 2025, net energy balance was calculated daily using both internal-external temperature gradients and solar radiation input. Results show that although the double-layer system requires higher energy input, it maintains a more stable interior climate and demonstrates superior energy retention. Correlation analysis highlights the impact of wind and humidity on thermal losses. The study proposes a practical efficiency indicator, expressed in MJ/day, to support future design and optimization decisions for protected cultivation systems.

Key words**:** *consumption, organic products, Romania*

INTRODUCTION

Passive solar greenhouses are among the most energy-efficient forms of protected horticulture in continental climates, combining low construction cost with substantial solar thermal gain (von Zabeltitz, 2011; FAO, 2017) [26, 11].
The overall heat transfer coefficient (U-value) of the covering system is the primary determinant of nocturnal heat loss (Sonneveld & Voogt, 2009; Sethi, 2009) [24, 22].
Double-layer structures with inflated air gaps and deployable thermal blankets achieve substantially lower U-values than single-layer polycarbonate (Boulard & Baille, 1987; Choab et al., 2021) [4, 8].
In the study area, two greenhouse typologies coexist: the Chinese-style passive double-layer solar greenhouse (SD) with two polyethylene films separated by an air gap and a heavy insulating quilt deployed nocturnally; and a single-span polycarbonate greenhouse (SL) without active nocturnal buffering. ISO 6946:2017 (ISO, 2017) provides the steady-state standard for calculating thermal resistance of building components, including greenhouse coverings.
The objectives of this study are:
(1) to calculate the hourly and daily net energy balance for each greenhouse;
(2) to characterise the indoor temperature regime under cold continental conditions;
(3) to identify the dominant climatic drivers through Pearson correlation analysis; and
(4) to document the nocturnal humidity accumulation pattern specific to the quilt-insulated typology.
Baptista et al. (2000) [3] validated a similar comparative approach for low-technology greenhouses, demonstrating the reliability of simplified energy balance models.
Figure 1 presents the analyzed protected areas. Description of structures: The solar array analyzed is a double foil structure, comprising an outer and an inner layer, separated by an aerial interlayer acting as a passive thermal barrier.

Fig. 1. Map of analyzed protected areas
Source: Own results, drone photo.

At night, this system is supplemented by a roll of insulating duvet covering the inner foil, and the heating system includes 18 radiant panels of 500 W each, activated during the night (approximately 10 hours/night in winter if is necessary).
The air vents are automatically controlled, and data is collected using a Zenong weather station and sensors mounted in the solar house.
In a recent synthesis study, the authors show that the combined use of double foil, thermal curtains and passive thermal mass can reduce heat loss in temperate greenhouses by up to 70% (Castro et al., 2024) [7].

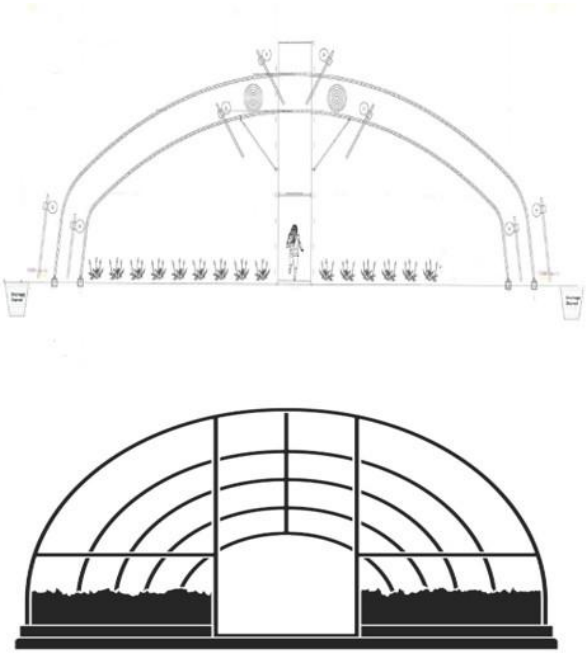
Fig. 2. Structural drawings, Project data sheet
Source: Own concept.

The structure of the polycarbonate solar house is made of metal covered with 10 mm polycarbonate.
The **surface area (S)** used in the energy calculations differs significantly between the two greenhouses:
For the **Double Solar (SD)**, (45 m x 20 m, height 7m) a total surface of **1,727 m²** was considered, corresponding to the full envelope of the protected structure.
For the Polycarbonate Greenhouse, the surface was geometrically computed based on its dimensions (20 m × 8 m, height 4 m) as a half-cylinder, yielding **301.6 m²** of exposed polycarbonate area.
The structural drawings are shown in Fig. 2.

MATERIALS AND METHODS

Meteorological data were recorded by a Zenong automatic weather station installed on site and cross-validated against the PINOVA reference station of USAMV Bucharest. Parameters included global solar radiation ($W \cdot m^{-2}$), outdoor air temperature (°C), relative humidity (%), and wind speed ($m \cdot s^{-1}$). Indoor sensors were positioned at canopy level in each greenhouse (Katsoulas & Kittas, 2008) [14].
Data were transmitted at 10-minute intervals, archived in an InfluxDB time-series database, and aggregated to hourly means for energy balance computation. The monitoring period covers 1–28 February 2025, yielding 649 hourly observations per sensor channel.
Photo 1 shows sensors, equipment and controllers.

Photo 1. Sensors, equipment and controllers
Source: Own results, solar photos

The integrated monitoring and control system deploys outdoor meteorological and indoor sensor streams simultaneously through a Home Assistant-based IoT platform (Zărnescu et al., 2019) [27].

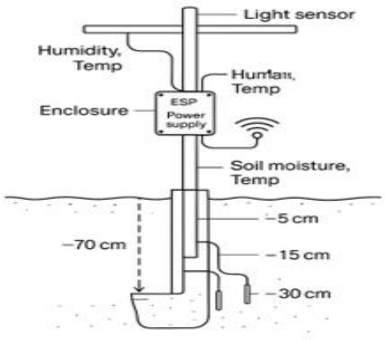

Fig. 3. Drawing of a measurement probe used
Source: Own results.

The Zenong system provides web-based access and cloud data export, enabling remote supervision of both structures under identical external conditions (Fig. 4).

Fig. 4. Values provided by Zenong Company
Source: Zenong Company.

Calculation method and analysis

The net energy balance was calculated separately for each greenhouse using the classical energy balance formulation (Kimball, 1973; Boulard & Baille, 1987) [17, 4]: Enet = Ein – Elost, where Ein is solar energy captured (Wh) and Elost is thermal energy lost (Wh).

$$E_{net} = E_{in} - E_{lost} \quad (1)$$

where:
E_{in} = solar energy captured (Wh)
E_{lost} = thermal energy lost (Wh) through the surfaces exposed to the exterior
Although widely used, this model does not account for latent heat exchanges or soil thermal storage (Boulard et al., 2015) [6]. These limitations are acknowledged; the simplified model is applied here in a comparative context where systematic biases affect both structures equally (Mesmoudi et al., 2010; Boulard & Wang, 2000) [20, 5].
Solar energy input was estimated as Ein = G × S, where G ($W \cdot m^{-2}$) is global horizontal irradiance and S (m^2) the projected envelope area. Supplementary electrical heating was included only for SD (18 panels × 500 W × 10 h/day × 28 days = 2,520 kWh); no heating was operated in SL.
where:
Hourly conductive-convective heat loss was estimated using:

$$E_{lost} = U \times S \times \Delta T \times \Delta t \quad (2)$$

(ISO 6946:2017; Sonneveld & Voogt, 2009) [24],
where:
U is the heat transfer coefficient ($W \cdot m^{-2} \cdot K^{-1}$),
S the surface area (m^2),
$\Delta T = T_{interior} - T_{exterior}$ (°C), and Δt = 3,600 s.
U-values:
U = 2.0 $W \cdot m^{-2} \cdot K^{-1}$ for SD (plastic film + thermal night blanket) and
U = 3.5 $W \cdot m^{-2} \cdot K^{-1}$ for SL (aged single-layer polycarbonate; (Sethi, 2009; von Zabeltitz, 2011) [22, 26].
Table 1 presents global transfer coefficients by solar type.

Table 1. Global transfer coefficient

Solar Type	U value (W/m^2K)
Solar single foil	3.5-5
Solar double foil (air between)	1.5-3
Solar single polycarbonate	2.8-3.5
Solar double or triple polycarbonate	1.2-2.5

Source: Own results.

Note: for higher accuracy, transpiration and roof-level heat exchanges should be incorporated (Fuchs et al., 1997; Mostafavi & Rezaei, 2019) [13, 21]. The simplified formulation is appropriate for comparative purposes. In addition to the energy balance model, Pearson correlation coefficients (r) were calculated between the daily SD net energy balance and four climatic variables: solar radiation, external relative humidity, wind speed, and external air temperature (n = 28 days). Hourly temperature vs. RH correlations were computed for daytime (07:00–18:00) and nocturnal (18:00–07:00) periods (Katsoulas & Kittas, 2008; Shen et al., 2018) [14, 23].

RESULTS AND DISCUSSIONS

Energy balance comparison. Results of the hourly energy balance model are presented in Table 2. These are first-order comparative estimates consistent with Kimball (1973) and Mesmoudi et al. (2010) [17, 20].

Table 2. Net energy balance (kWh)

Data	Daily Net Energy Balance (kWh) - Double layer (SD)	Daily Net Energy Balance (kWh) - Polycarbonate (SL)	Solar Radiation (W/mp/day)
2/1/2025	577.54	141.46	669
2/2/2025	877.87	174.06	880
2/3/2025	-53.30	29.72	331
2/4/2025	2,435.60	497.82	1,933
2/5/2025	1,727.65	328.14	1,429
2/6/2025	2,029.73	372.87	1,623
2/7/2025	3,000.28	555.13	2,242
2/8/2025	19.58	49.41	547
2/9/2025	5,155.36	922.06	3,587
2/10/2025	4,712.18	886.06	3,395
2/11/2025	4,600.34	868.35	3,322
2/12/2025	3,020.28	614.71	2,394
2/13/2025	4,052.37	774.58	2,907
2/14/2025	4,822.68	866.41	3,163
2/15/2025	131.08	92.80	467
2/16/2025	-215.90	46.23	429
2/17/2025	681.60	188.83	954
2/18/2025	442.62	156.66	670
2/19/2025	4,954.11	946.91	3,221
2/20/2025	5,548.29	1,047.89	3,774
2/21/2025	5,571.30	1,005.10	3,915
2/22/2025	4,943.93	903.75	3,659
2/23/2025	5,721.22	1,052.38	4,170
2/24/2025	5,838.39	1,086.67	4,244
2/25/2025	5,584.51	1,051.59	4,013
2/26/2025	5,671.00	1,063.76	3,977
2/27/2025	1,579.73	315.61	1,373
2/28/2025	1,074.18	247.23	887

Source: Own results.

Both structures recorded predominantly positive net daily energy balances.

The mean daily net balance was 3,018 kWh for SD and 582 kWh for SL (ratio 5.2:1), attributable primarily to the 5.7-fold difference in envelope area (1,727 m² vs 301.6 m²). Only SD recorded two negative-balance days (3 and 16 February). When normalised by envelope area, the specific balance was 1.748 kWh·m^{-2}·d^{-1} for SD and 1.929 kWh·m^{-2}·d^{-1} for SL. The cumulative net balance for February was 84,504 kWh for SD and 16,286 kWh for SL. The slightly higher specific balance of SL per m² reflects proportionally greater solar gain on a smaller loss surface, not superior insulating capacity (Boulard & Baille, 1987; Costantino et al., 2021) [4, 9].

The marginally higher specific balance of SL reflects proportionally greater solar gain on a smaller loss surface, not superior insulating capacity. Supplementary heating (3.0% of SD net balance) confirms the essentially passive character of SD (Boulard & Baille, 1987; Costantino et al., 2021) [4, 9].

Table 3. Absolute and area-normalised net energy balance for SD and SL, February 2025

Parameter	SD (S = 1,727 m²)	SL (S = 301.6 m²)
Total net balance (kWh)	84,504	16,286
Mean daily balance (kWh·d^{-1})	3,018	582
Specific balance (kWh·m^{-2}·d^{-1})	1.748	1.929
Negative-balance days	2 (3 Feb, 16 Feb)	0
Supplementary heating (kWh / % of net balance)	2,520 (3.0%)	0

Source: Own results.

Figure 5 illustrates the daily net energy balance evolution for both greenhouses. The pronounced response of SD to partly-cloudy days (20–26 February) confirms the dominant role of solar radiation (r = +0.996; Fatnassi et al., 2003; Castro et al., 2024) [12, 7].

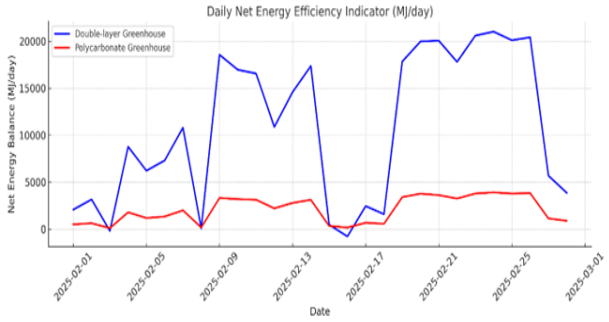

Fig. 5. Daily energy efficiency
Source: Own results.

These results confirm the superior absolute energy retention of the double-layer structure. Classical energy balance models (Boulard & Baille, 1987; Kimball, 1973) [4, 17] predict this outcome; more advanced dynamic models (Boulard et al., 2015) [6] provide higher accuracy but require detailed crop data not available here.

In summary, the predominantly positive energy balance is consistent with the known behaviour of passive solar greenhouses in continental winter climates (von Zabeltitz, 2011; Castro et al., 2024) [26, 7].

Sub-period analysis.

February 2025 can be divided into three distinct meteorological sub-periods based on sky conditions and daily global solar radiation. Period P1 (1–8 February, n = 8 days) was characterised by predominantly overcast skies with a mean daily irradiance of 1,207 W·m⁻²·day⁻¹. Period P2 (9–19 February, n = 11 days) showed variable cloudiness and increasing irradiance, averaging 2,228 W·m⁻²·day⁻¹. Period P3 (20–28 February, n = 9 days) included the six partly-sunny days, with mean daily irradiance reaching 3,335 W·m⁻²·day⁻¹.

Mean daily net energy balances by sub-period are presented in Table 4. For SD, the mean daily balance rose progressively from 1,327 kWh (4,777 MJ/day) in P1 to 4,615 kWh (16,613 MJ/day) in P3 — a 3.5-fold increase driven almost entirely by the corresponding increase in solar input. For SL, the mean daily balance rose from 269 kWh (967 MJ/day) in P1 to 864 kWh (3,110 MJ/day) in P3. The SD/SL ratio remained stable across sub-periods (4.94×, 5.08×, 5.34×), confirming that the structural advantage of SD is consistent regardless of irradiance level.

Table 4. Net energy balance by meteorological sub-period, February 2025

Sub-period	n (days)	Mean solar (W·m⁻²·day⁻¹)	SD mean balance (kWh/day | MJ/day)	SL mean balance (kWh/day | MJ/day)
P1: 1–8 Feb	8	1,207	1,327 | 4,777	269 | 967
P2: 9–19 Feb	11	2,228	2,942 | 10,589	579 | 2,083
P3: 20–28 Feb	9	3,335	4,615 | 16,613	864 | 3,110
All Feb	28	1,966	3,018 | 10,865	582 | 2,094

Source: Own results.

The slight increase in ratio from P1 to P3 is attributable to proportionally greater solar capture on the larger SD envelope under clearer skies (Boulard & Baille, 1987; Castro et al., 2024) [4, 7].

Thermal regime.

For the polycarbonate greenhouse (SL), the mean daily minimum indoor temperature was −1.09°C — below the freezing threshold for most vegetable crops. The absolute indoor minimum reached −6.77°C. This near-complete thermal coupling with the outdoor environment is characteristic of single-layer unheated polycarbonate structures under continental winter conditions (Kittas et al., 2005; Dimitropoulou et al., 2023) [19, 10].

As shown in Figure 6, indoor minimum temperatures in SL consistently fell below 0°C during nocturnal hours, with no detectable thermal buffering.

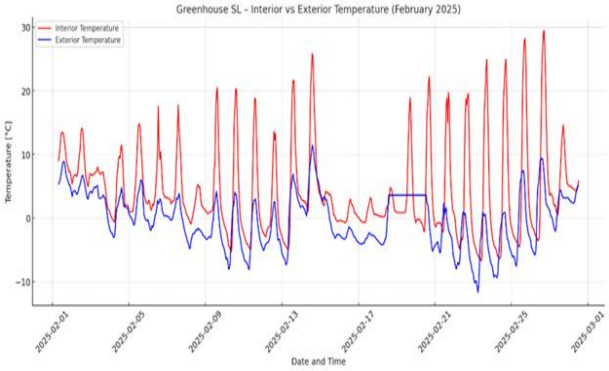

Fig. 6. Daily indoor and outdoor temperature in polycarbonate greenhouse
Source: Own results.

For the double-layer greenhouse SD, the mean daily minimum indoor temperature was +8.34°C, well above the chilling injury threshold. The indoor minimum never fell below +4.35°C despite outdoor minima of −11.69°C (von Zabeltitz, 2011; Boulard & Baille, 1987) [26, 4].

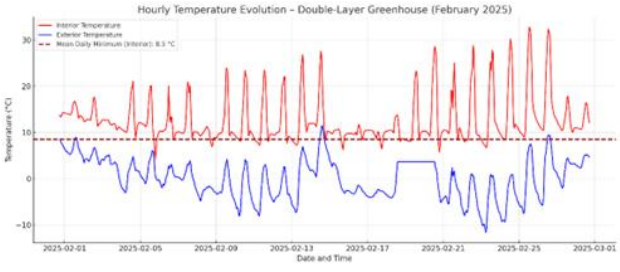

Fig. 7. Daily indoor and outdoor temperature in double solar (SD)
Source: Own results.

Figure 8 confirms the sustained nocturnal temperature floor maintained by the quilt insulation system throughout February 2025.

As shown in Figures 6–7 and Table 5, the two structures respond very differently to identical outdoor forcing. Key statistical contrasts are summarised below.

Table 5. Statistics

Measurement	Double solar (SD)	Polycarbonate (SL)	Exterior Temperatures
Min. Temperature	+4.35°C	-6.77°C	-11.69°C
Max.Temperature	+32.77°C	+29.46°C	+11.45°C
Average Temperature	+12.55°C	+4.34°C	-0.14°C
Amplitude	28.42°C	36.23°C	23.14°C
Mesurements	Double solar(SD)	Polycarbonate (SL)	Exterior Temperature
Average daily minimum	+8.34°C	-1.09°C	-3.74°C
Average daily maximum	+21.32°C	+15.96°C	+6.72°C
Average daily temperature	+14.05°C	+6.13°C	+0.98°C
Average daily amplitude	12.98°C	17.05°C	10.46°C

Source: Own results.

Statistical findings:

1.Mean indoor temperature:

SD (+12.55°C) was 2.9× higher than SL (+4.34°C), under a mean outdoor temperature of −0.14°C.

2.Mean ΔT:

SD = +12.70°C vs. SL = +4.49°C (Kittas et al., 2005).

3. ΔT stability:

SD σ = 4.53°C vs. SL σ = 7.28°C (38% reduction).

Hours with indoor T < 0°C (n = 649): SD = 0 h (0.0%), SL = 183 h (28.2%) — confirming inadequacy of single-layer unheated polycarbonate for year-round cultivation (Dimitropoulou et al., 2023) [10].

Table 6. Diurnal vs. nocturnal ΔT and sub-zero temperature exposure, February 2025 (n=649 h).

Period	Statistic	SD – Double Layer	SL – Polycarbonate	Ratio SD/SL
Daytime 07:00–18:00	Mean ΔT (°C)	+12.61	+1.87	6.7×
	Std. dev. σ	3.57	3.06	—
Nocturnal 18:00–07:00	Mean ΔT (°C)	+12.76	+6.74	1.9×
	Std. dev. σ	5.21	6.22	—
Hours T<0°C (n=649)	**Exterior**	**Indoor SD**	**Indoor SL**	
Count / frequency	325 h (50.1%)	0 h (0.0%)	183 h (28.2%)	—

Source: Own results.

SD maintains consistently high ΔT throughout day and night (+12.61°C / +12.76°C) while SL shows stark contrast (+1.87°C / +6.74°C). SD recorded zero sub-zero indoor hours vs. 183 h (28.2%) for SL (Dimitropoulou et al., 2023; Kittas et al., 2005) [10, 19].

4. Supplementary heating (SD only): 2,520 kWh = 3.0% of cumulative net balance — confirming the essentially passive character of the SD thermal regime. February 2025 had 22 cloudy days, 6 partly-sunny days, and no fully clear days. No day exceeded the clear-sky threshold of ~6.7 kWh·m^{-2}·d^{-1} (Kavga et al., 2008) [15], confirming that the observed performance was achieved under near-worst-case winter conditions.

Effect of wind speed on ΔT.

Figure 8 shows a scatter plot (n = 649 hourly measurements) with wind speed (m·s^{-1}) on the horizontal axis and ΔT (°C) on the vertical axis. Hourly correlations: SD r = −0.032 (negligible) and SL r = −0.132 (moderate negative).

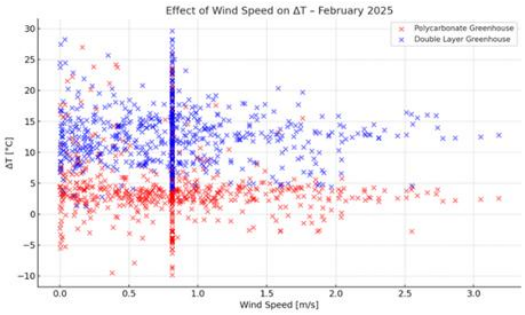

Fig. 8. Effect of the wind speed
Source: Own results.

For SL, the negative association is consistent with enhanced convective stripping from the single polycarbonate layer (Kittas et al., 2005; Fatnassi et al., 2003) [19, 12]. For SD, ΔT remains high and wind-independent, reflecting the protection of the double-film air gap and deployed quilt (Boulard et al., 2015) [6].

Correlation analysis.

Pearson correlation coefficients between daily SD net energy balance and four climatic variables are shown in Table 7 and Figure 9 (n = 28 days).

Table 7. Basic data used to calculate the coefficients of correlation

Data	Day Type	Solar Radiation (kWh/day)	Net Energy Balance (kWh)	External Temperature	External Humidity	Wind Speed
2/1/2025	Cloudy	1,155.36	577.54	6.36	91.87	0.85
2/2/2025	Cloudy	1,519.76	877.87	4.53	85.39	0.51
2/3/2025	Cloudy	571.64	-53.30	3.24	83.27	1.13
2/4/2025	Cloudy	3,338.29	2,435.60	0.8	73.94	0.62
2/5/2025	Cloudy	2,467.88	1,727.65	1.66	73.52	0.78
2/6/2025	Cloudy	2,802.92	2,029.73	0.47	73.52	0.55
2/7/2025	Cloudy	3,871.93	3,000.28	0.73	61.64	1
2/8/2025	Cloudy	944.67	19.58	-2.75	78.63	0.76
2/9/2025	Cloudy	6,194.75	5,155.36	-1.29	65.67	0.51
2/10/2025	Cloudy	5,863.17	4,712.18	-2.64	71.69	0.72
2/11/2025	Cloudy	5,737.09	4,600.34	-3.03	75.27	0.7
2/12/2025	Cloudy	4,134.44	3,020.28	-2.38	73.5	0.59
2/13/2025	Cloudy	5,020.39	4,052.37	0.16	70.38	0.66
2/14/2025	Cloudy	5,462.50	4,822.68	5.4	71.64	0.88
2/15/2025	Cloudy	806.51	131.08	0.31	80.83	1.67
2/16/2025	Cloudy	740.88	-215.90	-2.7	87.26	0.82
2/17/2025	Cloudy	1,647.56	681.60	-3.26	94.23	1.89
2/18/2025	Cloudy	1,157.09	442.62	-0.4	88.88	1.32
2/19/2025	Cloudy	5,562.67	4,954.11	3.6	80	0.81
2/20/2025	Partially Sunny	6,517.70	5,548.29	1.26	78.3	0.79
2/21/2025	Partially Sunny	6,761.21	5,571.30	-2.45	67.05	0.54
2/22/2025	Cloudy	6,319.09	4,943.93	-4.46	69.89	0.68
2/23/2025	Partially Sunny	7,201.59	5,721.22	-5.42	71.78	0.62
2/24/2025	Partially Sunny	7,329.39	5,838.39	-4.38	71.45	1.21
2/25/2025	Partially Sunny	6,930.45	5,584.51	-0.7	69.58	0.53
2/26/2025	Partially Sunny	6,868.28	5,671.00	1.93	67.68	0.57
2/27/2025	Cloudy	2,371.17	1,579.73	1.73	90.33	0.62
2/28/2025	Cloudy	1,531.85	1,074.18	3.74	93.94	0.27

Source: Own data.

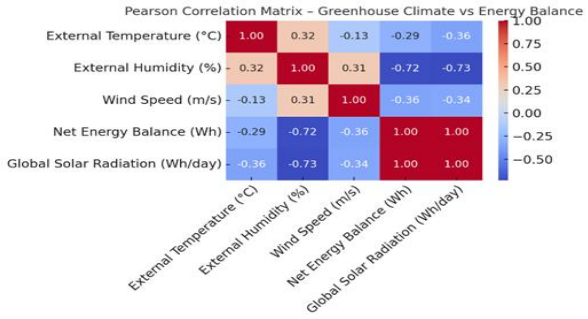

Fig. 9. Correlation matrix
Source: Own results.

1.Solar radiation vs. net balance: r = +0.996. Over 99% of day-to-day variance is explained by solar radiation alone (Fatnassi et al., 2003; Castro et al., 2024) [12, 7].

Solar energy stored in soil and air during daylight is retained nocturnally by the quilt. When solar input is low, stored energy is insufficient to offset overnight losses (Boulard & Baille, 1987; Kimball, 1973) [4, 17].

2. External humidity vs. net balance: r = −0.72. High humidity is associated with cloud cover in winter (Bailey, 2010; Kearney et al., 2014) [2, 16]. The 3.0% auxiliary heating contribution confirms SD functions as a primarily passive collector even in an overcast month.

3. Wind speed vs. net balance: r = −0.36. The moderate negative correlation reflects additional convective losses from the outer film (Kittas et al., 2005; Fuchs et al., 1997) [19, 13]. The relatively weak effect confirms the double-film buffer reduces wind-driven heat stripping.

Physical explanation:

4. External temperature vs. net balance: r = −0.29. The weak counter-intuitive negative correlation is attributable to management interactions: on warmer days, supplementary heating was operated less (Thaler, 2024) [25].

Humidity correlation analysis.

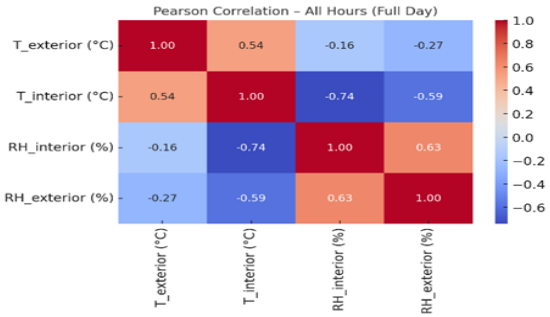

Fig. 10. Correlation matrix
Source: Own results.

Figure 10 shows the daytime (07:00–18:00) humidity correlation matrix for SD:

Indoor temperature vs. indoor RH (daytime): r = −0.74 (Katsoulas & Kittas, 2008) [14]. Indoor RH vs. outdoor RH (daytime): r = +0.63, indicating moderate coupling through infiltration and ventilation. These daytime correlations do not capture the nocturnal behaviour of the quilt-insulated greenhouse. A separate nocturnal analysis (Figure 11) reveals a qualitatively different regime.

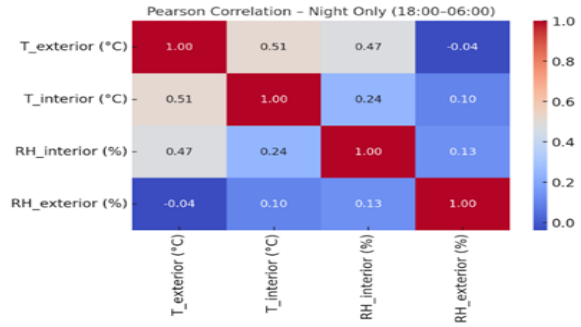

Fig. 11. Correlation of environmental factors at night
Source: Own results.

Nocturnal analysis (18:00–06:00):
Indoor temperature vs. indoor RH (nocturnal): r = +0.24. The sign reversal from the daytime value (−0.74) confirms that without ventilation, rising nocturnal temperatures slightly enhance absolute humidity release (Fatnassi et al., 2003) [12].
Indoor RH vs. outdoor RH (nocturnal): r = +0.13. The near-zero correlation confirms indoor humidity dynamics are almost entirely decoupled from outdoor conditions when the quilt is deployed (Kearney et al., 2014) [16].

Table 8. Additional microclimate parameters and hourly correlation coefficients, SD, February 2025.

Parameter (SD greenhouse)	Value — February 2025
Soil temperature (°C)	mean 13.52 ± 2.82 | min 9.21 / max 25.39
CO_2 concentration (ppm)	mean 539 | min 398 / max 744
Daytime RH indoor ↔ RH outdoor	r = +0.63 (moderate coupling)
Nocturnal RH indoor ↔ RH outdoor	r = +0.13 (effectively decoupled)
Wind vs. ΔT_SD (n=649)	r = −0.032 (negligible)
Wind vs. ΔT_SL (n=649)	r = −0.132 (moderate negative)
Sky conditions (28 days)	22 cloudy | 6 partly sunny | 0 clear

Source: Own results.

Stable soil temperature (mean 13.52°C) confirms thermal mass contribution as passive heat buffer (Kimball, 1973) [17]. Mean CO_2 of 539 ppm reflects moderate nocturnal metabolic activity. Wind–ΔT correlation for SD (r=−0.032) confirms effective decoupling from wind-driven losses vs. SL (r=−0.132; Fatnassi et al., 2003) [12].

In summary, the nocturnal regime is characterised by progressive humidity accumulation in a thermally sealed environment:
With the quilt deployed, ventilation is effectively zero. Plant transpiration accumulates throughout the night at a reduced but non-negligible rate. These dynamics are reproducible across all 28 monitored nights (Fatnassi et al., 2003) [12].
The accumulation pattern is clearly visible in the mean hourly indoor RH profile averaged over all 28 nights (Figure 12).

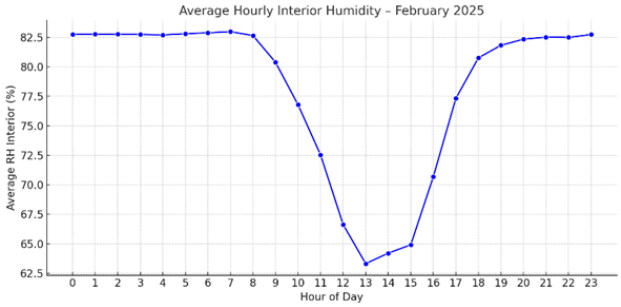

Fig. 12. Average indoor humidity behavior per hour
Source: Own results.

After 18:00, indoor RH rises sharply, peaking consistently around 05:00–06:00, with plant transpiration accumulating without dilution by outside air.
After 07:00, RH declines as ventilation resumes, solar heating raises air temperature, and outdoor air dilutes the moisture-laden indoor atmosphere.
Closing the double-layer greenhouse at night leads to predictable, reproducible indoor humidity accumulation manageable through automated pre-dawn ventilation (Zărnescu et al., 2019) [27].
In conclusion, solar radiation is the dominant driver (r = +0.996), followed by humidity as cloud-cover proxy (r = −0.72), wind speed (r = −0.36), and external temperature (r = −0.29). The nocturnal humidity accumulation is a structural feature requiring systematic management (Kearney et al., 2014) [16].

Energy Performance Indicator (EPI).

To enable comparison with other greenhouse types reported in the literature and to fulfil the objective stated in the abstract, a practical Energy Performance Indicator (EPI) is proposed, expressed in MJ per degree-day ($MJ \cdot HDD^{-1}$), where HDD is the heating degree-day calculated against a 10°C base temperature (the minimum threshold for most vegetable crops). For February 2025, the cumulative HDD(10) was 279.9 degree-days (mean 10.0 HDD/day), representing a near-

worst-case continental winter scenario (Dimitropoulou et al., 2023) [10].

EPI is defined as: EPI = E_net (MJ·day⁻¹) / HDD (degree-days·day⁻¹). For SD: EPI = 10,865 MJ·day⁻¹ / 10.0 HDD·day⁻¹ = 1,087 MJ·HDD⁻¹. For SL: EPI = 2,094 MJ·day⁻¹ / 10.0 HDD·day⁻¹ = 209 MJ·HDD⁻¹. Normalised by envelope area: EPI_SD = 6.29 MJ·m⁻²·day⁻¹; EPI_SL = 6.94 MJ·m⁻²·day⁻¹ (Table 9).

The near-equal area-normalised EPI values confirm that both structures capture available solar energy with similar efficiency per unit envelope; the absolute advantage of SD derives from its 5.7-fold larger area combined with nocturnal thermal retention (Costantino et al., 2021) [9].

Table 9. Energy Performance Indicator (EPI) comparison, February 2025

Parameter	SD	SL	Unit	Notes
Mean daily net balance	10,865	2,094	MJ·day⁻¹	kWh × 3.6
HDD base 10°C (Feb 2025)	279.9	279.9	degree-days	Identical outdoor conditions
EPI (absolute)	1,087	209	MJ·HDD⁻¹	Ratio 5.2×
EPI (per m² envelope)	6.29	6.94	MJ·m⁻²·day⁻¹	Comparable solar capture efficiency
Supplementary heating	3.0%	0%	% of net balance	SD is essentially passive

Source: Own results.

Discussions

The results presented in this study confirm and extend findings from previous comparative greenhouse energy studies, while providing novel quantitative data under near-worst-case continental winter conditions. The dominant role of solar radiation ($r = +0.996$) is consistent with the theoretical framework established by Kimball (1973) and Boulard & Baille (1987) [17, 4], and with experimental findings by Fatnassi et al. (2003) [12] and Castro et al. (2024) [7]. The slight drop in the daytime ΔT for SL (mean +5.39°C) relative to SD (mean +13.88°C) is a direct consequence of the higher U-value and the absence of any nocturnal insulation layer.

The statistical difference in ΔT between SD and SL is highly significant ($t = 29.18$, $p < 2.9 \times 10^{-144}$, $n = 649$ hourly pairs), confirming that the two structures represent fundamentally different thermal regimes rather than a matter of degree. The nocturnal ΔT advantage of SD (+11.67°C vs. +3.70°C for SL) demonstrates that the quilt insulation system effectively decouples interior temperature from exterior forcing during the critical overnight period, consistent with Choab et al. (2021) [8] who reported up to 70 % reduction in heat loss with combined double-foil and thermal curtain systems.

The CO_2 data provide an independent indicator of biological activity within SD. The nocturnal mean of 562 ppm versus the daytime mean of 512 ppm (min 398, max 744 ppm) reflects the transition from photosynthetic CO_2 assimilation during daylight to respiratory CO_2 release at night, confirming that plant metabolic activity was maintained throughout the study period (Katsoulas & Kittas, 2008) [14]. Soil temperature in SD remained stable (mean 13.51°C, $\sigma = 2.83$°C, min 9.21°C) throughout February, providing thermal mass buffering that contributes to nocturnal heat retention independently of the quilt system (Kimball, 1973; Shen et al., 2018) [17, 23].

The economic implications of the observed thermal performance differential are substantial. To raise the interior temperature of SL to the level maintained by SD would require an estimated 5,626 kWh of supplementary electrical heating over the 28-day period:

$$(Q = U \times S \times \Delta T_extra \times \Delta t = 3.5 \times 301.6 \times 8.21 \times 649 \text{ h} / 1{,}000),$$

equivalent to approximately 844 EUR at the Romanian industrial electricity tariff of 0.15 EUR·kWh⁻¹ (February 2025). By contrast, SD achieved its superior thermal performance with only 2,520 kWh of supplementary heating (378 EUR), representing a cost ratio of 0.45: SD delivered a 2.9× higher mean interior temperature at less than half the equivalent heating cost of SL. This energy-economic advantage is attributable to the structural properties of the double-film plus quilt system rather than to

differences in management intensity (Aguilar-Rodriguez et al., 2020; Mostafavi & Rezaei, 2019) [1, 21].

The weak wind effect on SD ($r = -0.032$, $p = 0.41$) compared to SL ($r = -0.132$, $p = 0.001$) confirms the protective function of the inflated air gap between the two polyethylene films. Wind-driven convective stripping, the dominant mechanism of film greenhouse heat loss at wind speeds above 2 $m \cdot s^{-1}$ (Kittas et al., 2005; Fuchs et al., 1997) [19, 13], is effectively buffered by the dead-air layer in SD. This finding has practical design implications: for sites with mean wind speeds above 1 $m \cdot s^{-1}$ (as recorded here: mean 0.81 $m \cdot s^{-1}$, max 3.18 $m \cdot s^{-1}$), the double-film configuration provides meaningful wind protection in addition to its primary nocturnal insulation function.

The nocturnal humidity pattern in SD (indoor RH decoupled from outdoor RH, $r = +0.109$; progressive accumulation peaking at 05:00–06:00; mean nocturnal RH 82.4 %) represents both a disease risk and a design opportunity. Automated pre-dawn ventilation, triggered when indoor RH exceeds a defined threshold (e.g., 88 %), could substantially reduce pathogen pressure without significant thermal penalty, as the maximum indoor RH recorded was only 92.4 % and the nocturnal temperature floor remained above +4°C throughout. Such a control strategy is technically feasible with existing IoT infrastructure, and aligns with dehumidification management guidelines for confined greenhouse environments (Kittas & Bartzanas, 2007) [18] (Zărnescu et al., 2019) [27] and would complement the findings of Kearney et al. (2014) [16] on microclimate management in thermally isolated enclosures.

Several limitations must be acknowledged. First, the energy balance model omits latent heat exchanges and soil thermal storage, which together may account for 10–20 % of the total heat budget in heated greenhouses (Boulard et al., 2015; Fuchs et al., 1997) [6, 13]. Second, the study covers a single winter month; performance during shoulder seasons (October–November, March–April) and summer may differ substantially due to ventilation requirements and the risk of overheating in SD. Third, the absence of replicate structures precludes formal statistical inference about population-level differences between typologies; the results are specific to the monitored units under February 2025 conditions. Future work should extend monitoring to a full annual cycle and incorporate crop-specific latent heat measurements (Mesmoudi et al., 2010; Mostafavi & Rezaei, 2019) [20, 21].

CONCLUSIONS

Under identical outdoor conditions throughout February 2025, SD maintained a mean indoor temperature of +12.55°C (2.9× higher than SL, +4.34°C) and never fell below +4.35°C despite outdoor minima of −11.69°C. SL recorded indoor temperatures below 0°C for 183 hours (28.2%), confirming its unsuitability for frost-sensitive crops without supplementary heating (Dimitropoulou et al., 2023; Kittas et al., 2005).

These results confirm that double-layer greenhouses with deployable nocturnal insulation can maintain biologically viable temperatures throughout February without significant supplementary heating. The supplementary electrical input (3.0% of cumulative net balance) confirms the essentially passive character of SD. The specific net balance of SL (1.929 $kWh \cdot m^{-2} \cdot d^{-1}$) marginally exceeded that of SD (1.748 $kWh \cdot m^{-2} \cdot d^{-1}$) per unit area — reflecting proportionally greater solar gain on a smaller loss surface, not superior insulating capacity (Boulard & Baille, 1987; Costantino et al., 2021) [4, 9].

In practical terms, this typology is recommended for farms seeking to extend the productive season into winter with minimal energy investment. The nocturnal RH accumulation pattern (peak at 05:00–06:00, $r = +0.13$ with outdoor RH) represents both a disease risk and an opportunity for automated pre-dawn ventilation management (Zărnescu et al., 2019; Kearney et al., 2014) [27, 16].

Key limitations include the simplified energy balance model (omitting latent heat and soil thermal storage), the single-month temporal window, and the absence of replicate

structures. Future work should extend monitoring to the full growing season and incorporate latent heat components (Fuchs et al., 1997; Mostafavi & Rezaei, 2019) [13, 21]. Further improvements could be achieved by coupling the quilt insulation with photovoltaic-powered automated actuation, hybrid thermal storage, or dynamic control strategies (Thaler, 2024; Shen et al., 2018) [25, 23].

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CIRCULAR ECONOMY MODELS IMPLEMENTABLE ON THE FOOD COMMERCE CHAINS: A MULTIPLIER EFFECTS PERSPECTIVE

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Abstract

The expansion of food commerce is a reality of the socio-economic space, and food consumption is growing at the same pace, becoming a main generator of waste. This expansive dynamic was also facilitated by the huge involvement of commercial strategies. Given the growing concerns about widespread pollution, this expansion occurred in parallel with initiatives to launch green policies. And those aimed at the transition from the linear economy to the circular one have become a priority, so food commerce chains are forced to adapt to these requirements. This paper is focused on the usefulness of circular economic models appropriate to the functioning of food commerce. A new value model of the circular economy is proposed, and the indicators for quantifying the multiplier effects of food commerce are highlighted. The research started from the two models of the circular economy: Pearce & Turner Model (1990) and MacArthur Model (2013). These laid the foundations of the circular economy, considering the already controversial connection between economies focused on consumption and requests to protect the environment. The value concept, complex and multidimensional, in this model is approached for the three categories of values: planned, created and obtained. This paper presents the value model for the food commerce, taking into account its multiple effects, not just to sell food. Methodologically, the analysis is empirical and qualitative with focus on highlighting the need to move from the linear economy to a circular one. The results indicate that the circular economy strengthens commercial chains, along the entire producer-consumer path, and produces beneficial and sustainable multiplier effects.

Key words**:** *circular economy, equilibrium, consumption, food, commerce*

INTRODUCTION

The global economy and today's society are in an era of expanding green policies, especially as a result of the reorientation towards balance in the consumption of resources and saleable goods, in general. In this context, the circular economy proves to be both a modern concept and a way to enable the implementation of these policies. Specific strategies to stimulate consumption are in opposition to green policies to reduce consumption, and this aspect is also valid for food consumption and strategies of the food industry. The transition from a linear economy to a circular one is not only an individual responsibility, but depends, first and foremost, on the interests and capacity of enterprises in the food production, to make decisions related to the responsibility of consumption and the adoption of measures that converge towards facilitating the functioning of circular economy models.

The transition to circular economic systems practical is slow, although the eco-economic principle according to which "infinite growth in a finite world is impossible" is recognized as viable [4]. This principle is valid for both the production sectors and those for the distribution and marketing of food products. In the current context of pressure on production resources and the threat of waste from food consumption, it is impossible to produce food without a pragmatic recognition of the need for sustainable management of productive sources and inputs for production.

However, production without marketing is real nonsense. In this context, we propose to analyze in this paper the issue of food retail chains from the perspective of the transition to circular economy systems.

Economic growth strategies aim at the maximum utility of retail chains, since their

presence and functionality stimulate the growth of production and, implicitly, economic growth. Recent statistics confirm, however, an unsustainable direction of food consumption, associated with the linear economy, through the increasing volume of food produced and traded, but also of huge waste resulting from food consumption that contributes to the intensification of pollution alert status [26].

For these reasons, the orientation towards circular economic models proves to be a justified requirement in the food sector.

The current major problems of the linear economy are: increasing dependence on new resources, the decrease in the value of products, services and raw materials, the threatening volume of waste resulting from consumption. Annually, about 2.1 billion tons of food waste are produced in the European Union [24]. These, but not only, are strong arguments for emphasizing the need to move to circular economy systems.

The development of commercial systems, as a perfectly functional whole, has brought numerous benefits to consumers, but also major problems, especially by increasing the volume of products purchased and, implicitly, the waste resulting from consumption. Therefore, commercial chains were determined to make decisions in the field of waste management, primarily because the resulting waste was part of the composite products already marketed for which companies recorded a profit. In this sense, circular economy models have proposed waste management solutions, including food, to reduce the volume of waste or to reconsider the way in which it is recovered [23].

The problem of food waste proves to be as serious as in the case of other categories of waste, which is why we have chosen in this paper to refer to commercial chains that could contribute directly, through specific measures, to the transition to a circular economy by promoting implicit models. A new element brought in this paper is the proposal to analyze the food consumption sector from two different perspectives, at least conceptually: a solution to meet basic needs and support for the implementation of circular economy models. Therefore, we propose to reconsider the production-consumption relationship as a symbol of the specific equilibrium of the circular economy.

The main goal of this paper is to highlight the functionality of an economic model based on the circular economy functionality, valid for the food sector, too. The objectives pursued in the paper are:

O1. Highlighting the advantages of the transition to the circular economy specific to the food sector;

O2. Analysis of the functionality of some consumption models of the circular economy;

O3. Bringing to the forefront a new model of the circular economy, which has as its core the complex concept of value.

Argumentatively, value is what must support the decision and actions of transition to the circular economy. All these objectives aim at recognizing the importance of consumption models based on circularity, oriented towards more efficient, balanced and sustainable production and marketing systems.

The paper is structured in the following sections: 1. Materials and methods, with the presentation of the research context, the established literature and the research methodology; 2. Results and discussions, in which the results obtained are presented and argued, respectively the following research directions are outlined; 3. Conclusions.

MATERIALS AND METHODS

The basic concepts and notions analyzed in the paper are: circular economy, food consumption, commercial chain, waste, waste. The circular economy, both conceptually and applied, is of great interest, but also controversial, both in the entrepreneurial and academic environment. ”Circular economy is an emerging paradigm which strives to modify human and organizational behavior and practice patterns” [15]. The concept, developed as an extension of the requirements of sustainable development, is specific to sectors of activity. Thus, the food production and consumption sector is directly targeted by the requirements of green policies that have pointed out the shortcomings of food

consumption that has become unsustainable and the involvement of commercial chains in producing these shortcomings.

Food consumption is carried out in a commercial system of a complex scope and generates both consumption value and multiplier effects. A very useful orientation is towards assuming the complexity given by the expansion of international trade with novel challenges in ensuring food and feed safety across the globe [2]. ”The food value chain is a vertical axis connecting or coordinating supplying, production, processing and selling the food from farm to table” [16]. A commercial chain (from the French "chaîne commerciale") is a set of forms of distribution of goods, organized in an integrated or coordinated structure, in accordance with consumer needs. The expansion of commercial chains has been carried out both vertically and horizontally. This expansion is accompanied by major transition requirements from the linear economy to the circular economy, because the increasing consumption, although it has beneficial effects in monetary terms, attracts unfavourable effects for the security of resources and future generations.

Implementing circular economy strategies is a complex task that requires substantial investments of capital, personnel, technology, and legal frameworks, involving both the responsible institutions and the citizens who stand to gain a higher standard of living [8]. The essential aspects of the circular economy that intersect with the policies and strategies of food commercial chains, which would determine common remediation solutions, are:

- reducing food waste, taking into account that about 48% of waste occurs in households, 37% in industry and 3% in agriculture [1];
- the recovery of food waste in the form of compost or biogas, a solution that is quite easy to implement;
- the production and use in commerce of ecological packaging, especially since the unfavorable effect on the environment of disposable packaging is proven;
- planning food production based on indicators that reflect multiple efficiency, primarily starting from the analysis and measurement of real demand for food consumption;
- reconsidering the quality of commercialized foods which, if they do not bring added health benefits through their nutritional value, at least should not cause harm to health, as is recognized for many fully industrialized foods.

Integrating circular economy principles into food supply chain management contributes to increasing efficiency and achieving sustainability goals. It is true that the requirements for implementing strategies to preserve the resources consumed for the food industry have been issued for more than 30 years, at least by considering the principles of sustainable development, but not all companies, focused mainly on increasing profits, have responded to these requirements. Moreover, it is not requested to give up production and trade, but to reconfigure production and consumption models so that resource consumption, pollution and waste management are pillars of the strategies adopted on the consumer market in general.

They are responsible for sourcing and moving 100 billion tons of materials that enter the global economy each year [30].

Food waste is an implicit part of the functioning of commercial chains. ”Food waste refers to the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers” [14]. The recovery of food waste is proving to be a transformative solution and a way to implement the solutions proposed by the circular economy. Agricultural by-products and food waste can be transformed into other valuable products such as bioenergy, compost, fertilizers, animal feed, so not only is waste reduced, but new economic opportunities are created [7, 28].

The current major problems of food consumption are increasing due to the dual force of the production system and the marketing system. The most obvious problems faced by food retail chains are:

- production resources, including pressure on land and natural factors of production;
- packaging used for packaging, transport and delivery, some of which is direct waste

immediately after unpacking (bags, casseroles, boxes, etc.); in addition to the excessive packaging of food products for reasons of commercial image, the composition of packaging is also added, which contributes to the increase in pollution levels (some plastics being among the most harmful);
- food waste, generated primarily by the supply-demand imbalance; at EU level (2022) 132 kg. of food waste/inhabitant were generated [10];
- the nutritional quality of food, with an impact on consumer health.

Another aspect correlative to the circular economy theme is given by the hyper-emphasis on food consumption accompanied and maintained by the numerical expansion of commercial chains that facilitate the increase in consumption and the volume of waste resulting from consumption. Food trade, a basic contributor to economic growth, by expanding at an accelerated pace, has produced major deficiencies in the management of production resources and, implicitly, waste.

The dynamics of food consumption of the population is measured by the consumption availability of the population, i.e. the average annual consumption of food products per capita and the average daily consumption of food products per capita, expressed in calories and nutritional factors [17].

One of the main factors influencing the consumption models is the consumer education, which begins in the family, and the participation in the general education systems is one of the most important conditions to develop a more responsive nation. The adoption of circular economy models hinges on all levels of education; however, the absence of budgetary allocations and investments makes difficult the transition from linear to circular economy, especially when pro-consumption trends prevail; this means that a lack of educational focus in this domain results in a diminished comprehension of the circular economy's benefits [20].

Commercial chains have directly contributed to the increase in the availability of food consumption, and consumption without trade is impossible to evaluate with macroeconomic indicators. Table 1 shows a dynamics of food consumption in Romania [18].

Table 1. Evolution of availability for human consumption in Romania (2010-2020)

Year	Kcal/person/day	Animal protein grams/person/day
2010	3,147	51.7
2015	3,464	57
2016	3,467	58.4
2017	3,500	59.3
2018	3,552	61.8
2019	3,548	62.3
2020	3,554	62.3

Source: [18].

Through observation and synthesis of relevant studies, together with confirmatory statistical data, it is found that the linear economy has a certain specificity in the food trade: the route from supply to waste resulting from consumption is predominantly unsustainable, especially when measures taken from circular economy models are missing, packaging recycling being the most common example. But for the entire food chain to become more sustainable, changes are needed along the entire food consumption route. Among these, the main ones would be: improving production, food processing, packaging, distribution, consumption, waste recovery [3, 7].

Without solid political and strategic support, the transition to a circular economy is difficult and arduous. Therefore, one of the objectives of the European Union's sustainability policies is to reconfigure the social and economic environment to be more competitive and based on a considerable reduction in pollution [12]. In this regard, the European Union is updating legislation regarding the management of waste resulting from consumption [13]. A main argument is that at the level of global production, the total value of trade in raw materials has tripled since 2002, and food production is no exception to this situation. Statistics show that the EU still imports more than it exports, with a trade deficit of €35.5 billion in 2021 [23]. The consumption of raw materials has, however, been slowly decreasing over the past 15 years. According to Eurostat, in 2023, 14.1 tonnes of raw materials were consumed per person in

the EU, compared to 16.3 tonnes in 2009, the EU generates over 185 kg of packaging waste per capita, and only 38% of this waste is recycled and can be reused to produce new goods [11]. Currently, only 10% of the materials used in the EU come from recycled materials, and the circularity rate of materials was 11.8% in 2023, an increase of only 1.1% since 2010.

Methodologically, the paper is a descriptive-empirical analysis, based on the methods of synthesis, comparison and argumentative criticism. A bibliometric analysis of the literature dealing with the functional models of the circular economy is carried out. The paper aims to expose and argue the need and viability of implementing food production-consumption models in the scenario of the transition from a linear to a circular economy. Therefore, the solution of waste reuse as an alternative source of raw materials is considered. It is important to mention that circular economy models are also supported by measurable performance indicators: material flows, circular use rate of materials, material footprint, employment, gross value added, resource productivity and material dependence [6, 29].

The indicators used for the model's representation are from four categories: economic, environmental, social, protection of future generations. Depending on the specifics of each model presented, the indicators are organized to measure:

- the effects of commercial activities, in a simple and multiplier sense;
- multiplier effects in economic, social and environmental protection.

The first two basic circular economy models ("Pearce & Turner" and "MacArthur") had limited success in implementation, precisely because the incentive consumption was predominant. However, the new model based on planned, created and obtained value proves to be more reliable and easier to implement in food commercial chains. The reconsideration of other forms of inputs in production systems, with added value in economic, social and environmental terms is another approach with a significant degree of novelty. This is the main contribution of the paper to completing the local literature and indicates the degree of novelty of the proposed theme. A question that we aim to answer is: how can the circular economy be connected with food chains and trade?

The presented models, built through indicators for quantifying the multiple effects of commerce, are:

(1) Pearce &Turner Model (1990) which substantiates the relationship between economy and environment.

(2) MacArthur Model (2013) oriented towards reducing the resources consumption.

(3) The Values Model: the implicit values of the new proposed model consist in planned value, created value and resulted value.

All of these must become circular, to obtain beneficial multiplier effects.

It can be observed, in the last around 5 years, how the circular economy models are spreading between European countries, so they are present, fortunately, in the Romanian practical transition from linear to circular models. In this regard, the Romanian food sector looks to be an important player in the transition to the circular economic models. The food sector has an essential contribution such as: reconsidering the value of resources, reducing waste from food consumption and minimizing pollution through food industry production and food consumption.

Practically, the most recognized and relatively easily adapted models are:

1. The model for combating food waste: visible in food consumption and food marketing chains. Although not too much used for now, the Bonapp.eco platform is a very good example in this regard; in fact, is an application designed to connect supermarkets and restaurants with consumers or charitable organizations regarding unsold food, so that it does not become food waste.

2. The model for recycling food by creative valorisation: transforming unconsumed or unsightly food products into new consumable products as creams, biscuits, juices, etc.

3. Sustainable supply model through short supply chains and local integration both horizontally and vertically.

4. Urban and peri-urban "small" agriculture model: agricultural practices near cities for

self-consumption agricultural production and strengthening contact with the natural environment, understanding in this way the real value of the natural resources.

5. Eco-packaging model: bulk sales, reducing the volume of packaging in supermarkets, using biodegradable or ecological packaging as paper, canvas, etc.

6. Organic waste recovery model: composting food waste and transforming it into natural fertilizer or biogas.

RESULTS AND DISCUSSIONS

This section is dedicated to presenting three circular economy models, two being classic, and one being state-of-the-art, a value model proposal that we will adapt to the specifics of food retail chains.

Model 1. Pearce &Turner (1990)

This model considers that the circular economy is a closed system and most of the inputs for food production come from the exploitation and valorization of natural resources. Given that food trade and consumption result in waste, the circular economy based on the value model puts into operation mechanisms to transform this waste into inputs for production, thus implicitly protecting natural resources (Fig. 1).

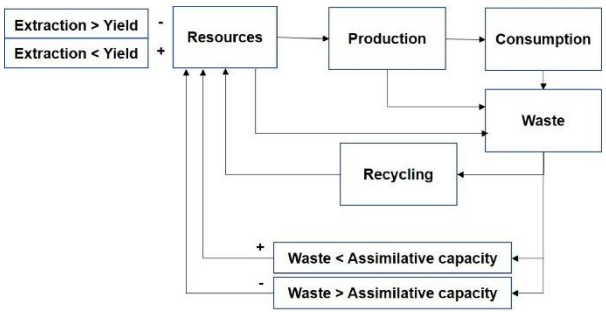

Fig. 1. Circular economy model - Pearce &Turner approach
Source: [27].

The capacity of the environment to assimilate waste is known, but without a carefully organized management, based on solid rules and principles for the recovery of waste resulting from food consumption, this capacity is altered, and the costs of remediation are either extremely high or inefficient.

Model 2. MacArthur Model (2013)

Named the "The Butterfly Diagram" and recognized as "Model 4.0." this model emphasizes how to visualize the circular economy in a practical manner and contains 2 parts: biological cycle and technical cycle.

a. The biological cycle of the butterfly diagram (the left side). This describes the processes that return nutrients to the soil and help regenerate nature. It is available for materials that can biodegrade and safely return to the earth. This cycle mainly concerns products that are consumed, such as food. But, some other biodegradable materials, such as cotton or wood, may eventually make their way from the technical cycle into the biological cycle once they have degraded to a point where they can no longer be used to make new products.

The components of this biological cycle are: regeneration, farming, composting and anaerobic digestion, cascades, extraction of biochemical feedstock.

b. The technical cycle of the butterfly diagram (right-hand side). It is relevant for products that are used rather than consumed. For this reason, is very important to approach the circularity process still from the agricultural production stage, starting with the land fertilization, for instance. In this regard, a modern fertilization is not just an appliance of nutritive substances, in fact it is a complex process integrated in the long chain including food safety, circularity, food waste, recycling and ecosystems protection [19]. The focus in on how each step allows materials to remain in use rather than becoming waste. The smaller inner loops are surrounded by the larger outer loops. These inner loops are where most value can be captured because they retain more of the embedded value of a product by keeping it whole.

These loops also represent a cost saving to customers and businesses as they make use of products and materials already in circulation, rather than investing in making them new.

The components of this biological cycle are:

- sharing;
- maintaining;
- reusing;

- redistributing;
- refurbishing;
- remanufacturing;
- recycling.

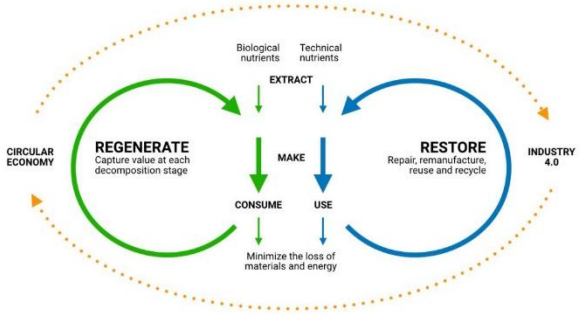

Fig. 2. Circular economy model 4.0
Source: [9]

Model 3. Circular economy based on the planned, created and resulted value (Fig. 3).
It is a new model, proposed as a result of the permanent economic requirements to create value from any action. In essence, the model aims not only to draw attention to the problems of the linear economy, but to create and accumulate value by minimizing the amount of waste while maximizing the use of resources in a closed loop.

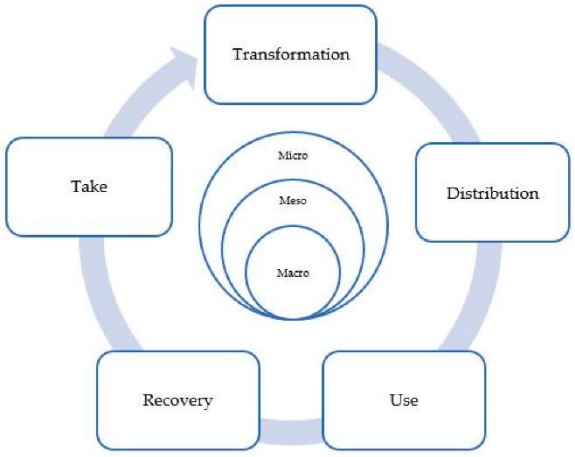

Fig. 3. Circular economy circle: the value model
Source: [25].

Models 1 and 2 were highly appreciated as innovations and solutions to the shortcomings related to unjustified consumption, but difficult to put into practice, because they seemed to issue more requirements than they offer benefits. Therefore, it is considered that the novelty and attractiveness of Model 3, value, are given by the fact that value is like a magnet for various entities and market actors that seek benefits and advantages as a motivational engine (Table 2). For example, recycling could be much more attractive if it brings newly created value.

Table 2. Benefits of a circular model based on value as nucleus of the proposed transition

Areas	Benefits of circular model based on values
Economic	Creates new revenue streams Reduces costs from raw materials Lead to more resilient supply chains. Business opportunities Optimizing material inputs, and resources consumption
Environmental	Minimizes wastes Reduces pollution Protect the resources exploitation Manage the ecological footprint Decouples economic growth from the consumption of finite resources. Reduces risks related to resource scarcity
Social	Creates new jobs (in recycling, too) Increasing brand loyalty Improvement of commerce chains Improving public health Develop the social equity
Product lifecycle	Integrate circularity in every stage A better management of lifecycle Extending the product life
Supply chain collaboration	Work with partners across the supply chain Create effective reverse logistics and material recovery systems Ensure an efficient traceability Creates competitive advantages

Source: the authors' creation, through the synthesis of the relevant literature.

We further propose adapting the value benefits of Model 3 for the food trade, considering both the resource issue and especially food waste.
The transition to the circular economy is not only a requirement that implies major efforts, but is also a source of opportunities for new food businesses, for balancing the production-consumption connection in the food sector and for reconciling the environment-economy relationship, but a condition to be obtained is that the entities involved in the functionality of commercial chains respond favorably to the transition requirements (Table 3). The slow pace of the transition is also given by the fact that these opportunities are not so profitable, in the first stage, especially since they involve investments, adaptation and changes in mentality. And, when is about the mentality

subject, it is mandatory to involves the values based on ethics, morality and responsibility related to the food consumption models. In this regard, a solution could be the education developed in an organizational systems and culture based on ethics, and coherent educational policies [19]. Efforts to change the purchasing and consumption mindset in favor of adopting circular economy models are large, not easy, and sometimes expensive.

Table 3. Transition practices to the circular economy based on value creation in the food sector

Principles and practices	Ways to plan, create and obtain value
Building a complex circular design	Food is designed to limit the temptation to waste. Attributes of the new design: quality, fair price, limiting the production of ultra-processed foods, eco-foods, limiting excess packaging.
Adding complementary services	Consumption of healthy foods in social spaces (canteens, buffet restaurants). Organization of courses and non-formal education on balanced food consumption.
Involving marketing through special promotional techniques	Discounts on food close to its expiration date. Public events promoting food donations. Expanding digital applications aimed at reducing food waste. Encouraging more entrepreneurs to participate in such programs.
Reintroducing food waste into the production system	The use of food waste as materials for other production areas (biofuel, compost) is prioritized, thus reducing the need to exploit new and new resources.
Innovation	Creating new recipes based on unused foods (ex: Italian pizza) New efficient storage and preservation technologies. Smart labels.
Social-individual organization	Careful planning of the food program. Co-opting nutritionists in programs promoting the circular economy for the food sector
Food packaging management	SGR System Reuse where possible Avoid overpackaging and excessive packaging solely for unethical commercial purposes. Use recyclable packaging.

Source: the authors' creation, through the synthesis of the relevant literature.

The results of the proposed model indicate that the circular economy, among the many opportunities offered, also has the role of consolidating the structure of commercial chains, contributing to increasing economic performance reflected in the values of social and environmental indicators, too. A different and important attribute of the transition to the circular economy through specific mechanisms for reducing the volume of waste is the temporal one, starting from the question: when does the transition begin? The answer, based on the arguments in the literature, indicates that waste management it is being analyzed starting from the production phase. Practical literature in the field mentions that over 80% of the negative impact that a product has on the environment and human health is assumed from the design phase of the respective good, through the inputs used, packaging, design, content [22]. So, this is an aspect that limits the transition to the circular economy, including in European Union countries.

Overall, the value model of the circular economy is appreciated as a good driver for various fields and sectors, therefore creating beneficial multiplier effects [21]. The most relevant values are: cost and risk reduction, increased innovation capacity, higher value generation, alignment with consumer market expectations, entry into new markets.

Another direction supported by the orientation towards the circular economy is that of environment protecting against the effects of climate change. Most data, reports and studies inform us about the negative strong impact of these on societies and economies. Climate change is connected to both the reduction in quantity and quality of natural resources, and to the degradation of environmental elements necessary for human health, economic systems to function, and for a real socio-economic progress [5]. Also, in a circular approach, it is important to remember that climate change brings changes in agricultural production, too, so the temptation or necessity to substitute highly industrialized foods for what is undesirable is and this is really essential for a sustainable and efficient economy.

The transition to a circular economy also allows for a better understanding of the requirements for the protection and conservation of environmental resources, seen as means of production. From another perspective, in order to assess the success rate

of the implementation of circular economy models, it is necessary to build a system of progress indicators and their periodic monitoring. In a complementary perspective, the commerce must be in accordance with environmental plans and protection strategies.
A food system can be considered to have become circular when, among other things, it stops pollution, stops or slows down the loss of biodiversity, and therefore can combat or mitigate climate change - knowing that food waste is among the biggest sources of pollution and unsustainable exploitation of natural resources.

CONCLUSIONS

The circular economy is more than recycling by promoting activities based on reuse, repair, refurbishment or rental. Therefore, solving the waste problem with focus only on the sales stage or the end of consumption is by no means a realistic or sustainable solution, as measures are needed starting from the product design phase and the organization of inputs necessary for food production.
In these conditions, some essential objectives pursued by the transition to the circular economy are:
- minimizing production involving massive volumes of waste, which have become very difficult to manage after or at present;
- protecting natural resources by creating specific programs to reintroduce food waste into production systems;
- reducing the interest in exploiting new and new resources, given that the recovery of food waste is possible;
- stimulating innovation and creating new production markets using waste resulting from consumption as raw material (biofuel, compost, bioplastics, animal feed, donations, accelerating sales, platforms for the rapid sale of products about to expire);
- increasing economic competitiveness through lower production costs and commercial offers based on the real needs of the consumer market;
- determining responsible consumption, through social and financial levers (SGR system).

And, for the continuation of the research in a future paper, the remark of ICLEI (Local Governments for Sustainability) is taken into account according to which ”Linear food systems are failing people and the planet.” A circular economy in the food consumption system, at least compared to the linear one, should not be considered or appreciated as an economic degrowth because, in fact, its role is to balance, not to decrease, food consumption, accentuating the quality instead of quantity.

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FOOD CHAIN IN BULGARIA: REGIONAL DIFFERENCES, FARMERS' MARKETS AND SUSTAINABLE DEVELOPMENT

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Abstract

This study aims to assess Bulgaria's regional production capacity by analysing the influence of cultivated area size on crop and livestock yields. The methodological approach includes comparative analysis and multiple regression to model dependencies among indicators. The regional distribution of agricultural resources is used to forecast potential production quantities and their realisation at local farmers' markets. The results show apparent differences between regions and confirm that the country has significant production capacity, sufficient both to satisfy the needs of the local population and to participate in international trade. The study emphasises the importance of the regional approach in food chain planning. It offers recommendations for policies aimed at stimulating local production, strengthening farmers' markets and achieving economic and social impact through sustainable development of the agricultural sector.

Key words**:** *production capacity, food sovereignty, regional differences, food chain, sustainable development policies*

INTRODUCTION

The food supply chain in the European Union is considered a comprehensive system encompassing all stages from production, processing, distribution, and trade to consumption and food waste management. According to the European Commission (2020) [7], the food chain involves interconnected economic, social, and environmental processes that must ensure the safety, quality, sustainability, and accessibility of food for the population. Within the framework of the Farm to Fork Strategy and the Common Agricultural Policy, the EU emphasizes the importance of short food supply chains, market transparency, fair remuneration for producers, and the reduction of regional imbalances. This approach highlights the role of local producers and farmers' markets as key elements in strengthening the resilience and security of the food system.

Over the past decades, the development of the food supply chain in Bulgaria has been shaped by the intersection of regional economic characteristics, evolving agricultural production patterns, and growing public attention to sustainability. Increasing requirements for food safety and traceability, together with the need to strengthen local markets and support small-scale producers, place particular emphasis on spatial disparities in the country's agricultural potential. In this context, the analysis of production capacity becomes crucial for assessing the sustainability of the national food system. The study is justified in light of leading European priorities related to nutritional security and shared food sovereignty.

Recent studies highlight several challenges, including the decline in the number of small farms and the growing dependence on food imports in Bulgaria (Boneva, 2012; Grozdanova, 2019; Georgiev et al., 2021; Kotseva-Tikova & Mochurova, 2021; Foltz, 2025) [4, 12, 11, 17, 8]. Researchers

recommend policies aimed at integrating sustainable practices, supporting local production, reducing food waste, and addressing socio-economic inequalities (Zhelev, 2025) [26] and provide evidence that family farms constitute a sustainable model for rural development (Sarov & Tsvyatkova, 2020; Tsvyatkova, 2024) [22, 23]. Other studies demonstrate that Bulgaria has not yet achieved an effective balance between the requirements of European legislation concerning free access to agricultural land and the protection of national food sovereignty (Georgiev & Grozdanova, 2022) [10]. Furthermore, the Bulgarian economy remains strongly dependent on domestic demand and is vulnerable to external shocks (Hristozov et al., 2025) [15].

An important aspect of food sovereignty is nutritional independence (European Commission, 2020), UNICEF, 2024), Abdugani et al., 2025) [7, 24, 1]. According to the World Health Organization (UNICEF, 2024) [24], nutritional security refers to consumers' access to an adequate quantity of high-quality food that provides all essential nutrients: vitamins, minerals, proteins, fats, and carbohydrates, required for a healthy lifestyle. In Bulgaria, research has examined trends in traditional Bulgarian cuisine, which possesses a distinctive cultural character. Studies have analyzed traditional food preservation methods that do not rely on chemical additives or preservatives and that emphasize superior taste and nutritional properties. These practices highlight the importance of preserving Bulgarian culinary traditions as a national cultural asset (Bogueva et al., 2021) [3]. Also, interaction with supply chain actors, wholesalers, and technology providers contributes to more effective risk management by improving information exchange, coordination, and the ability to respond to market and operational uncertainties (Harizanova-Bartos & Stoyanova, 2023) [14]. Transformations in agriculture affect the use of natural resources and social capital and create new opportunities for added value and sustainable rural development, which are key elements of modern agri-food supply chains (Doichinova & Stoyanova, 2024) [6]. In recent years, however, a paradox has emerged: modern consumers often eat large quantities of food that are predominantly low in nutritional value instead of following a recommended balanced diet (Pocol & Mihai, 2020) [20]. The authors identify a link between culinary traditions in the studied countries (Romania, Bulgaria, and Moldova), unfavorable economic conditions, and the food consumption habits of younger populations, whose dietary behavior increasingly aligns with the global trend toward fast and inexpensive food consumption.

According to Jámbor and Varga (2024) [16], achieving long-term sustainability of food systems requires policies that combine the principles of food security and food sovereignty while taking into account the importance of local context, community participation, and sustainable resource management.

The present study defines a small farm as one with up to 2 ha of arable land. According to Eurostat (2020) [27], the size of arable land in small farms in the examined region (18,520 ha) represents 42% of the total arable land in small farms in the country (44,340 ha). Eurostat data (2020) also show that nearly two-thirds of agricultural holdings in the European Union in 2020 had less than 5 ha of land. The statistical office identifies small farms as important actors in reducing the risk of poverty in rural areas and in providing additional income and food supply.

This study examines the economic importance of small agricultural holdings across the six economic regions of Bulgaria (Northwestern, North Central, Northeastern, Southwestern, South Central, and Southeastern). The results are presented quantitatively, under equal conditions, based on the available arable land of farms and the proportional distribution of their specialization, ensuring compliance with the nutritional security guidelines of the World Health Organization. Crop and livestock yields are calculated based on production data provided by the Ministry of Agriculture and scientific research institutes in the country. The analysis aims to determine whether small farms in Bulgaria (up to 2 ha)

and registered agricultural holdings at the NUTS 2 level represent a sufficient driver for achieving nutritional security for citizens and contributing to shared food sovereignty within the European Union.

MATERIALS AND METHODS

Several analyses were conducted in this study using the following methodological approaches: comparative analysis and econometric analysis.

Comparative Analysis

The comparative analysis is a widely applied approach in economic research (Matkovski et al., 2020; Castillo-Díaz et al., 2024; Sarkar et al., 2024; Yi et al., 2024; Balan et al., 2025; Gurgu et al., 2025; Marcuta et al., 2025) [19, 5, 21, 25, 2, 13, 18].

The aim of the analysis is to compare the annually produced quantities in the economic regions of Bulgaria, under equal conditions, with the required food quantities (according to the recommendations of the World Health Organization) sufficient to feed the population for one calendar year. Data from internationally recognized sources were used, including FAOSTAT [28], Eurostat [27], National Statistical Institute of Bulgaria [29], and the Ministry of Agriculture and Food of Bulgaria [30].

Econometric analysis

In the present study, the econometric analysis methodology developed in a previous author's publication (Gandeva, 2025) [9] is adapted, in which the production potential of the South Central Region of Bulgaria was demonstrated. Prior to the calculations within the empirical framework, the statistical relationship between the dependent variable, gross domestic product at purchasing power per capita, and the explanatory variables, population size and arable land area, was established.

The adapted methodology was subsequently tested in the remaining five economic regions of Bulgaria. For the application of the econometric analysis, the following formulas were used:

Area allocated to a food group = total area × percentage allocated to the group

Food production volume = area allocated to a food group × average yield

Required food quantity = population × recommended annual per capita consumption (WHO).

RESULTS AND DISCUSSIONS

The following analysis examines the six economic regions of Bulgaria (NUTS 2) in order to identify regional differences in the structure and potential of agricultural holdings within the food supply chain.

South Central Region of Bulgaria

The tested model for the South Central Region of Bulgaria from a previous author's study (Gandeva, 2025) [9] shows that, under an optimal distribution of arable land among the main food groups (fruits, vegetables, cereals, meat, and dairy products), the quantity of food produced by small farms is sufficient to ensure sustainable and balanced nutrition for the population in the region.

The calculations performed for the remaining economic regions of Bulgaria demonstrate that small farms (up to 2 ha) do not possess sufficient production capacity to meet the nutritional requirements of the population. The registered arable land for 2024 amounts to 3,486,550 ha, while the population totals 6,437,360 people. The study was conducted under the following assumptions:

Required food quantities for the population (World Health Organization, annual per capita):

Fruits: 146 kg
Vegetables: 182.5 kg
Cereals: 65.7 kg
Meat: 58.4 kg
Dairy products: 146 kg

Average yields (Ministry of Agriculture and Food of Bulgaria, annual, per ha) [30]***:***

Fruits: 102,400 kg/ha
Vegetables: 134,400 kg/ha
Cereals: 42,080 kg/ha
Meat: 40,000 kg/ha
Dairy products: 80,000 kg/ha

Land allocation (percentage share of food groups in the WHO recommended daily diet) [31]***:***

Fruits: 24% × 3,486,550 = 836,772 ha

Vegetables: 30% × 3,486,550 = 1,045,965 ha
Cereals: 11% × 3,486,550 = 383,520.5 ha
Meat: 11% × 3,486,550 = 383,520.5 ha
Dairy products: 24% × 3,486,550 = 836,772 ha

The results of the analysis are presented as a percentage share relative to the reference value (Table 1).

The required quantity by region is taken as the baseline and is set equal to 100%. Values exceeding 100% indicate a surplus, while values below 100% reflect a deficit. The results of the study show that small farms in Bulgaria cannot independently ensure food and nutritional security for the population according to the quantitative recommendations of the World Health Organization. The only exception is the South-Central Region of Bulgaria (Table 1).

Table 1 Percentage coverage of the population's needs by food groups from small farms across the economic regions of Bulgaria

Region	Fruits (%)	Vegetables (%)	Cereals (%)	Meat (%)	Dairy (%)
Northwestern	37.2	39.0	34.0	36.4	30.9
North Central	32.4	34.2	28.2	30.5	27.3
Northeastern	31.5	33.1	27.4	29.7	27.0
Southeastern	33.4	35.1	29.2	31.8	28.7
Southwestern	37.1	38.8	31.1	33.7	30.0
South Central	99.8	104.1	103.2	110.4	93.5

Source: Author's calculations.

An additional experiment was conducted to test the production potential of all agricultural holdings at the NUTS 2 level under equal conditions. The results demonstrate that, theoretically, all regions in Bulgaria possess sufficient agricultural resources to meet the food requirements of the population (Table 2).

Table 2. Production potential of Bulgaria under the utilization of all arable land

Food group	Area (ha)	Produced (kg)	Required (kg)	Deficit/Surplus
Fruits	836,772	85,684,492,800	940,860,560	+84,743,632,240
Vegetables	1,045,965	140,627,568,000	1,175,819,320	+139,451,748,680
Cereals	383,520.5	16,139,235,040	423,060,552	+15,716,174,488
Meat	383,520.5	15,340,820,000	375,936,824	+14,964,883,176
Dairy products	836,772	66,941,760,000	940,860,560	+66,000,899,440

Source: Author's calculations.

This finding indicates that the national production potential is adequate to ensure food security, nutritional security, and food sovereignty, provided that these resources are utilized efficiently and sustainably.

Table 3. Food production in Bulgaria by food groups, 2024.

Food group	Total production (t)
Fruits	363,425
Vegetables	315,457
Cereals	11,603,710
Meat	233,670
Dairy products	793,890

Source: Based on data from FAOSTAT [28].

The study also includes a comparison between the potential production (Table 3), under equal conditions, and the actual production recorded in 2024 (Table 4).

Production data for 2024 reveal pronounced structural imbalances among the different food groups.

This production structure highlights the insufficient development of sectors that are critical for balanced nutrition and raises questions about the sustainability of the national food system.

At the same time, the significant surplus in cereal production and the high volume of dairy output reveal substantial production potential for export, which could be considered when defining the country's strategic priorities in the agri-food sector in Bulgaria.

Table 4. Comparison between produced and required food quantities for one calendar year

Food group	Produced (kg)	Required (kg)	Surplus / Deficit (kg)	Coverage (%)
Fruits	363.425,000	939,854,560	−576,429,560	38.7 %
Vegetables	315,457,000	1,174,818,200	−859,361,200	26.9 %
Cereals	11,603,710,000	422,934,552	+11,180,775,448	≈ 2,743 %
Meat	233,670,000	375,941,824	−142,271,824	62.1 %
Dairy products	793,890,000	939,854,560	−145,964,560	84.5 %

Source: Author's calculations.

Recommendations for the Development and Functioning of the Food Supply Chain in Bulgaria

The integration of regional specialization, short supply chains, and export orientation in Bulgaria is essential for the sustainable development of the food system. Policies should be directed toward increasing the competitiveness of small farms, reducing price volatility, strengthening trust among participants in the food supply chain, and integrating national production into international markets while preserving food sovereignty. This multi-level approach would contribute to balanced regional development and enhance the long-term resilience of the agricultural sector in Bulgaria.

Policies for Effective Price Stabilization

Effective price stabilization requires an integrated approach that addresses producers, market infrastructure, and the regulatory framework simultaneously.

•**Ensuring contractual stability and transparency** would contribute to encouraging long-term contracts between producers, processors, and retail chains with pre-agreed price ranges; introducing transparent mechanisms for determining purchase prices linked to production costs and market indicators; and establishing a national system for monitoring prices at different stages of the supply chain, namely production, processing, and trade.

•**The formation of cooperatives** would lead to economies of scale and a stronger bargaining position for producers. It would also support the development of joint logistics centers and cold storage facilities at the regional level (NUTS 2) in Bulgaria, thereby reducing transaction costs.

•**The implementation of risk management mechanisms** would expand access to insurance instruments against climate and market risks and support the establishment of stabilization funds for small and medium-sized farms in the event of sharp price fluctuations.

Policies for the Market Realization of Bulgarian Agricultural Products

Improving the market realization of Bulgarian products requires recognizing the importance of farmers' markets as a key element of short food supply chains and as an instrument for increasing the income of small agricultural holdings in Bulgaria.

•**Institutional and regulatory support for the establishment of farmers' markets** aimed at increasing the income of national agricultural holdings. Such support would contribute to simplifying registration procedures for direct sales from producers to final consumers; establishing a unified national standard for "local products" with clear indication of origin in addition to existing European geographical indications; and providing municipal support through the allocation of public spaces under preferential conditions.

•**Digitalization for marketing purposes**. This would support the development of a national online platform for farmers' markets with geographical localization of producers; encourage participation in short supply chains through e-commerce and subscription-based models such as Community Supported Agriculture (CSA); and promote information campaigns highlighting the benefits of consuming locally produced food.

•**Effective management of logistics and quality**. National support in this area would contribute to investments in mobile refrigeration equipment and certification according to quality and safety standards, as well as training programs related to product branding, packaging, and direct sales.

Policies for Increasing the Participation of Bulgarian Products in International Trade

•**Establishing a strategic export specialization**. Its implementation would help identify competitive niches such as organic production, the production of Bulgarian rose oil, wine, and traditional dairy and meat products. It would also support the expansion of protected geographical indications and designations of origin, as well as the development of accessible promotional campaigns aimed at increasing consumer awareness.

•**Providing support for exporters**. This includes establishing advisory centers for small producers regarding the requirements of foreign markets; implementing financial

instruments to facilitate participation in international exhibitions and trade missions; and encouraging public–private partnerships to promote the national agricultural brand of Bulgaria.

•**Increasing value added**. This involves stimulating domestic production and processing in order to export products with a higher level of processing, as well as investing in innovation, sustainable technologies, and certified organic production.

CONCLUSIONS

The present study shows that small farms, defined as holdings with up to 2 ha of arable land, do not possess sufficient production capacity to meet the food needs of the population in five of the six economic regions of Bulgaria, except for the South Central Region of Bulgaria. The analysis of the country's overall production capacity demonstrates that, under equal conditions, the available arable land is sufficient to achieve food sovereignty, nutritional security, and active participation of Bulgarian agricultural products in the European food market. At the same time, there is a need to implement policies aimed both at meeting the nutritional needs of the population and safeguarding national food sovereignty, as well as at strengthening food sectors in which Bulgaria possesses absolute or comparative advantages. In Bulgaria, the integration of regional specialization, short supply chains, and export orientation is essential for the sustainable development of the food system. Policies should focus on increasing the competitiveness of small farms, reducing price volatility, strengthening trust among participants in the food supply chain, and integrating national production into international markets while preserving food sovereignty. This multi-level approach would contribute to balanced regional development and enhance the long-term resilience of the agricultural sector in Bulgaria.

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HISTORICAL OVERVIEW OF THE BULGARIAN ROSE OIL EXPORT

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Abstract

The Bulgarian rose oil sector origins in the late medieval period, with the spread of Rosa damascena cultivation in the Rose Valley, where unique natural conditions enabled the production of high-quality oil. During the Ottoman period, rose oil production expanded and became an important export commodity, gaining recognition in international markets for its high quality. In the nineteenth and early twentieth centuries, Bulgaria emerged as a global leader in rose oil, supplying perfumers in Europe and beyond. The socialist era brought state control and industrialization of production, ensuring stability but limiting innovation. After 1989, the transition to a market economy reshaped export structures, exposing producers to global competition and price fluctuations. This paper aims to analyse the sector's evolution and exports, accordingly we used historical economic data from the Bulgarian Ministry of Agriculture and Food and other institutions. The results show that despite past and recent challenges, Bulgarian rose oil remains a symbol of national heritage and continues to be exported worldwide, preserving its status as a high-value niche product.

***Key words*:** *Bulgarian rose oil exports, Rosa damascene, Rose Valley production, Essential oil trade, agricultural heritage*

INTRODUCTION

Bulgarian rose oil is one of the most valuable natural raw materials used in the global fragrance and cosmetics industries. Extracted primarily from *Rosa damascena*, cultivated in the renowned Rose Valley (Map 1) where 70% to 85% of the world's rose oil comes from (Staikov and Zolotovich, 1957) [13].

Map 1. Map of Bulgaria: the Rose Valley
Source: Maps of the Rose Valley.

This essential oil has historically represented a key export commodity for Bulgaria and an important element of the country's agricultural and cultural identity.

Due to its distinctive chemical composition and highly prized aromatic properties, Bulgarian rose oil has long been considered a benchmark product within the international perfume industry (Ministry of Trade, Industry and Labour, 1930) [10], (Palairet,1999) [9]. Despite its global reputation and economic significance, the historical development of Bulgarian rose oil exports—particularly in relation to changing political, economic, and market conditions—has not been comprehensively synthesized in the academic literature.

The large-scale production of rose oil in Bulgaria has its roots several centuries ago, when the favourable climatic and soil conditions of central Bulgaria encouraged the expansion of rose cultivation.

By the eighteenth and nineteenth centuries, rose oil had already become an important commercial product, exported to markets across Europe and the Middle East and playing a significant role in regional economic development. The rapid expansion of the

European perfume industry during the nineteenth century, particularly in production centers such as Grasse, further increased the demand for high-quality natural aromatic substances. Owing to its distinctive fragrance and high quality, Bulgarian rose oil quickly gained international recognition, enabling the country to establish a prominent position in the global market (Foreign Trade Bulletin, 1955) [5]. Nevertheless, the development of this export sector has been closely connected with broader historical processes, including transformations in international trade networks, industrialization, and major geopolitical events such as World War II.

During the twentieth century, the structure and export patterns of the Bulgarian rose oil industry were strongly influenced by political and economic changes. Following World War II, the establishment of a socialist economic system led to the centralization of production and foreign trade under state administration. In this period, export activities were managed through governmental institutions, ensuring relatively stable production levels and organized trade relations, particularly with countries belonging to the socialist bloc, while maintaining limited commercial links with Western perfume companies. After the political and economic transition of 1989, the sector experienced profound restructuring characterized by privatization, market liberalization, and the emergence of numerous private distillation enterprises. At the same time, increasing competition from other rose oil–producing countries, notably Turkey and Iran, began to challenge Bulgaria's historically strong position in the international market.

Although many studies have addressed specific aspects of Bulgarian rose oil, such as its chemical composition, cultivation practices, or current economic importance, basically any study provides a comprehensive historical analysis of the evolution of its export dynamics over time. Much of the existing literature focuses either on agronomic aspects or on contemporary market conditions (Dorev, 1937 [3], Georgiev, 1928 [6], Irinchev, 1964 [7], Smart consulting group, 2007 [12], leaving a gap in the systematic examination of long-term export trends and the historical factors that have shaped them. Moreover, earlier research rarely integrates historical trade analysis with an assessment of the institutional and geopolitical influences that have affected the development of the sector.

This study seeks to address this gap by presenting a historical overview of Bulgarian rose oil exports, tracing their evolution from the early expansion of commercial rose cultivation to their position in today's global market. The research brings together dispersed historical, economic, and trade-related information in order to construct a coherent account of how Bulgarian rose oil exports have developed under different political and economic circumstances. By situating the sector within broader historical transformations—including industrialization, centrally planned economic systems, and post-socialist market reforms—the study contributes to a deeper understanding of how traditional agricultural products maintain their international competitiveness over extended periods.

The relevance of this research extends beyond documenting the historical trajectory of one of Bulgaria's most emblematic export commodities. It also contributes to wider debates in economic history, agricultural history, and the study of global commodity chains. Through the examination of the historical development of Bulgarian rose oil exports, the study provides insights into the interaction between local agricultural traditions and global market forces, illustrating how culturally rooted agricultural products can adapt to changing economic environments while preserving their distinctive identity and international value.

MATERIALS AND METHODS

This study is based on the analysis of historical statistical data and documentary sources concerning the export of rose oil from Bulgaria. The research combines quantitative data from historical trade statistics, national statistical yearbooks, and agricultural reports with qualitative information obtained from

historical and economic literature related to the rose oil industry in the Rose Valley. Namely, historical data on quantities and value come from the First Bulgarian Conference of Rose Producers, 1906 [4] for the period 1885–1905; Statistical data from rose oil manufacturers and exporters, Shipkov, 1937 (1906-1930) [11]; Statistical Yearbook of the Kingdom of Bulgaria 1939 (1931-1939) [14]; Statistical Yearbook of the Central Directorate of Sofia, 1956 (1952-1956) [15]; Bulletin of the Bulgarian National Association of Essential Oils, Perfumery and Cosmetics (several years) [2]. The compiled dataset includes export quantities and values for different historical periods, allowing the identification of long-term trends in the international trade of Bulgarian rose oil. Descriptive statistical methods, including trend analysis and comparative period analysis, were applied in order to examine changes in export volumes and market dynamics over time.

The collection of consistent time-series data presents several methodological difficulties. Historical records are fragmented across different sources and institutions, and statistical reporting methods have changed considerably over time. In many cases, early trade statistics are quite deficient. In addition, gaps in the statistical series occur due to political and economic disruptions, changes in administrative structures, and differences in classification systems used in international trade statistics. These factors required careful verification and harmonization of the available data in order to ensure comparability across periods. Consequently, the resulting time series should be interpreted with caution, as certain inconsistencies and discontinuities remain unavoidable. Despite these limitations, the assembled dataset provides a sufficiently reliable basis for identifying the major historical patterns and transformations in Bulgarian rose oil exports.

RESULTS AND DISCUSSIONS

Background of Bulgarian rose oil commerce

The beginning of trade in rose products in Bulgaria is linked to the Turkish feudal empire in the 16th-17th centuries. The State's interest at that time was limited and was expressed through the collection of revenue from the sale of licences to trade in these products and from customs duties. Trade was carried out by small merchants and craftsmen, who were mainly subjugated people as Greeks, Armenians, Bulgarians, Lebanese, Syrians, etc.

Within the Empire, Bulgarian rose oil was sold in small quantities at fairs, where it competed for its high quality with rose oils from Egypt, India, etc.

The Turkish Empire initially traded rose oil internationally mainly with France through the port of Marseille, near the processing centre in the city of Grasse. Later, rose oil was exported from the city of Trieste via the Danube to the Austro-Hungarian Empire, from Liverpool and London to England, from Odessa to Russia and from New York to America. With the increase in trade relations at the end of the 18th century and the beginning of the 19th century, twenty-five countries established trade offices in the Turkish Empire, mainly in Istanbul and Odrina, which popularised the high quality of Bulgarian rose oil. Some travellers through Bulgarian lands also contributed to its popularity in Europe (Bulgarian National Association: Essential Oils, Perfumery and Cosmetics) [2].

In addition, some of the new local merchants also contributed to the increase in trade, establishing commercial offices in the capitals of a large number of countries.

The rose oil trade required special packaging. Rose water was transported to markets mainly in wineskins, later in wooden containers, and in recent times in iron barrels.

The requirements for the transport and sale of rose oil were much more demanding, as it was hundreds of times more expensive. Flasks were created and used for its transport and measurement. Flask traditionally called “muskal” is an Arabic unit of measurement. It refers to a glass flask filled with rose oil, which weighed 4,810 grams and was worth the equivalent of 24-carat gold or more.

Flasks came in different shapes and designs. To prevent them from breaking, they were

placed in small wooden bottles, which were introduced in 1870 according to the Bulgarian National Association of Essential Oils, Perfumery and Cosmetics [2].

When the oil was intended for longer transport within the Ottoman Empire or for export, flasks were placed in airtight tins lined with a woollen cloth specially prepared for this purpose (Fig. 1).

Fig.1. Flasks with Bulgarian Rose Oil
Source: [2]

For longer transport during the 19th century, flasks weighing up to 5 kgs were used.

The flasks were placed in special wooden boxes.

Rose oil was transported from the collection point (mainly Kazanlak) to its destination: Constantinople, Odrina, Burgas, Ruse, etc using the merchants' own vehicles, accompanied by an armed guard.

The main export centre for rose oil was Constantinople, while the main warehouse and market for oil produced in Bulgaria was Odrina. Odrina's market was preferred because, in 1860, it already had a well-equipped chemical laboratory that provided a certain degree of protection against the purchase of fake oils. German buyers, for example, who went directly to Odrina, avoided the competition from the commercial offices in Constantinople, which bought oil in any condition and at a lower price. The product was packed in wooden boxes and shipped to Trieste by the Austrian shipping company Lloyd's.

After the fall of Constantinople as an export centre for Bulgaria in September 1886, rose merchants moved their offices to Sofia.

The central oil warehouse was also moved from Odrina to Kazanlak and Karlovo. The rose oil trade in newly liberated Bulgaria continued with more or less the same organisation. In 1879, the first year after liberation, licences to trade in rose oil were decided upon by the relevant town councils in exchange for a payment.

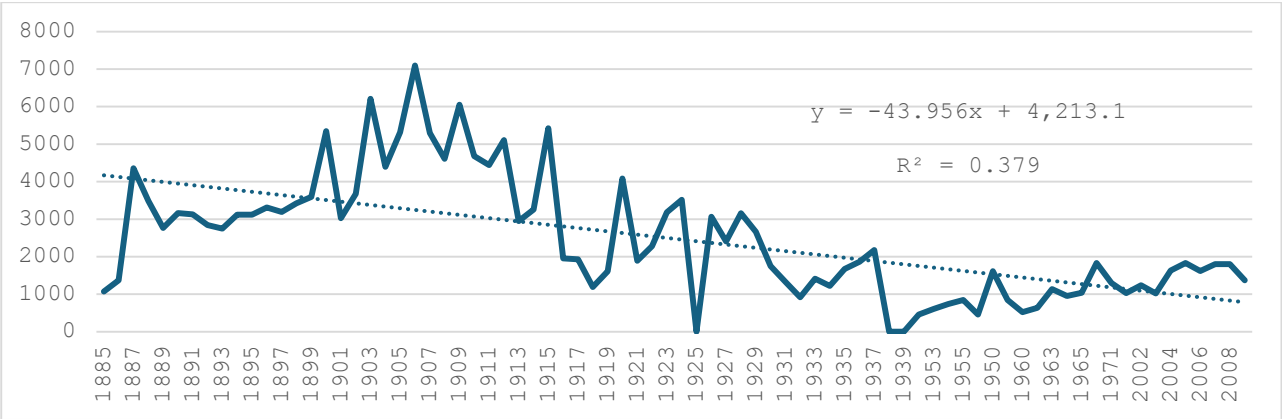

Fig. 2. Quantity of Bulgarian Rose Oil Export (kgs)
Source: First Bulgarian Conference of Rose Producers, Plovdiv, 1906, for the period 1885–1905 [4]; Statistical data from rose oil manufacturers and exporters, Shipkov, 1937 (1906-1930) [11]; Statistical Yearbook of the Kingdom of Bulgaria, Sofia, 1939 (1931-1939) [14]; Statistical Yearbook of the Central Directorate of Sofia, 1956 (1952-1971) [15], Ministry of Agriculture and Food, Bulgaria (2009) Program for the development of aromatic and medicinal plants in Bulgaria for the period (2009-2013) [8], Smart consulting group Analysis of the cultivation of oil bearing roses and rose oil production in Bulgaria, Sofia, p. 28 (2007) [12], Bulletin of the Bulgarian National Association of Essential Oils, Perfumery and Cosmetics (2024) [2], (All in Bulgarian)

Until 1905, the price was determined by the price of flask. From that year onwards, the price of rose flowers began to be decisive in relations between rose producers and traders,

and in international trade, the price of rose oil, the flask, was changed to per kg.

During 1885–1900 there was an expansion phase with average export volume of 3,080 kg.

This period shows relatively strong export performance with steady growth (Fig. 2).

The descriptive statistics for a period of 74 years is presented in Table 1.

Table 1. Descriptive Statistics
Number of observations: 74 years

Indicator	Value
Mean export volume	≈ 2,580 kg
Median	≈ 2,640 kg
Minimum	456 kg (1952)
Maximum	7,098 kg (1906)
Range	6,642 kg
Standard deviation	≈ 1,620 kg
Coefficient of variation	= 63%

Source: Authors' findings.
Note.Coefficient of variation= 1620/2580 X 100= 63%

The expansion corresponds to increasing demand from the European perfume industry, particularly from centres such as Grasse. The following period 1901–1914 there was a peak and the Average export volume was 4,790 kg

This was the most productive period in the period analysed. Exports frequently exceeded 5 tons annually indicating strong global demand for Bulgarian Rose oil.

During 1915–1919, there was a War disruption and the average export was about 2,420 kg, the exports fell during the years of World War I and we observe the lowest point of the period in 1918 which was 1,191 kg. Trade disruptions and economic instability reduced export capacity.

During the recovery period 1920–1929, the average export volume was around 2,900 kg. Exports recovered moderately during the interwar period but did not reach the high levels of the early 1900s. This period reflects the stabilization of international trade networks. During the Global Economic Crisis 1930–1939 the average export was 1,870 kg, so export declined significantly during the Great Depression. The lowest export was in 1932 with 917 kg. Demand for luxury products such as natural perfume ingredients decreased sharply. Throughout the socialist era, precisely 950–1971, the average export volume continued to be low 900–1,200 kg. Although, exports remained relatively low they were stable during the centrally planned economy following World War II. Production and trade were managed through state-controlled institutions. Over the modern market period 2001–2023 the average export increased to approximately 1,540 kg. Exports stabilized around 1–2 tons annually, reflecting the high value and limited supply of rose oil. Despite competition from producers such as Turkey and Iran, Bulgaria maintains an important role in the global market.

If we focus on the long-term growth rate, the first observation is in 1885 with 1,070 kg and the last observation in 2023 with 1,370 kg.

The growth rate for the whole period observed = (1,370−1,070)/1,070×100=28%.

Therefore, exports increased about 28% over the entire observed historical period, although with strong fluctuations.

The 63% coefficient of variation indicates high volatility, largely due to agricultural yield variability, global economic crises, changes in production systems and geopolitical disruptions.

The statistical analysis highlights several structural characteristics of Bulgarian rose oil as exports peaked during the early twentieth century, especially between 1900 and 1914. Then, global conflicts and economic crises significantly reduced export levels. However, after World War II, exports stabilized at lower, but consistent levels. In the modern period, exports remain relatively lower, but represent high-value trade in the global perfume industry.

Main international customers

Until the 1840s, rose oil exports were mainly directed towards France, England, Germany, the United States, Austria-Hungary, Holland, Sweden, Switzerland, Italy, Belgium, Russia, Egypt and Ethiopia, among others. Between 1845 and 1869, France purchased approximately 13 tonnes of rose oil. The average annual export to this country was 505 kgs. Exports to England during the period 1857-1859 amounted to 1,453 kgs and during the period 1863-1867 to 2,104 kgs, meaning

that approximately 450 kgs of rose oil were exported to England each year.

The total amount of rose oil exported during the various years leading up to liberation was 1,443 kgs in 1849, 960 kgs in 1862, and 3,364 kgs in 1866. The average annual export during the period 1872–1882 was 1,513 kgs.

In summary, export quantities were relatively stable around 2,500–3,500 kg for most years. The highest production/export peak occurred in 1906. A strong decline occurred during 1916–1918, reflecting economic disruption associated with World War I and the lowest values appear after World War II, particularly in 1952, indicating structural changes in the industry.

In addition to the rose oil, Bulgaria exported rose water and rose essence to the international market. Between 1885 and 1912, it exported 639,816 kgs of rose water worth 585,592 leva. The average amount exported was approximately 60 tonnes.

In the following years, the amount of rose water Exports declined, so the average annual export volume for the period 1926–1935 was 15 tonnes.

Concrete rose essence, which has been produced since 1906, established itself on the foreign market quite late.

During the period 1926-1940, a total of 8,648 kgs were exported, with a value of 157,424,570 leva. In 1937 were exported 1,673 kgs, the maximum amount of rose concrete essence.

After 1944, Bulgaria exported between 500 and 2,000 kgs of rose oil annually, 507 kgs in 1947, 2,089 kgs in 1949 and 1,614 kgs in 1950.

During these years, in addition to the countries mentioned above that purchased Bulgarian rose oil, Bulgaria also exported rose oil and rose concrete essence to the former USSR, the German Democratic Republic, Poland, the Czech Republic, etc. (Table 2).

In the years after 1945, exports of rose oil and rose products declined significantly (Fig.2) due to a decrease in production.

Table 2. Rose oil exports in some countries during the period 1950–1965 (kgs)

Year	UK	East Germany	USA	USSR	France
1950	139	25	10	1.211	145
1955	59	77	53	150	387
1960	34	50	50		259
1962	61		90		291
1963	90	50	179	350	283
1964	99	90	196	50	299
1965	116	91	247	100	254

Source: Statistical Yearbook of the Central Directorate of Sofia, 1956 (1950-1965) [15].

Regardless of the incomplete data on rose oil, rose concrete essence and rose water in some years, especially from 1965 onwards, the data shows that to meet global consumption demand for approximately 200 years, Bulgaria had exported more than 300 tonnes of rose oil and rose concrete essence and more than 10,000 tonnes of rose water.

Bulgaria held an almost monopolistic position in the production of rose oil, largely due to the exceptionally favourable climatic and soil conditions found in the Rose Valley. These natural advantages supported the cultivation of the Rosa damascena, a variety known for its particularly high oil yield compared with other rose strains (Palairet (1999) [9].

During the socialist period, Bulgaria's exports met approximately 30% of global consumption of rose oil and approximately 14% of rose concrete essence.

In the period 1990-1995, Bulgaria met 50% of global consumption of rose oil. From 1995 onwards, this percentage declined, reaching 40% in 2001.

However, from 1995 onwards, around 700-800 kgs were produced annually, and the difference between this and the quantities exported was covered by reserves from previous years. Before 1989, there was a very large state reserve of rose oil, which was depleted in subsequent years. Unfortunately, production has been declining every year since the end of the last century, and in 2001 only 700 kgs were produced.

Due to the high quality of Bulgarian rose oil, its price on the international market has approached the price of gold, hence its popular name ‘liquid gold’.

International price of Bulgarian rose oil and gold is comparatively shown in Table 3.

Table 3. Price of 1 kg of rose oil versus gold in lev

Year	Price of Bulgarian rose oil	Price of gold	Rose oil price in proportion of the gold
1933	37,000	92,000	40%
1943	66,800	138,000	48%
1966	1,500	1,200	125%

Table 4. Export and import of essential oils, rose concrete essence, rose absolute essence, and resinoids in 1997

Exports	Kgs	Value (USD)	Mean price USD/kg
Rose oil	981	3,143,557	3,204.44
Absolut rose essense	93	100,737	1,083
Concrete rose essense	1,614	738,421	457.510

Source: Bulletin of the Bulgarian National Association of Essential Oils, Perfumery and Cosmetics [2].

Quality

In order to exercise effective control and preserve the high quality of Bulgarian rose oil, as well as to prevent attempts to counterfeit it with oil produced in Turkey from the geranium plant, the National Laboratory was established in 1934, later renamed 'Bulgarian Rose' - Sofia.

There is a huge safe in its basement where rose oil intended for export is stored. The temperature there must not exceed 12º, so that the oil does not become resinous. As it is very aggressive towards metals, it must be stored in glass containers from the French company 'Pirex'.

The oil is shipped around the world in special tins ranging from 100 grams to 5 kgs. They are sealed with the original 1934 stamp, which is unique, and accompanied by the mandatory quality certificate signed by the laboratory director.

It is difficult to counterfeit even a small amount of this unique product, as in the narrow international market a report is made for the supply and purchase of each kg. Before fulfilling each order, the customer receives a sample, accompanied by the aforementioned certificate. Each kg of rose oil intended for export is accompanied by the mandatory protocols for quality control and all other documents necessary for the customer and customs officials.

The national laboratory 'Bulgarska rosa', SL., Sofia currently includes in its activities the development, research and standardisation of extractive products from essential oil-bearing and medicinal plants.

This is where the secondary processing of rose oil takes place. The work begins with a chemical analysis of each sealed container from the distilleries in Plovdiv, Karlovo and Kazanlak. After the analysis, the laboratory director conducts a study and makes recommendations for blending oils from different regions and years, as each year's harvest has different nuances, so the blending proportions are different. The aim is for the blend to contain the best of Bulgarian rose oil regardless of the different harvests; it must have the same aroma and quality.

According to the National Standardisation Company, Bulgarian rose oil must meet the specifications presented in Table 5.

Table 5. Quality specification

External appearance	**transparent oily liquid or heterogeneous mass below 23ºC**
Colour	yellow, yellow-green
Smell	characteristic of Bulgarian rose oil
Freezing point (ºC)	from 16.5 to 23
Acidity number (mg/1g oil)	no more than 3.75
Ether number (mg/1 g oil)	from 7.3 to 17.1
Acetyl number	from 202.6 to 244.8
Free alcohols such as geraniol (%)	from 26.9 to 35.5
Dissolved alcohols such as geraniol (%)	from 2.0 to 4.7
Total alcohols such as geraniol (%)	from 64.9 to 80.2
Micro component content (%):	
Citronellol	from 17.0 to 37.0
Geranium	from 12.0 to 37.0
Nerole	from 5.0 to 16.0
Normal paraffin carbons (Cl 7,C19,C20,C21,C23)	from 14.0 to 33.0

Source: Bulgarian National Standardisation Organisation Certificate [1].

An important fact is that the etheric oil and perfume-cosmetics industry was one of the first to adopt European cosmetics legislation Directive 76/768 EEC/ Regulation No. 26 of 6 July 2001 of the Ministry of Health. Now the main objective is to implement the EU

requirements and harmonised Bulgarian legislation at a regional level in SMEs. For instance, at the beginning of 2000, five SMEs were certified with the ISO 9000 standard, and thirty-one were in the process of preparing the procedures. The goal was that by 2003, 46.5% of producers of essential oils, perfumery and cosmetics would be certified under ISO 9000 in order to improve the competitiveness of Bulgarian producers.

In 2014 Bulgarian rose oil was registered in the European Union as Protected Geographical Indication.

Competitive advantage

With their strong culture and traditions, Bulgaria's essential oils, perfume and cosmetics industry has been recognised as a cluster where the Bulgarian economy has a significant competitive advantage. Bulgarian rose oil has set a global standard, being the only basis for luxury perfumery production in the world with essential oils that are the basis of these products. In the early 2000s, Bulgarian essential oil products were exported worth about 180 million euros to 65 countries in Europe, North America, Russia and other markets. Exports of essential oils, the perfume and cosmetics industry represent 8.2% of Bulgaria's total exports and as such the industry is one of the three priority sectors in Bulgaria's export-oriented economy.

Located mainly in the central-southern region of Bulgaria, the essential oils, perfume and cosmetics industry and in the late 1990s was a key regional employer, hiring some 150,000 people in 160 SMEs, largely micro-enterprises, in a region with a significant ethnic minority and high unemployment. However, due to the historical nature of the industry, traditionally based on family SMEs, the effects of the transition, especially land reform and restitution, together with the requirements of EU directives, meant that the cluster faced a number of challenges.

In the years immediately following the transition, the effects of land reform and restitution meant that the area under oil rose production was reduced from 2,500 hectares to 1,100 hectares, and, for comparison, lavender land from 4,200 hectares to 2,000 hectares. As a result, rose oil production fell by half and lavender oil production fell by four times. However, since 1997 this trend has changed, with production in 2000 growing by 19.5% compared to 1999. This is due to the emergence of a large number of companies and small farms, which in turn provide them with a good level of income. A family that planted 0.5 hectares of roses earns a net income of €1,000. Planting and regeneration continued, and by 2002, an additional 400 hectares of roses and 600 hectares of lavender had been planted. However, the resurgence, growth and development of the essential oils, perfumery and cosmetics sector has been hampered by the requirement that the production and processing of raw materials comply with the international quality control standards and directives mentioned above. The Ministry of Health, other relevant ministries and the Council of Ministers harmonised Bulgarian laws with EU legislation on the cosmetics industry so that EU directives and standards on quality were applied in practice through intensive training and modernisation of production in the sector.

The achievement of these standards and directives is accentuated by the problems of ensuring appropriate quality control at every level, which has been achieved and maintained by micro-SME producers and in processing activities. The achievement of these standards and directives is essential if Bulgaria is to retain its prominent position in the industry and its competitive advantage.

The sector includes 73 rose-processing enterprises, primarily located in the cities of Sofia, Stara Zagora, and Plovdiv.

According to the Bulgarian Chamber of Commerce, actually a total of 53 distilleries operate in the country, with a combined annual processing capacity exceeding 15,000 tons of oil-bearing roses. The cultivation of oil-bearing roses is carried out by nearly 3,000 growers across 17 administrative regions of Bulgaria, with production concentrated mainly in the regions of Plovdiv, Stara Zagora, and Pazardzhik. In 2024, Bulgaria has exported approximately 1,3 tonnes of rose oil to more than 30 countries worldwide. The main export destinations include the United States, China, Australia, Japan, India, and the

United Kingdom, with export prices ranging between 9,500 and 16,050 US dollars per kg.

Table 6. SWOT Analysis

Strengths	**Weaknesses**	**Opportunities**	**Threats**
• Unique climatic and soil conditions in the Rose Valley favourable for cultivating *Rosa damascena*.	• High dependence on climatic conditions and agricultural yields.	• Growing global demand for natural ingredients in the perfume and cosmetics industries.	• Increasing competition from other producing countries such as Turkey and Iran.
• Long-standing tradition of rose cultivation and distillation techniques.	• Labor-intensive production process requiring large quantities of rose petals.	• Expansion of international perfume markets, historically linked to centres such as Grasse.	• Price volatility and demand fluctuations in international markets.
• Unique product. Strong international reputation for high-quality rose oil.	• Limited production scale compared with global demand for essential oils.	• Increasing consumer preference for natural and organic aromatic products.	• Historical disruptions caused by geopolitical events such as World War II.
• Cultural heritage and accumulated local knowledge supporting product quality.	• Structural changes and institutional instability during political and economic transitions.	• Development of geographical indication protections and national branding strategies.	• Emerging challenges such as climate change and rural depopulation affecting agricultural production.
• Very high share at the international market.	• Bureaucracy.	• Weak competition.	• Loss of its position at the international market.

Source: Authors' findings.

CONCLUSIONS

The historical development of Bulgarian rose oil exports demonstrates the long-term economic and cultural importance of this product for Bulgaria, where the cultivation of *Rosa damascena* and the production of rose oil became a distinctive agricultural specialization closely connected with the region of the Rose Valley.

The research confirms that the emergence of Bulgarian rose oil as a major export commodity was closely linked to favourable natural conditions, the development of traditional distillation techniques, and the expansion of international trade networks during the eighteenth and nineteenth centuries, when Bulgarian rose oil gained a strong international reputation.

The analysis shows that during the twentieth century the export structure of Bulgarian rose oil was significantly influenced by political and economic transformations, particularly the centralized organization of production and trade during the socialist period following World War II, which ensured relatively stable production and the preservation of traditional cultivation practices.

The political and economic transition after 1989 led to major structural changes in the sector, including privatization, the emergence of new distillation enterprises, and the integration of Bulgarian producers into competitive global markets characterized by growing participation from countries such as Turkey and Iran.

Despite increased international competition and market fluctuations, Bulgarian rose oil has maintained its position as a high-quality natural aromatic product due to its distinctive chemical composition, traditional production methods, and strong historical reputation in the international fragrance and cosmetics industries.

The historical overview highlights that the long-term success of Bulgarian rose oil exports has depended on the interaction between natural resources, accumulated local know-how, institutional frameworks, and evolving global demand for natural aromatic materials.

The research contributes to the broader scientific understanding of how traditional agricultural products can preserve international market relevance over centuries while adapting to major economic, political, and technological changes.

The findings emphasize the importance of preserving traditional cultivation areas, production know-how, and product authenticity in order to sustain the global competitiveness and cultural significance of Bulgarian rose oil in the future.

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STATUS AND TRENDS IN AGRICULTURAL LAND USE IN BULGARIA

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Abstract

Agricultural land is a fundamental and irreplaceable natural resource that underpins national food security and the economic stability of rural areas. The purpose of this article is to analyze the status and trends of employment and use of agricultural land in Bulgaria for the period 2021-2025 to achieve a more balanced and sustainable use of agricultural territories, outlining the use of ecological agricultural practices that are environmentally friendly. The dynamics of land management are monitored, analyzing changes in land use and their regional specificity. To achieve the set goal, an important group of indicators are considered - functional land use; employment and composition of the production structure of main agricultural crops; arable land, used agricultural area, area with agricultural purpose in the national and regional plan, plant protection measures carried out and fertilized areas, outlining possible directions in the use of agricultural land. The study found that Northern Bulgaria retains its role as a major agricultural production center, while in the southern parts of the country intensive processes of fragmentation and abandonment of agricultural areas are taking place. The technological analysis reveals a dominant use of nitrogen fertilizers and herbicides in cereal crops, against the background of a drastic decline in the use of phosphorus and potassium fertilizers. The need for balanced land management policies is emphasized, which would stimulate environmentally friendly practices and prevent further abandonment of agricultural territories.

Key words**:** *agricultural land, land use, trends, indicators, statistical regions*

INTRODUCTION

The importance of agriculture for the national economy is determined by its contribution to food security and its ability to generate additional income for a large part of the population in the rural areas of the country, establishing it as a primary source of raw materials for industry. The implementation of agricultural production is a natural basis for the development of human society based on the rational use of the most important natural resource - land. The Law on the Ownership and Use of Agricultural Land (LAOAL) [7] is the main normative document that regulates the status, acquisition, management and use of agricultural land in Bulgaria. According to it, in Art.2, para. 1, para. 2, para. 3 and para. 4 it is clearly defined which lands are designated as agricultural – these are properties intended for agricultural production, which are not in the forest fund, are not built up and are not included in the construction boundaries of settlements. The law regulates the process of restoring the right of ownership, regulates the conclusion of agreements for land consolidation, the formation of land use areas and determines the purpose of the land for agricultural production. It is the legal framework that turns agricultural land into regulated property with specific rules for ownership and use (Law on the ownership and use of agricultural lands, last amended, SG No. 70/20.08.2024.) [7].

Article 2, paragraphs 1 and 2 of the Agricultural Land Protection Act state that they are a fundamental national asset and are used only for agricultural purposes related to the production of crop production and grazing of farm animals in such a way as not to impair the quality of soil fertility (Law on the Protection of Agricultural Lands, last amended SG No. 95/07.11.2025) [8].

Although agricultural lands are primarily governed by the Agricultural Land Protection Act (ALPA), the relationship between the Spatial Planning Act (SPLA) [5] and land is fundamental, because this law regulates their

transformation and development. According to Art. 7, para. 1 and para. 2 of the ZUT, the territory of the country is divided into different types according to their purpose, with agricultural lands being one of these main categories. It defines the boundaries and fixes which zones are "agricultural" and which are "urbanized" (populated areas) through the General Development Plans (GDP) (Law on Spatial Planning, last amended SG No. 87/17.10.2025) [5].

Agricultural land is the main means of carrying out any agricultural production. Agriculture is one of the main branches of material production. Land is characterized by a number of features. It is a natural basis for any production, and its territory is a personal and national wealth. The land does not wear out, because it was not created by human labor. As the most important irreplaceable resource, it is unique in its universality, characterized by its immobility, limited in size and possesses the most valuable property - fertility.

In this context, ***the main objective of the publication*** is to analyze the status and trends of employment and use of agricultural land in Bulgaria for the period 2021-2025 to achieve a more balanced and sustainable use of agricultural territories, by outlining the use of some ecological agricultural practices that are environmentally friendly. Based on the data provided by the Ministry of Agriculture and Food, a comparative national and regional analysis by year of key economic indicators is made, revealing the significance and potential for development of the agricultural sector.

To achieve the goal, the following ***research tasks*** have been set:

- a literature review of the existing theoretical statements and scientific publications related to the use of agricultural land in Bulgaria has been carried out.
- analysis of the status and monitoring of trends in the employment and use of agricultural land, by examining specific indicators characterizing the sector.
- outlining the impact of the carried out plant protection measures and fertilized areas on the environment.
- deriving generalizations and guidelines from the conducted research for a more balanced and sustainable management of agricultural territories.

The topic of agricultural land is the subject of attention of many Bulgarian authors. For example, Petrova in her publication examines the multifunctional role of land as an economic category representing an object of land relations. In the conditions of a market economy, land is an object of purchase and sale, which is sought, offered, brings real additional income and has a market price. According to it, land is a public asset that belongs to the present and future generations of a given country, who must strive for its ecological use and preservation of its condition as a natural resource (Petrova, 2017) [14].

In his publication, Kirechev analyzes the state and trends in the use of agricultural land, focusing on the improvement of agricultural territories at the national and regional levels. Clarifying the specific characteristics of agricultural land and regulating land relations are fundamental prerequisites for ensuring sustainable and balanced development of national agriculture (Kirechev, 2019) [3].

Another author examines the transformations in agricultural land use resulting from the complex impact of urbanization, land redistribution, and varietal structure dynamics. These processes require continuous monitoring and timely adaptation of the agricultural sector to ensure its long-term economic sustainability (Dimanov, 2023) [2].

The analysis of Bulgarian agriculture and its development in the context of global transformation towards sustainability is emerging as a priority and undoubtedly topical topic (Nikolova, 2021) [12]. The transformation of ownership and new economic realities raise serious questions about the effective use of land. Digitalization in land resource management is emerging as a prerequisite for modernization of the sector. Such an innovative administration would serve as a barrier against the degradation of the social and demographic structure in rural areas (Nikolova & Chernaeva, 2025) [13].

Stoyanov in his scientific publication points out that sustainable land use is a strategic management of soil resources that preserves their productivity for future generations, while maintaining the health of ecosystems. It unites ecological, economic and social priorities in a unified approach to reduce degradation, protect biodiversity and support natural ecological processes. Rational land use is the basis for the conservation of resources and guarantees sustainable economic growth of agricultural territories in the long term (Stoyanov, 2025) [18].

Agricultural land and water resources are the basis of agricultural production. That is why the way they are managed directly affects the stability and future development of the entire sector. Asenov analyzes the influence of the eurozone on the agricultural land market in the member states, and through an integrated approach predicts trends in the price of Bulgarian land. His main goal is to clarify how the transition to the single currency transforms the dynamics of the value of this asset (Asenov, 2025) [1].

Agricultural land is establishing itself as a sustainable asset for long-term investment. It forms its value based on two main factors: the expected profitability from its exploitation (fertility and productivity) and its demand as an object of speculative investment (Reydon, 2014) [17]. Therefore, the purchase of land is not dictated only by the possibility of profit, but also as a strategic means of protecting savings from rising inflation.

As a priceless asset, agricultural land occupies a central place in every business unit and every Bulgarian household. Tracking the dynamics of its market value provides the necessary information base for effective management planning. Ultimately, rational land management is what guarantees the economic growth and stability of every agricultural holding in the sector (Nikolova, 2019) [11].

Land use serves a variety of purposes, from urban planning and economic development to agricultural production, recreation, and tourism. Through the use of land, people inevitably change its character and purpose. This is observed both in the expansion of urban areas and infrastructure, and in the processes of abandonment of agricultural lands or changes in forest ecosystems (Popescu et al., 2025) [16].

In another scientific publication, a team of authors analyzes the efficiency of agricultural land use by applying a methodology of key indicators with priority on the volume of production and the generated gross value added per unit of area. Optimizing these indicators is fundamental for increasing the competitive advantages of the agricultural sector and for refining its production structure (Popescu et al., 2019) [15].

Based on the literature sources and scientific publications on the proposed topic, we can summarize that the use of agricultural land as an irreplaceable and limited natural resource is the basis of national food security and is of key importance in ensuring the economic sustainability of agricultural holdings. Land is the most valuable capital and is established as a low-risk asset for long-term investments, because it guarantees not only our biological existence, but at the same time also shapes the socio-economic and cultural image of each country.

MATERIALS AND METHODS

The scientific article focuses on studying trends in agricultural land use in Bulgaria for the period 2021-2025. For the purposes of the study, a number of key indicators are analyzed, such as functional land use, employment and composition of the production structure of main agricultural crops, dynamics in the distribution of arable land, utilized agricultural area and area with agricultural purpose at the national and regional level, expressed in hectares. The plant protection measures carried out on the main agricultural crops - wheat, barley, corn for grain, rapeseed and sunflower on areas treated with various types of pesticides, such as herbicides, insecticides and fungicides, are monitored based on a survey conducted by the Ministry of Agriculture and Food (MAF) "Yields of field crops - harvests `2020-2024" [9], expressed in percentage. The analysis also continues with fertilized areas of the same

main agricultural crops with nitrogen, phosphorus, potassium and combined fertilizers - harvests `2020-2024, expressed in percentage.

Within the framework of this study, various methods are applied, which include synthesis, induction, comparative and logical analysis of empirical data from official sources, tabular and graphical presentation of the current state and trends. The main source of data is publicly available information from the Agrostatistics Department, final results on employment and use of the territory of Bulgaria (BANSIC) of the Ministry of Agriculture and Food for the period 2021-2025 [9] and the author's own calculations.

RESULTS AND DISCUSSIONS

Dynamics of agricultural land use in Bulgaria

According to the latest data of the National Statistical Institute, the balance of the territory of the Republic of Bulgaria as of 31.12.2024 is 110,996.76 km^2. According to the intended use of the land properties, the largest area is occupied by agricultural territories - 54.5%, and forest territories - 33.3% of the total area of the country, while urbanized territories predominate, covering nearly 5,299.48 km^2, or 4.8% of the country's territory. Measured agricultural areas cover 60,489.70 km^2 or 6,048,969.80 ha (National Statistical Institute https://www.nsi.bg/en/statistical-data/45/166) [10].

To achieve the set goal, we will examine the most important indicators characterizing the use of agricultural land, outlining the current state and trends in employment and agricultural land use in Bulgaria for the period 2021-2025. We will use a BANSIK-type sample survey. The Bulgarian Agricultural and Economic Survey (BANSIK) is annual and this makes it possible to track changes in employment on the territory of Bulgaria over the years. Table 1 presents current statistical data on the functional use of land in Bulgaria for the period 2021–2025 (Ministry of Agriculture and Food, Department of Agrostatistics (BANSIC) , 2021-2025) [9].

Table 1. Functional land use in Bulgaria for the period 2021-2025, (ha)

Name	2021	2022	2023	2024	2025	Percentage change 2025/2021
Mining and landfills	32,383	32,480	32,684	32,678	31,578	-2.49
Agriculture and fisheries	5,623,252	5,603,153	5,592,336	5,602,166	5,327,329	-5.26
Forestry and environmental protection	3,870,869	3,873,815	3,880,861	3,881,152	4,081,668	5.45
Industry, energy production and trade	68,247	69,035	69,627	69,924	74,355	8.95
Networks (navigation, road, air, etc.)	152,533	151,815	152,121	152,479	144,988	-4.95
Administration and local government	24,041	22,145	22,042	22,041	21,055	-12.42
Army	47,154	47,055	47,157	47,160	36,416	-22.77
Education, culture and places of worship	8,293	8,293	8,394	8,395	8,492	2.40
Health and social centers, sports and entertainment	45,334	45,431	45,323	45,397	47,186	4.09
Individual and collective housing	268,203	268,312	267,709	267,206	263,872	-1.61
Not used or temporarily not used, have no special purpose	959,883	978,656	981,937	971,592	1,063,251	10.77

Source: based on data from the Department of Agrostatistics (BANSIC), Ministry of Agriculture and Food [9] and own calculations.

For the indicated period, it is evident that there are two dominant categories that occupy the majority of the country's territory. These are agriculture and fish farming with over 5.3 million hectares and forestry and environmental protection with over 4 million hectares. The smallest share is occupied by categories such as education, culture and places of worship with just over 8.4 thousand hectares, followed by administration and local government with just over 21 thousand hectares and mining and landfills with over 31 thousand hectares. In 2025, the remaining categories occupying territory in the country are in the following sequence: army - 36,416 ha, health and social centers, sports and entertainment - 47,186 ha, industry, energy production and trade - 74,355 ha, networks

(navigation, road, air, etc.) -144,988 ha, individual and collective housing - 263,872 ha and lands that are not used or temporarily not used, as well as those that do not have a special purpose - 1,063,251 ha. Based on the above data, the percentage change in 2025 compared to 2021 can be calculated. A slight decrease is observed in the categories of individual and collective housing with -1.61%, Mining and unloading depots with -2.49% change, networks (navigation, road, air, etc.) with -4.95% and agriculture and fish farming -5.26%. The most drastic decrease is observed in the army sector -22.77%, with areas decreasing from 47,154 ha to 36,416 ha, administration and local government -12.42%. This significant decrease may be due to optimization of administrative buildings, digitalization or re-categorization of terrain. A positive percentage change is reported in forestry and environmental protection + 5.45%, industry, energy production and trade +8.95%. The increase from over 68 thousand hectares to over 70 thousand hectares in 2025 is due to investment and development of renewable energy sources, such as solar and wind parks and systems. The most noticeable growth is observed in the unused land sector with +10.77%. This is the category with the largest growth in absolute values (an increase of over 100 thousand hectares). This suggests a process of land abandonment or a change in their status.

From the structured analysis, the data show a period of significant changes in the distribution of land, with the general trend being towards the contraction of traditional production and administrative areas at the expense of ecological and unused terrains. The large mass of unused lands or those that do not have a special purpose have the potential to be converted into agricultural territory, with future investments being made. We can undoubtedly note that Bulgaria continues to develop its industrial and energy base with effective and rational use of its land fund.

Table 2 shows a detailed picture of the distribution of arable land, utilized agricultural area and area with agricultural purpose in Bulgaria for the period 2021–2025. It also presents two specific changes in the last analyzed year 2025 compared to the initial year 2021, as well as to the previous year 2024. From the indicated data, dynamics are observed in cereal and oilseed crops. The largest positive change in 2025 compared to 2021 was observed in wheat +93,828 ha and continued to grow significantly by +134,002 ha in the last year compared to the previous year 2024. Despite the smooth increase in sunflower for the indicated period +93,251 ha, in the last year 2025 there was a sharp decline of -51,459 ha compared to 2024, while for barley the data show a stable and progressive growth, with the areas increasing by +81,698 ha compared to 2021 and by +30,158 ha compared to 2024 in the last year alone.

The data confirm a negative trend in maize and high value-added crops, namely a decline in permanent crops and specialized crops. For the period 2021–2025, the largest decrease in cereal crops was observed in maize -188,789 ha, total permanent crops decreased by 27,366 ha, vineyards decreased by 14,043 ha, and orchards by 10,590 ha. Industrial oilseed crops report a serious decline of 31,206 ha for the entire period and a positive trend towards an increase compared to 2024 +42,888 ha. Arable land remains relatively constant, as in 2025 it amounted to 3,467,614 ha, but reports a decrease of -19,134 ha compared to 2021 and -11,271 ha compared to 2024. Areas set aside have decreased dramatically by 60,323 ha compared to 2021 and by 35,316 ha compared to 2024, which indicates a more complete and intensive use of agricultural land for cash crops. The utilized agricultural area (UAA) for the period 2021–2025 has decreased by 464,518 ha. and by 431,974 ha compared to 2024. The main reason for this decline can be found mainly in the reduction of areas with permanent crops and permanent grasslands and meadows-orchards, which also decreased for the analyzed period - 415,428 ha. By 2025, the total area used for agricultural purposes (TAA) is 4,775,137 ha, which is 452,213 ha less than in 2021 and 440,739 ha less than in 2024.

Table 2. Arable land, utilized agricultural area and area with agricultural purpose for the period 2021–2025, ha

Employment	2021	2022	2023	2024	2025	Amendment 2025/2021	Amendment 2025/2024
Wheat	1,247,453	1,207,969	1,301,482	1,207,279	1,341,281	+93,828	+134,002
Barley	139,109	127,270	151,880	190,649	220,807	+81,698	+30,158
Rye and triticale	35,053	31, 327	42,042	29,323	35,908	+855	+6,585
Oats	10,421	13,632	15,210	24,710	29,447	+19,026	+4,737
Corn	633,735	572,048	595,560	595,092	444,946	-188,789	-150,146
Other cereals	21,903	14,549	19,930	18,123	31,618	+9,715	+13,495
Sunflower	840,185	985,591	892,956	984,895	933,436	+93,251	-51,459
Tobacco	3,015	3,207	2,502	2,399	3,400	+385	+1,001
Industrial oilseed crops	142,838	146,800	86,532	68,744	111,632	-31,206	+42,888
Other industrial crops	64,261	48,837	45,574	51,575	44,428	-19,833	-7,147
Potatoes	12,363	10,285	8,948	8,301	8,239	-4,124	-62
Peas, beans, broad beans, lentils and other legumes	30,584	22,198	14,934	28,757	26,879	+3,705	-1,878
Fresh vegetables	31,015	21,206	23,681	28,293	30,887	-128	+2,594
Annual forage crops	8,115	5,940	8,528	16,693	14,305	+6,190	-2,388
Meadows sown with legumes	119,942	104,618	103,168	104,847	105,587	-14,355	+1,679
Meadows sown with wheat	7,345	5,010	4,402	4,399	5,220	-2,125	+740
Fallow	137,707	132,752	153,480	112,700	77,384	-60,323	-35,316
Greenhouses	1,704	1,904	2,006	2,105	2,210	+506	+105
CULTIVATED LAND:	**3,486,748**	**3,455,143**	**3,472,814**	**3,478,885**	**3,467,614**	**-19,134**	**-11,271**
Family gardens	13,728	13,332	12,739	12,730	11,138	-2,590	-1,592
Fruit plantations	90,261	83,572	82,561	83,281	79,671	-10,590	-3,610
Vineyards – pure culture	50,252	47,551	46,948	46,258	36,209	-14,043	-10,049
Mixed perennials	6,820	6,310	6,016	5,918	4,287	-2,533	-1,631
Nurseries	1,709	1,907	1,506	1,508	1,509	-200	+1
Total perennial crops:	149,042	139,341	137,031	136,966	121,676	-27,366	-15,290
Permanently grassed areas and meadow-orchards	1,397,079	1,414,246	1,380,408	1,385,473	981,651	-415,428	-403,822
USED AGRICULTURAL AREA:	**5,046,597**	**5,022,062**	**5,002,992**	**5,014,053**	**4,582,079**	**-464,518**	**-431,974**
Uncultivated land	180,753	204,026	205,490	201,823	193,058	+12,305	-8,765
AGRICULTURAL AREA:	**5,227,350**	**5,226,087**	**5,208,482**	**5,215,876**	**4,775,137**	**-452,213**	**-440,739**

Source: based on data from the Department of Agrostatistics (BANSIC), Ministry of Agriculture and Food [9] and own calculations.

We can summarize that over the 5-year period, the area of arable land has remained extremely stable, with crops such as wheat, barley and sunflower being the main preferred areas, while high value-added sectors such as viticulture and fruit growing continue to shrink.

There has been a significant decrease in fallow land, which indicates that farmers are bringing more and more land into active crop rotation, rather than leaving it unused for the season.

Bulgarian agriculture is becoming more oriented towards annual field crops (cereals and oilseeds) at the expense of livestock (pastures) and permanent crops.

From the published statistical data of the Ministry of Agriculture and Food, a regional distribution and comparison can be made in the use of agricultural land in Bulgaria of arable land, utilized agricultural area and area with agricultural purpose by statistical regions for the period 2021-2025.

According to the Law on the Administrative-Territorial Organization of the Republic of Bulgaria, the territory of Bulgaria is divided into administrative-territorial units - districts and municipalities (Law on the Administrative-Territorial Organization of the Republic of Bulgaria, last amended. SG. No. 102/08.12.2023) [6].

The administrative districts are grouped into 6 statistical regions with a territorial scope at

level 2 of the Nomenclature of Territorial Statistical Units (NUTS), as follows: Northwestern – Vidin, Vratsa, Lovech, Montana and Pleven; Northcentral – Veliko Tarnovo, Gabrovo, Razgrad, Ruse and Silistra; Northeastern – Varna, Dobrich, Targovishte and Shumen; Southeastern – Burgas, Sliven, Stara Zagora and Yambol; Southwestern – Blagoevgrad, Kyustendil, Pernik, Sofia (capital) and Sofia region; Southcentral – Kardzhali, Pazardzhik, Plovdiv, Smolyan and Haskovo.

Figure 1 presents the distribution of arable land by statistical planning regions for the period 2021-2025.

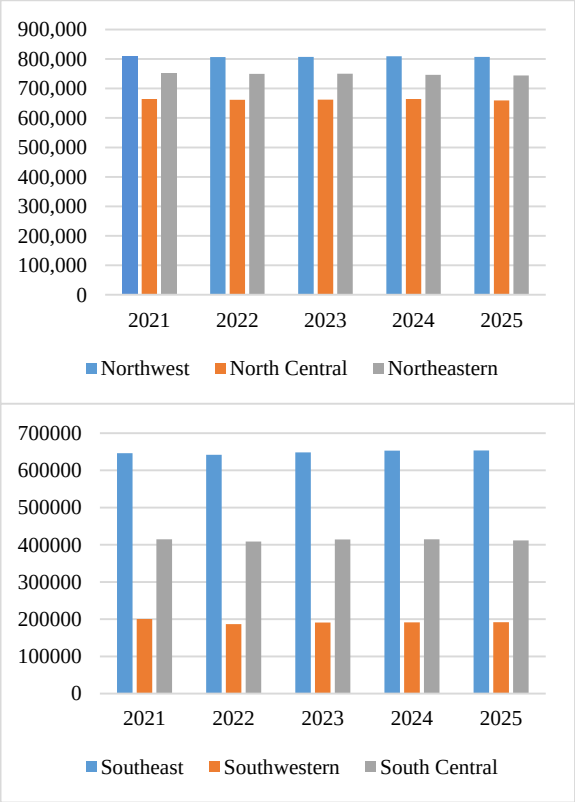

Fig. 1. Distribution of arable land in Northern and Southern Bulgaria by statistical regions for the period 2021-2025

Source: based on data from the Department of Agrostatistics (BANSIC), Ministry of Agriculture and Food [9].

Arable land includes areas that are cultivated annually and are included in crop rotation. These are annual crops, berry crops and artificial pastures (alfalfa, clover, ryegrass), as well as specialized plantations such as hops, oil-bearing rose and lavender, along with areas under fallow and those for seed production. From the data shown in the figure, it is evident that the distribution of arable land confirms the dominant role of Northern Bulgaria over Southern Bulgaria, where the main areas for grain production are concentrated. The absolute leader in the country is the Northwestern planning region. The highest level of arable land reaches 810,585 ha in 2021. In 2024, a gradual decrease is observed and reaches 809,347 ha, continuing and in 2025 a slight decrease of 2,462 ha is reported. The region maintains stability with slight annual fluctuations. In 2025, the North-Eastern region occupies 744,155 ha of arable land. Here a slight decrease is noted compared to 2021 - 750,675 ha and compared to 2024 - 746,419 ha, which may be due to land conversion or urbanization. The North-Central region shows the greatest stability.

The areas vary in a narrow range around 660,000 ha, ending the period with levels of 659,688 ha. The strongest agricultural region of the three statistical regions in Southern Bulgaria is the Southeast, which in 2025 occupied the highest share of arable land - 653,596 ha. It marked a significant increase compared to 2021 (645,956 ha), which corresponds to the national trend for expanding sunflower areas. The South Central maintains relatively constant levels over the years, and in 2025 occupied the highest share with 411,489 ha. The region with the least arable land is the Southwest, due to the mountainous terrain, with the lowest share being reported in 2022 - 186,507 ha, and the highest in 2021 - 200,424 ha.

About 63% of the total arable land in Bulgaria is concentrated in the three northern regions - Northwestern, Northcentral and Northeastern, which is a result of the greater degree of sowing of areas with cereals, which are favorably influenced by the natural and climatic conditions in these regions of the country. The data in the indicated five-year period show that there are no drastic collapses in any of the regions considered. Land use is conservative and sustainable, with the land rarely changing its purpose on a large scale. While in the Southeastern region an expansion of arable areas of 7,640 ha is observed for the

entire period, in the Southwestern region there is a tendency to shrink by 8,623 ha. This is most likely due to the more difficult cultivation of agricultural land in these regions, with the economy reorienting towards other sectors - tourism or services.

The term ***Utilized Agricultural Area*** (UAA) refers to the total area used by a given farm, regardless of its legal basis (ownership, rental or lease). Structurally, it includes arable land, permanent crops, permanent grassland and family gardens. The following figure 2 presents the distribution of utilized agricultural area in Northern and Southern Bulgaria by statistical region for the five-year period. The data on arable land reveal a large-scale decline in utilized areas in all regions in 2025, which is consistent with the general national trend of contraction of the sector. Northern Bulgaria retains its position as a leading agricultural region, despite reporting serious losses of area at the end of the period.

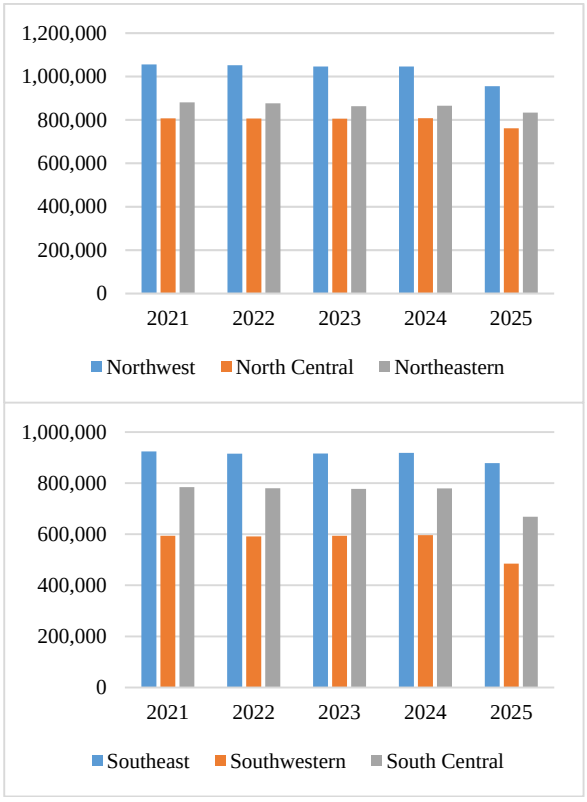

Fig. 2. Distribution of utilized agricultural area in Northern and Southern Bulgaria by statistical regions for the period 2021-2025

Source: based on data from the Department of Agrostatistics (BANSIC), Ministry of Agriculture and Food [9].

The region with the largest UAA in the country is the North-West. However, a gradual decline of about 9.5% is observed - from 1,055,769 ha in 2021 to 955,282 ha in 2025. The largest decrease in Northern Bulgaria is reported in the North-Eastern region, where the areas shrink from 881,462 ha to 833,757 ha over the five-year period. North-Central demonstrates relative stability until 2024 at about 807 thousand ha, but in 2025 it decreases to 761,853 ha. South-Eastern is the leading region in Southern Bulgaria. After a period of slight fluctuations in 2025, the UAA falls below the 900 thousand hectares mark, reaching 878,204 ha. The lowest point is reported in 2022 at 915,162 ha, with the peak observed in 2021 - 923,791 ha. The South Central region reports one of the most serious declines in the country in the last year. From relatively stable levels of over 770 thousand ha in 2025, the utilized area shrinks to 668,366 ha. Due to the specific mountainous terrain, the South-Western region has the least utilized agricultural area. A sharp decrease is observed in 2025 to 484,617 ha, after maintaining levels of around 590–596 thousand hectares in previous years.

No statistical planning region sees an increase in the utilized agricultural area in 2025, i.e. an overall regional decline is observed. Northern Bulgaria continues to have larger and more sustainable agricultural areas, while in Southern Bulgaria (especially in the South-West and South-Central) the withdrawal of land from use is more noticeable. While the changes until 2024 are minimal, the data for 2025 show a structural change that affects Southern Bulgaria the most.

The area used for agricultural purposes (AUA) is formed by arable land, permanent crops, permanent grassland used for agricultural purposes, family gardens and agricultural land that has not been cultivated for more than five years. This category is the broadest, as it includes both used agricultural area and uncultivated land. Figure 3 shows the distribution of agricultural areas by statistical region. The largest areas in the country are observed in the Northwestern region, although with a slight decrease from 1,105,019 ha in 2021 to 1,002,885 ha in 2025, which is a

decrease of nearly 9.2%. The most noticeable decrease in Northern Bulgaria is reported in the Northeastern region - from 910,849 ha to 864,065 ha for the period. This is a decrease of nearly 46,784 ha. The North Central region demonstrates the highest stability until 2024, but in 2025 it marks a sharp decline to 782,137 ha, losing over 45 thousand hectares in just one year. In Southern Bulgaria, more dynamic processes of land use and land use change are observed. The Southeastern region has the largest resource in the southern part of Bulgaria, although it maintains levels above 930 thousand ha for most of the period, in 2025 the areas decrease to 901,312 ha. South Central records a serious decline in the PSSA of 112,334 ha for the entire period, with areas decreasing from 815,788 ha in 2021 to 703,454 ha in 2025. South Western has the smallest share, suffering the most drastic relative collapse in the last year - from 636,832 ha in 2024 to 521,284 ha in 2025.

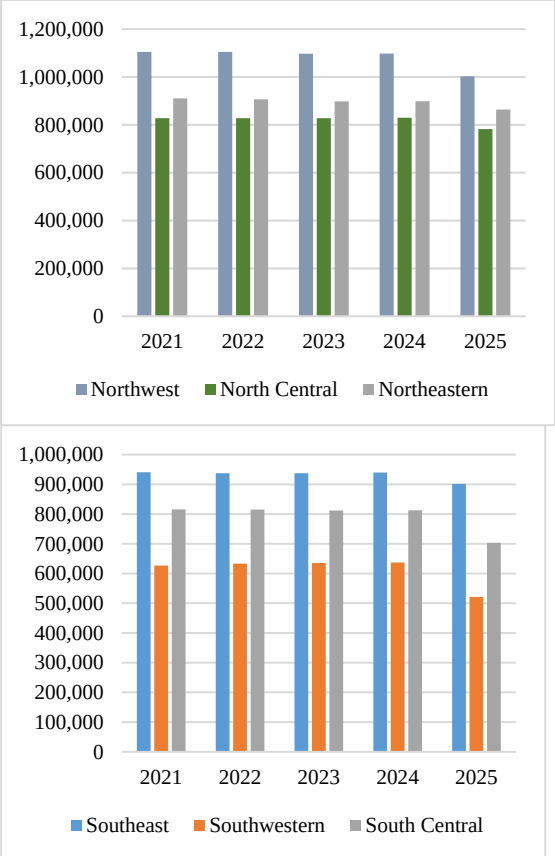

Fig. 3. Distribution of agricultural areas in Northern and Southern Bulgaria by statistical regions for the period 2021-2025

Source: based on data from the Department of Agrostatistics (BANSIC), Ministry of Agriculture and Food [9].

Northern Bulgaria remains the leader in terms of total resource, but two of its three regions (Northwestern and Northeastern) are losing areas. The Northwestern region remains the only one with over 1 million hectares of agricultural land by 2025. The Southwestern region is losing nearly 17% of its agricultural land in 4 years, which is the highest rate of decrease in the country. Similar to the utilized agricultural area, the area under agricultural use also shows a sharp negative jump in 2025 in all regions without exception. The agricultural sector is characterized by a long-standing intensive use of chemical pesticides and synthetic fertilizers. Although conventional methods aim to optimize high yields, they generate serious environmental risks and pollution of the natural environment. Modern challenges require a transition to the implementation of sustainable agricultural models, focused on reducing the levels of chemicalization in order to ensure long-term protection of soil and agricultural resources (Krasteva et al., 2024) [4].

The effective management and use of agricultural territories are directly dependent not only on their area availability, but also on the intensity of the applied agrotechnical and plant protection practices. The restructuring of crops towards grain and oilseed sectors, which is observed in the analyzed data for the period 2021–2025, inevitably reflects on the needs for chemical protection of agricultural crops. In this context, in order to assess the sustainability of land use, it is necessary to analyze the degree of chemicalization through the carried out area treatment activities.

The analysis of the following table 3 shows the intensity of plant protection measures carried out on areas treated with herbicides, insecticides and fungicides for main agricultural crops in Bulgaria - wheat, barley, grain corn, rapeseed and sunflower.

The most widespread practice is the use of herbicides in agriculture. The highest use is reported for wheat, barley, corn and rapeseed, which maintain treatment levels between 83% and 91% throughout the period. The percentage change in 2024 compared to 2020 is minimal, which shows that weed control is a mandatory and permanent stage of the

technological process. Only in barley is it visible that there is practically no change (0%).

Insecticides show the greatest dynamics and a general trend towards a decrease in treated areas. Although rapeseed remains the crop with a high level of insecticide use of 73% in 2024, it reports a decrease of -9.88% compared to 2020, and wheat use decreases by -10%, falling from 70% in 2020 to 63% in 2024, while corn and sunflower show serious declines, respectively - 26.09% and -14.29%. The largest decrease in treated areas with fungicides is observed in corn for grain (-42.86%), sunflower (-18.75%), rapeseed (-10.67%) and wheat (-1.23%). Only barley shows a slight positive trend of increase (+1.35%).

Table 3. Plant protection measures carried out - harvests `2020-2024, %

Areas treated with pesticides	Cultures	Years					Percentage change 2024/2020
		2020	2021	2022	2023	2024	
Herbicides	Wheat	89	90	90	89	87	-2.25
	Barley	83	86	85	84	83	-
	Corn for grain	88	89	90	91	85	-3.41
	Rapeseed	87	90	88	82	83	-4.60
	Sunflower	85	87	87	88	84	-1.18
Insecticides	Wheat	70	66	65	68	63	-10
	Barley	58	55	54	58	56	-3.45
	Corn for grain	23	29	29	25	17	-26.09
	Rapeseed	81	81	69	69	73	-9.88
	Sunflower	21	26	25	29	18	-14.29
Fungicides	Wheat	81	81	78	84	80	-1.23
	Barley	74	72	70	75	75	+1.35
	Corn for grain	28	27	17	21	16	-42.86
	Rapeseed	75	75	66	69	67	-10.67
	Sunflower	32	38	33	36	26	-18.75

Source: Ministry of Agriculture and Food, Department of Agrostatistics [9], survey "Yields of field crops – harvests `2020-2024" and own calculations.

Herbicides remain the most widely used group of pesticides, with crops such as wheat (87%) and maize (85%) maintaining high levels of treated areas throughout the period. There is a noticeable trend towards a decrease in the intensity of treatment with insecticides and fungicides, with the most drastic decline being in maize for grain, where the use of fungicides decreased by -42.86%. In rapeseed and sunflower, a steady decrease in the intensity of spraying is observed in all categories of preparations, with the decline in fungicides in sunflower reaching -18.75%. The data indicate a trend towards a decrease in the areas treated with pesticides in most agricultural crops, which gives a positive signal and potential for the implementation of more sustainable agricultural practices in the crop sector.

In order to ensure sustainable and productive land use, the analysis of quantitative changes in areas must be supplemented by a review of the intensity of their technological cultivation. The effective use of agricultural resources is directly linked to soil nutrition practices, which aim not only to achieve high yields, but also to preserve soil fertility in the long term. The analysis of the following table 4 shows what percentage of the sown areas of main agricultural crops (we use the same crops from the previous table 3) in Bulgaria were nourished with different types of fertilizers. The data reveal significant differences in technological approaches for individual crops and types of fertilizers.

The table shows that nitrogen fertilization remains the main practice for Bulgarian agriculture, covering the highest percentage of areas. The most intensively fertilized crops with nitrogen are areas with wheat and barley with over 80%, followed by corn for grain with just over 70%. The largest decrease in the use of nitrogen fertilizers is observed in sunflower - from 70% in 2020 to 62% in

2024, with the percentage change being -11.43%.

Rapeseed also reported a decrease of nearly 10% in nitrogen treatment over the five-year period. There is a persistent trend of decreasing areas fertilized with phosphorus and potassium, which may lead to an imbalance in the use of soil nutrients.

Table 4. Fertilized areas - harvests `2020-2024, %

Fertilizers	Cultures	Years					Percentage change 2024/2020
		2020	2021	2022	2023	2024	
Nitrogen fertilizers	Wheat	82	83	83	82	81	-1,22
	Barley	78	84	76	78	77	-1,28
	Corn for grain	71	67	69	70	73	+2,82
	Rapeseed	83	82	79	69	75	-9,64
	Sunflower	70	63	59	59	62	-11,43
Phosphorus fertilizers	Wheat	14	12	12	13	11	-21,43
	Barley	13	11	7	13	10	-23,08
	Corn for grain	10	9	8	8	6	-40
	Rapeseed	12	11	11	10	11	-8,33
	Sunflower	11	7	8	10	6	-45,45
Potassium fertilizers	Wheat	4	4	4	4	3	-25
	Barley	3	3	2	4	2	-33,33
	Corn for grain	4	3	4	4	2	-50
	Rapeseed	4	5	5	3	2	-50
	Sunflower	3	3	4	4	2	-33,33
Compound fertilizers	Wheat	55	53	59	63	57	+3,64
	Barley	45	43	54	56	55	+22,22
	Corn for grain	48	50	51	47	41	-14,58
	Rapeseed	56	61	66	68	61	+8,93
	Sunflower	48	53	59	60	52	+8,33

Source: Ministry of Agriculture and Food, Department of Agrostatistics [9], survey "Yields of field crops – harvests `2020-2024" and own calculations

A decrease in areas fertilized with phosphorus is observed in all crops, with the most drastic decrease in sunflower (-45.45%) and grain corn (-40%). Potassium fertilizers are used on the smallest percentage of areas - between 2% and 5%, with the largest decrease being reported in corn and rapeseed of -50%. Compound fertilizers show growth, with the largest increase being observed in barley of +22.22%, wheat and rapeseed with +3.64% and +8.93% respectively, and only grain corn saw a decline of -14.58%.

Based on the analysis, we can summarize that cereal crops (wheat and barley) maintain the most stable fertilization levels, which guarantees their yields. The sharp decline in phosphorus and potassium fertilizers is probably due to their high price in recent years, which makes farmers limit their use at the expense of nitrogen. The growth of compound fertilizers shows a desire for more effective and balanced nutrition, despite the general decrease in fertilized areas in other categories.

CONCLUSIONS

As a result of the analysis of the status and trends in the use of agricultural land in Bulgaria, the following generalizations and conclusions can be formulated:

- The theoretical review of author's opinions and scientific publications emphasizes that agricultural land is an irreplaceable national resource with strategic importance for agricultural production, ecological balance and economic stability of rural areas in Bulgaria. The studied 5-year period reveals a serious structural transformation, in which the quantitative contraction of the agricultural resource is combined with a high degree of monocultural specialization.
- According to the functional purpose of land use, the largest area is occupied by

agricultural territories - 54.5% of the total area of the country. In the structure of arable land, a trend of increase is observed for wheat +93,828 ha and sunflower +93,251 ha, while the areas under fallow decrease dramatically by 60,323 ha, which indicates a more complete and intensive use of agricultural land for cash crops. There is a steady decline in permanent crops with a total of 27,366 ha, family gardens with 2,590 ha, permanent grassland and meadows with over 415 thousand ha, which directly reflects on the potential for the development of ecological livestock farming. Bulgarian agriculture is becoming increasingly dependent on a narrow range of crops intended for export, while the total volume of utilized agricultural area is decreasing by nearly 464,518 ha. This requires an urgent rethinking of land management policies, with the aim of limiting land abandonment and stimulating multifunctional agriculture.

- Regionally, the data confirm the role of Northern Bulgaria as the main agricultural center of the country, while revealing specific trends of stability and slight decline in the different statistical regions. The territorial distribution of arable land remains highly concentrated in the North-West and North-East regions, which are the core of grain production. The North-West region is the absolute leader, maintaining the highest levels of arable land over 806 thousand ha and UAA - 955 thousand ha by 2025. The Southwestern region remains with the least arable land and the lowest level of utilization of agricultural potential. Data on agricultural land at the national level confirm a loss of 452,213 ha for the entire period. This shows that regional changes are not a simple redistribution, but a lasting process of land withdrawal from the agricultural sector, especially noticeable in Southern Bulgaria.

- The use of nitrogen fertilizers and herbicides remains the leading practice, covering between 80% and 90% of the areas in strategic crops such as wheat and rapeseed. There is a critical decline in the use of phosphorus and potassium fertilizers, the scope of which decreases by up to -45% and -50% (especially in corn and sunflower). The only positive trend is the growth in combined fertilizers, which signals a transition to a more efficient and balanced introduction of nutrients in a single operation.

Agricultural land use in Bulgaria is characterized by territorial concentration in the northern regions and increased specialization in grain production, which ensures high production intensity, but leads to the abandonment of areas in the southern parts of the country. The long-term sustainability of the sector depends on balancing economic efficiency with the protection of soil resources by optimizing fertilization and limiting negative structural changes in the land fund.

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ASSESSMENT OF FARM SUSTAINABILITY IN THE VULNERABLE SECTORS OF THE EUROPEAN UNION – PERMANENT CROPS

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Abstract

This manuscript aims to present how and where inequalities and weaknesses appear for the farmers from the non-favourable production specializations in the implementation of the European Union`s Common Agricultural Policy. By its area payments, CAP is widely supporting the large-scale field farming systems that are characterized by comparatively low value added and production intensity. On the other hand, all the other plant production specializations that are not related to the mass field crop production might be considered as vulnerable sectors. Their recourse usage correlates to the value added creation and accumulation and furthermore, their costs are significantly higher as well. By normalizing and accumulating variables, the used approach compares all types of farming and EU Member States provided by the Farm Accountancy Data Network through all three sustainability dimensions – economics, social and environmental, represented by essential complex indicators. The references used are the average farm levels and the average of current investigated farming type. The only Member States that realized above the mean EU results are Austria, Italy, and Spain.

Key words**:** *permanent crops, vulnerable sectors, farm sustainability, CAP, Relative Comparative Assessment*

INTRODUCTION

The vast majority of authors state that agricultural and farm sustainability is among the most relevant contemporary issues, widely discussed in the scientific circles, institutions, policy makers, non-governmental organizations, administration, agricultural producers and stakeholders (Bachev et al., 2021; Häni et al, 2006; Talberth et al., 2007) [3, 8, 12]. Farm sustainability is directly linked to the United Nation`s Sustainable Development Goals (SDGs) as a primary mechanism to end hunger, poverty and environmental degradation by 2030. Sustainable agriculture drives progress across multiple SDGs by ensuring food security (SDG 2), managing water (SDG 6), combatting climate change (SDG 13) and preserving ecosystems (SDG 15) (Atapattu et al., 2024; Sustainable Agriculture Network, 2024) [1, 10]. Defining one of the most important – zero hunger, agriculture is dedicated to a very exclusive role – to increase the food quality and quantity (supply), to decrease the resource usage while maintaining the natural environment in a more respectful way by "doing more and better with less" (UNOOSA, 2025) [15]. SDGs function as a holistic policy framework and are fundamentally connected to the three main forms of capital that represent the "wealth" a nation has to manage to achieve sustainable, long-term prosperity (Dai et al, 2024) [5]. Capital assets are the main ingredients of economic progress – human, natural and manufactured – and they constitute the inclusive wealth of a sustainable economy (EC, 2019) [6], which focuses on the basic assets generating income streams inducing a change in stock of productive capital, which could be monitored through measures of inclusive wealth to ensure the achievement of the short and long-term SDGs (UNEP, 2023) [14].

United Nations also stated a strong connection between the lack of energy and an increased systematic inefficiency reflecting in food loss and waste while threatening food security and rural development. In the crop, livestock and fishery supply and value chains, about a quarter of the total energy consumed is at the

initial production stage while all the phases of agrifood systems are responsible for around 30 percent of the total global consumption of energy (UN, 2026) [13]. This research aims to reveal what is the trend of European Union`s farms development in one of the most labour and resource intensive agricultural sectors towards the ambitious plan of the Green Deal, European Commission and United Nations in implementing strategies to decrease the use of energy, mineral fertilizers, chemical pesticides and the set of accompanying targets and Sustainable Development Goals.

MATERIALS AND METHODS

Building a Composite Sustainability Index (CSI) insists on the construction of complex indicators. Therefore, in this study five are used to present each sustainability pillar. The structure of an integrated dataset framework can be adapted and expanded to organize data related to the environmental and social dimensions of sustainability (Bizikova et al., 2026) [4]. The Farm Accountancy (Sustainability) Data Network (EC, 2025) [7] possesses a huge variety of economic variables to create the most important farm sustainability pillar – the economic one, which forms a funding base to the other sustainability values. The environmental pillar requires some proxy variables to be involved in order to express the intensity level of detrimental production factors usage.

A sustainability ranking system is applied according to a formula that normalizes all indicators involved in establishing the CSI by first averaging them into a pillar score.

Economic variables

1. Labour productivity is expressed as division of the total farm output on the total labour input. It is measured in euros per annual working unit.
2. Production diversification level is summarized as the reciprocal value of farm specialization, which is extracted out of the sum of the differences between the max and mean output and mean and min output which sum is therefore divided by the total farm output.
3. Profitability is presented by farm net income divided by the total farm inputs from which the own produced factors of production are excluded.
4. Capital productivity is a ratio of the total farm output divided by the average farm capital.
5. Economic resilience presents how many times the total output (excluding subsidies) covers the farm fixed costs, which are represented by the other direct inputs, depreciations and the total external factors (Bachev et al., 2017) [2].

Social Variables

6. Total farm income divided by the family working units measured in euros per annual family working unit.
7. Internal farm consumption articulate what is the attitude of the farmer and its family to their production. If they prefer to buy goods from a shop instead of consuming their own produce, it is not a positive social reference. The indicator is equal to the ratio of the total farmhouse consumption and unpaid labour input measured in euros per annual family working unit.
8. Annual farm salary is equal to costs for wages and insurances per unit of paid labour input in euros per annual working unit.
9. Farm own factors of production gives an idea to the level of independence to suppliers and their chains for dependencies. It is measured in euros per hectare and presents the amount of seeds and/or seedlings and or propagation material used per unit of area.
10. Share of own land is estimated by finding the ratio of rented to the total agricultural area, which is subtracted out of one. The difference between these two categories rests on respect and treatment of the land, just as one would treat one's own children compared to those of someone else.

Ecological Variables

11. Share of agro-ecological payments in total subsidies for crop production.
12. Costs for fertilizers per unit of input intensified area*, in euros per hectare.
13. Costs for crop protection products per unit of input intensified area*, in euros per hectare.

* Input intensified area is the sum of arable land and the permanent crops area.

14. Energy intensity measures the costs for

energy in terms of fuel, electricity and others per unit of utilized agricultural area, in euros per hectare.

15. Protein crops share in the crop rotation is presented by the output of protein crops out of the total crop output. Their usage as cover crops is essential in maintaining biodiversity in agroecosystems (Szeikely et al., 2024) [11].

Assessment method

To concentrate on the majority of results, normalize the data and form a score, Relative Comparative Assessment uses the following ranking formula (Ivanov, 2022) [9]:

$$\text{Indicator Score} = \frac{\text{Original Value } (0.5 + 0.5\ VC^2)}{\text{St Dev}^{**} + \text{AVG}^{**}}$$

where:

$$\text{Variation Coefficient} = \frac{\text{Standard Deviation}^{**}}{\text{Average}^{**}}$$

** Taken out of the FADN population that covers eight types of farming (including all six economic size classes) and average MS farms in order all specializations and sizes of the farms to be compared in further authors` observations. To exclude some value extremums, the following restricting actions to the values are undertaken:

1. VALUE < 0 = 0
2. VALUE > 1 = 1

The referent values for EU farm averages are presented by the national averages of the EU Member States, where a single synthetic production unit combining all types of agriculture represents each Member State. All five pillar indicators are normalized and further accumulated into the pillar sustainability evaluation, which by averaging constructs a final assessment in the CSI formation.

RESULTS AND DISCUSSIONS

Permanent Crops sector is characterized by smaller farms according to an average EU farming system concerning the physical farm size (Table 1). However, when farm size is expressed in economic units (euro) there are some exceptions.

Table 1. Selected main economic parameters of the EU permanent crop farms

Member State	**Economic size (x 1,000 €/farm)**		**Total Utilised Agricultural Area (ha/farm)**		**Total output (1,000€/farm)**		**Total output / Total input (ratio)**		**Total labour input (AWU/farm)**	
	2007-2014	2015-2022	2007-2014	2015-2022	2007-2014	2015-2022	2007-2014	2015-2022	2007-2014	2015-2022
EU Farm Averag	111	153	71.8	74.3	129.5	177.3	1.074	1.101	2.40	2.20
EU Perm. Crops	79	90	15.0	18.0	83.50	108.0	1.275	1.223	2.30	2.30
(BE) Belgium	305	385	19.8	24.1	336.30	442.1	1.320	1.243	5.80	7.07
(BG) Bulgaria	**11**	**15**	**10.9**	**9.80**	**13.80**	**17.4**	**1.000**	**0.904**	**2.50**	**2.10**
(CZ) Czechia	54	141	25.4	54.9	63.70	170.7	0.939	0.840	2.53	3.79
(CY) Cyprus	11	11	2.90	3.50	8.20	9.4	1.080	1.044	0.99	1.11
(DK) Denmark	238	96	35.0	33.5	162.6	218.5	1.135	1.060	1.21	1.84
(DE) Germany	184	242	20.8	30.9	158.0	235.3	1.213	1.136	3.26	3.68
(EE) Estonia	35	28	37.5	22.7	27.70	30.8	0.710	0.848	0.88	0.84
(EL) Greece	12	14	4.90	5.40	14.80	17.3	1.634	1.509	1.07	0.94
(ES) Spain	26	46	17.4	23.1	29.40	56.2	1.510	1.600	1.30	1.47
(FR) France	168	235	31.8	29.2	201.5	218.9	1.073	1.086	4.46	3.87
(HR) Croatia	14	10	6.60	5.40	16.60	18.5	0.825	1.068	1.97	1.65
(IT) Italy	27	44	7.40	10.4	31.70	43.4	1.669	1.619	1.17	1.24
(AT) Austria	79	87	9.50	11.3	77.40	107.0	1.285	1.233	2.06	2.13
(LV) Latvia	12	25	24.2	26.4	18.90	68.2	0.950	1.142	1.60	2.52
(LT) Lithuania	13	21	23.1	26.5	32.60	20.4	1.674	1.086	1.91	1.42
(HU) Hungary	27	31	16.1	13.1	29.60	34.7	0.998	1.205	1.80	1.54
(NL)Netherlands	237	323	12.8	15.1	306.30	418.6	1.191	1.129	3.88	4.87
(PL) Poland	16	20	9.30	8.30	26.90	23.2	1.329	1.333	2.16	1.91
(PT) Portugal	22	30	14.6	14.8	22.10	33.4	1.503	1.693	1.66	1.74
(RO) Romania	**10**	**12**	**5.20**	**5.20**	**14.10**	**18.6**	**1.595**	**1.905**	**1.63**	**1.51**
(SI) Slovenia	22	18	4.90	4.20	22.50	20.8	1.105	1.034	1.63	1.08

Source: Farm Accountancy Data Network (FADN) [7].

As expected, this makes sense only for the EU founders and the Scandinavian MS, where despite the relatively small area of those specialized farms, are able to generate very high income compared to farms in other parts of Europe. Such production specifics might concern several economic aspects. Social standard and purchasing power of the northern countries are quite higher while on the other hand, those permanent crops farming systems are extremely intensive.

There is such a wide difference in the used labour force even compared to the sectoral average. Another input intensifying condition is going to be further considered – the detrimental factors of production – energy, pesticides and fertilizers.

Most of the EU`s Member States lose value in their agricultural activity (the output to input ratio) – up to 10%, while Poland, Spain, and France seem stable and slightly raising.

Croatia, Hungary and Latvia significantly improved their ratios by converting it to an above the bottom-line level in contrast of a 4% decline in the sector on EU level. They succeeded in gaining the highest increasing rate – above 20%, Croatia – almost 30%. The other countries that achieve good results in this aspect, remain at the opposite end with the severe 35% decline, which is compensated by an expansion in cultivated area and economic size, while the total output and labour force still decrease.

Bulgaria and the Czech Republic (Czechia) are the next ones in downgrading by losing about 10% of the ratio going deeper below the bottom line of equity between costs and income. Those two cases are different. Bulgaria is on the bottom line during the first period of CAP implementation (up to 2014) while thereafter the agricultural area and workforce are declining.

The Czech Republic doubled most of the measurements noted in Table 1 (labour input +50%) except the input/output ratio, which is below the bottom line until 2014 and even worsen afterwards.

Composite Sustainability Assessment

Spain, Austria and Italy are the only MS performing above the EU farm average and respectfully – the sectoral sustainability leaders (both ends on Figure 1).

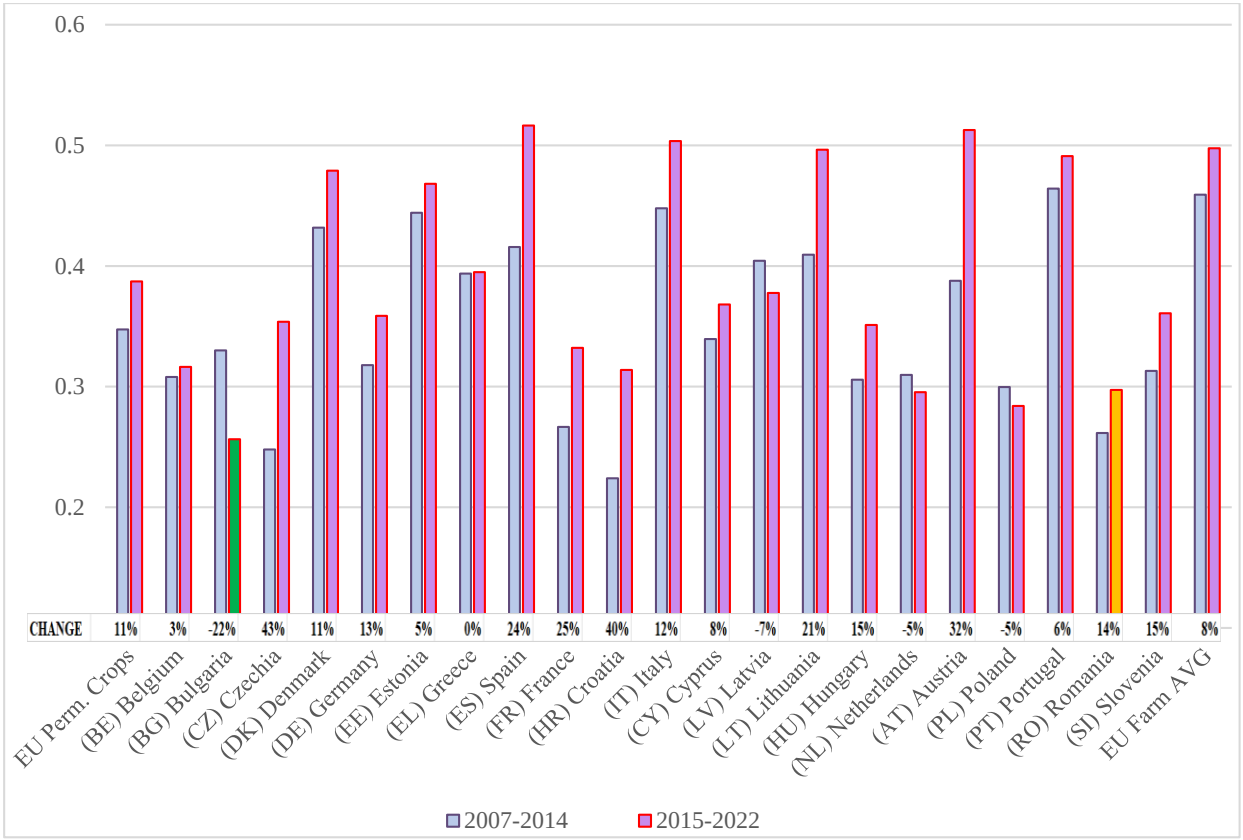

Fig. 1. Composite Sustainability Index
Source: Own calculations based on FADN dataset [7].

Austria achieves this through its dominant position in terms of social dimensions (Figure 3) and by reaching the environmental average (Figure 4). Italy and Spain also perform above the separating line. The highest values for the key sectoral parameter are observed in Estonia and Romania – almost 20% and Portugal – 12.6%. Lithuania is a performer in economic terms (Figure 2).

France and Germany also have common development of CSI trend, even higher than the permanent crops reference as sharing economic and social progress above the sectoral average while failing ecologically.

Uniform and colossal increases (above 40%) are also observed in the Czech Republic and Croatia, as well as Cyprus and Romania but with moderate intensity. Balkan MS share improving but very poor ecological sustainability that is exactly the opposite in the other two countries, even around the average farm level in EU while only Romania gains economic sustainability above the average of the sector.

Most of the new MS representatives are below the average of the sectoral EU average, just like Bulgaria and Poland, which expose a decreasing trend due to the downsizing of both ecological and social indicators while their economic performance is not successfully triggered to compensate the lag.

Estonia and Hungary are also struggling with environmental issues but their CSI is raising. The same is relevant to Latvia besides the recovery of the social indication and stabilizing the economic variables.

Lithuania has a top 5 CSI touching the EU farm average mainly because of ecological pillar but could not maintain the economic level (-10%) as well as Slovenia (-4%) where the ecological increase is about 60%.

Portugal is the last top 5 representative and besides a low decrease in the ecological indicators, all the sustainability pillars have balanced values.

Denmark (a top performer) and Greece, as old MS, put significant efforts into the environmental topics but allowed a decline in their other sustainability fundamentals where still succeeded in keeping their CSI levels higher than the common sectoral level.

Belgium and the Netherlands are also experiencing difficulties with the environmental conservation and their sustainability level is below the average level of the sector.

Economic Sustainability Assessment

The average economic performance of permanent crops sector is significantly lower than EU farm average, where during the first observed CAP period Denmark and Greece are situated (Figure 2).

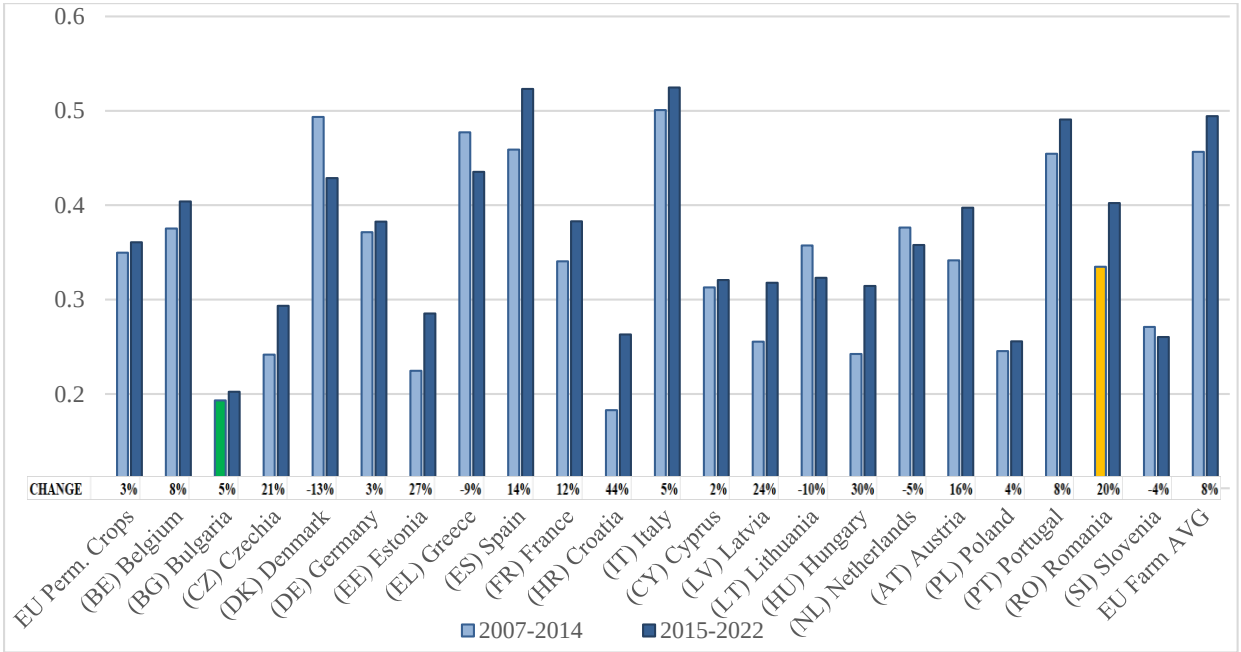

Fig.2. Economic Sustainability Index
Source: Own calculations based on FADN dataset [7].

After demonstrating higher results, the farmers worsen in maintaining the major economic indicators – profitability, capital productivity and economic resilience so their sustainability results are no longer that significant, which in Denmark corresponds with drastic decrease in the economic size (60%), a reflection of very slight 4% reduction in the farm physical size. Reasons might be concentrated in several different directions, but lower producer prices are fact. Drivers might be a combination of high import dependency, intense retail competition, and a decline in the local productivity. Consumer prices might remain high or volatile due to inflation, but the producer side could face pressure with decreasing local production volumes. Such a conjuncture insists a protective influence of a complementary national policy even it could be in a conflict with long-term EU or CAP goals.

However, Spanish farmers succeeded to keep their production diversity among the highest in that complicated farm specialization while improving all the other economic indicators at the same time to become among the best economic sustainability performers, together with the leader from the first CAP period – Italy.

Portugal is closing the top 3 leaders following the common EU trend and touching the overall reference level due to an increase in most of the parameters but especially – the capital productivity and profitability.

Romania, Belgium and Austria are below the EU benchmark but above the sectoral average gaining higher economic results raising all the used indicators. The only exception is Austria`s profitability rate that is decreasing by 6.5% and falls below the average which improves by the same trend.

Germany and France are the last MS that perform above the sectoral reference. Their strengths are concentrated in labour productivity and portfolio diversification enhancement while despite a reduction of their capital productivity, the values are still among the highest in the sector.

The Netherlands and Lithuania are among farms that lost positions and their indexation drop below the sectoral average. Declines are registered in profitability, capital productivity and economic resilience where the Baltic country is losing the crucial 85% of its ability to cover the fixed production costs. So, there is another case of deficiency in economic protectionism policy in the EU concerning the permanent crops as a vulnerable sector.

Large part of the new MS earned the most significant increases in the Economic Sustainability Index between 20% and 30% – Czechia, Estonia, Latvia, Hungary and Croatia where it is even 44%. All of them managed to improve most economic indicators, most successfully – labour productivity. The Czech Republic could not do it in terms of economic resilience and profitability, Estonia – capital productivity and diversification along with Latvia and Hungary. Croatian farms succeeded in being better in all the surveyed economic parameters, but most noticeably – the profitability where also Estonia and Hungary are very successful.

Bulgaria is situated at the bottom of Economic Sustainability results, accompanied by Poland and the declining Slovenia. Those MS could not improve their economic resilience. The most affected is the eastern Balkan MS (over -50%) which is compensated by profitability increase with the same value. This is one of Slovenia`s problems – lack of progress in terms of capital productivity, which is a major Poland`s strength.

Social Sustainability Assessment

Austria is the only MS that is above the EU farm average in terms of social sustainability among the representatives of the permanent crops sector (Figure 3). All the social indicators are at a very high level and are further developing.

On the other hand, Denmark is at the highest social sustainability sectoral level until 2014, but labour remuneration is the only increasing while all the other studied parameters are decreasing.

Italy and Latvia are sharing top three social sustainability rates after providing better income for both involved in the labour force parties – employees and farmers.

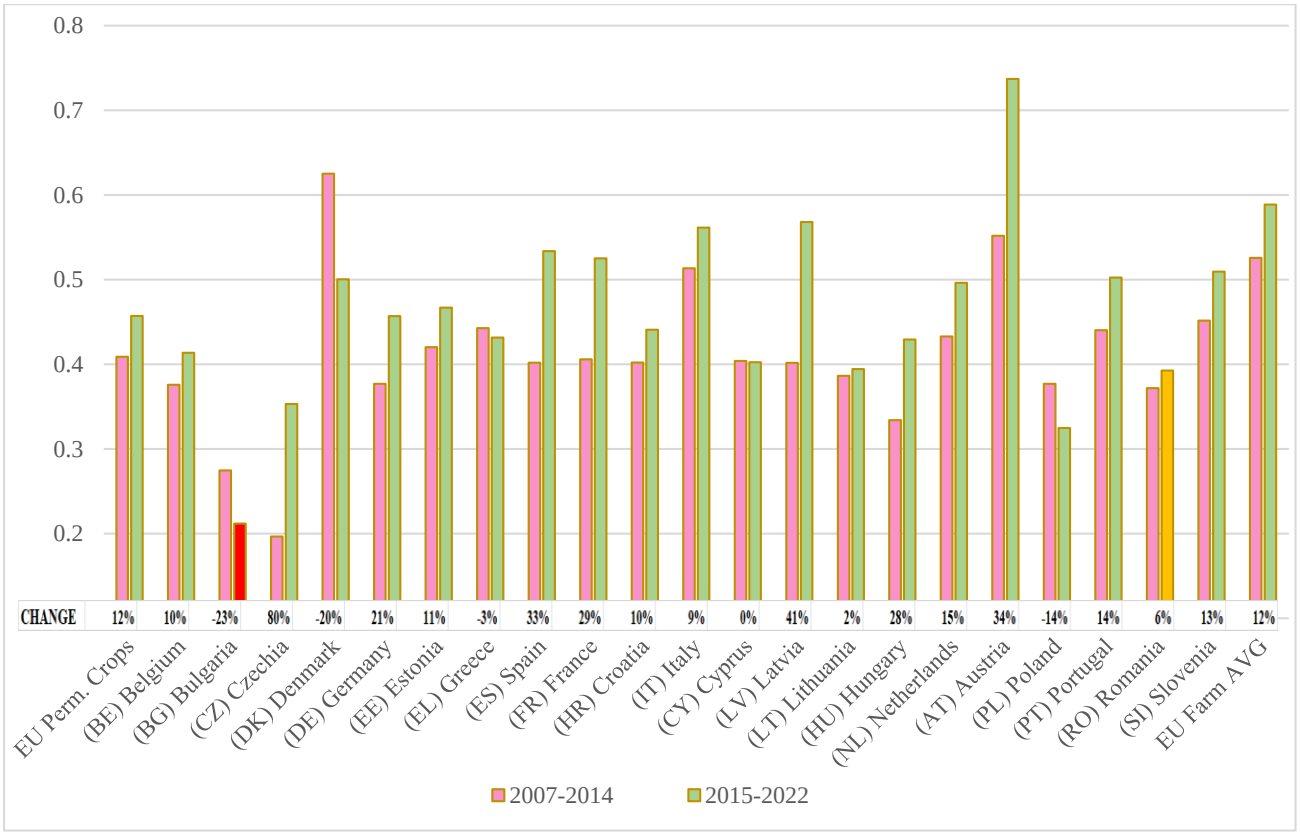

Fig. 3. Social sustainability index
Source: Own calculations based on FADN dataset [7].

They also improve several times their independency from suppliers by own production factors but that is happening at the cost of declining share of own farm land.

Spain and France, where incomes of involved parties are higher than the sectoral, complete top five social sustainability performers.

The last representative that is performing above the EU sectoral level is Estonia where incomes are lower, but the own factors of production are at a very high level and further rising as well as the farmer`s family opinion about their own produced goods. Below the sectoral average, there is a threshold (0.4), which separates two groups of MS.

Above the threshold is Belgium where farms are among the largest in terms of economic size and the incomes of the involved labour force (paid and unpaid) is quite higher than the average. Common trend is also observed in Hungary. Both MS decrease the internal consumption while enlarging the share of own land and used home-grown production factors which gives the new MS even a higher ranking score. The other above threshold MS are Greece, Cyprus, and Croatia. Their relatively small farm size (economic and physical) corresponds to comparatively low incomes of the involved labour parties, but the own production is highly evaluated by the farm families. Below the threshold are some of the smallest farms – Romania and Poland (leader in cultivating own land – 90%), and even the comparatively large farms of Lithuania where farmers` incomes stay below the normal for the sector as well as the workers` remunerations, which are slightly improving, while the internal consumption is declining.

The Czech Republic is increasing all the measured dimensions as properly managed are all the studied incomes and own production factors.

Bulgarian permanent crop farms are at the bottom of the social sustainability in that EU sector. Farmers' income and salaries are barely improving pushed by the inflation. Profitability is sharply improving but the other inspected indicators are at very low levels and are even worsening – product diversification and economic resilience fall down by 50%.

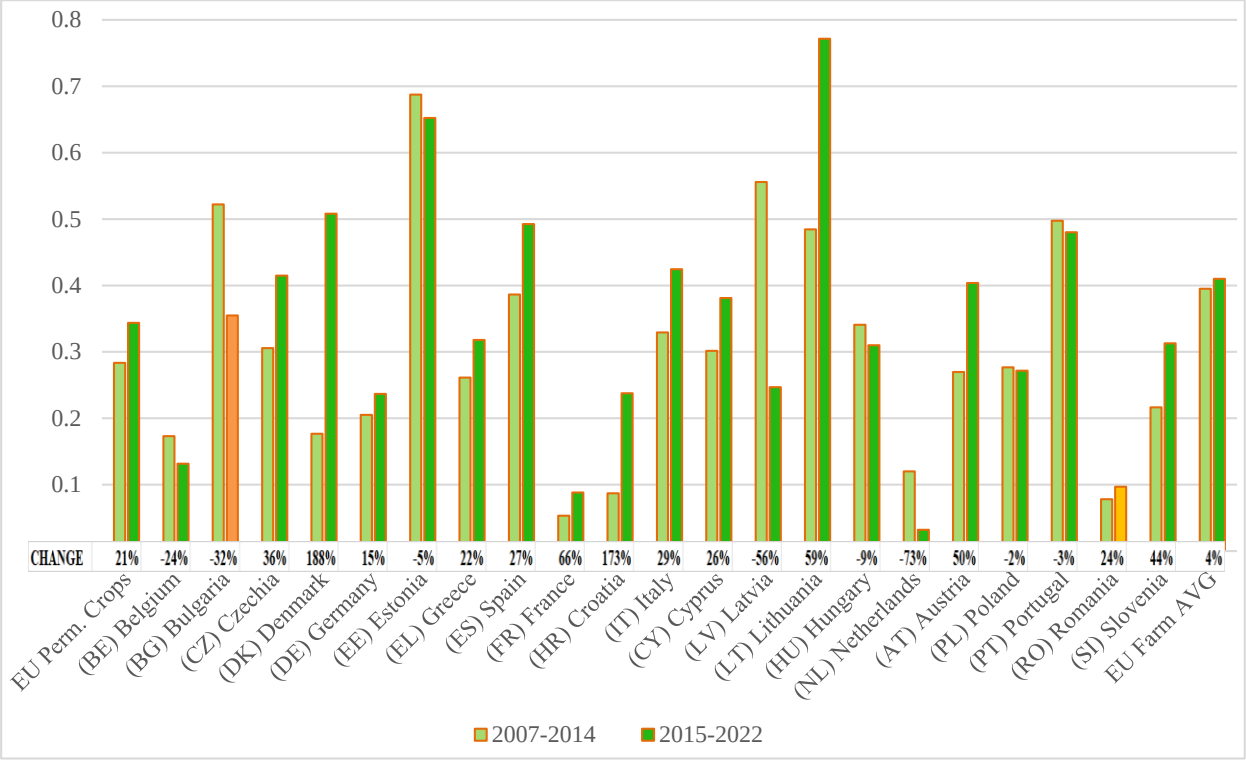

Fig. 4. Ecological sustainability index.
Source: Own calculations based on FADN dataset [7].

Ecological Sustainability Assessment

According to the contemporary policy descriptions, environmental protection is the most important sustainability pillar.

According to the behaviour of the EU founding MS, only the average sized farms of Italy are maintaining above the average rate of ecological sustainability concerning both used benchmarks.

Before the MS comparison, some common points need to be cleared. Shares of protein crops output and the ecological CAP schemes in the total payments are higher, costs for fertilizers are lower, expenditures for pesticides and energy are also higher in the sector of permanent crops than the common farming level of the EU. That makes the sector resource and energy intensive.

Therefore, in this section, the reference values are going to be the sectoral average as more appropriate.

Baltic MSs are usually at a very high ecological level. Latvia is the best performer during the first surveyed CAP application but all of the indicators worsen and the Ecological Sustainability Index drop is more than 50%. After a major boost, Lithuania is leading, followed by Estonia. They share some of the lowest rates in the usage of detrimental inputs. Lithuania surpasses in nitro-fixing crops inclusion and by very high share of eco-schemes application.

Bulgaria also is losing its leading position after slight but increasing use of energy, fertilizers and pesticides while the shares of eco-payments and legume cultivation remain comparatively low.

Large farms of Denmark, and mid-sized of Spain and Portugal also share a top condition by maintaining ecological CAP engagements and keeping the detrimental production factors at low level of application.

Mid-sized Italian holdings and the largest of the Czech Republic carry the load of implementing heavy eco engagements and succeed to perform well in energy and pesticide usage, but not in fertilizers.

The smallest farms of Cyprus and the mid-sized of Austria are improving their levels of environmental sustainability and are very close to the sector benchmark. Some of their strengths are high share of environmentally friendly engagements and cultivation of nitro-fixing legume crops but their energy intensity is higher than the average in the sector while increasing most of the harmful inputs.

Under the sector reference level are situated the majority of EU founding MS characterised by medium to high production scale – Belgium, the Netherlands, Germany, and France. They share very common environmental attitude. Very low or none cultivation of legume crops, very low and decreasing share of environmentally friendly agronomical engagements, very high and increasing levels of energy usage and detrimental factors` application.

Small-scale farms of Croatia and Slovenia and the mid-sized of Hungary have the ambition to implement some eco-schemes and keep the share of payments high. Their fertilizer application is low, but the pesticides usage is comparatively high, while the energy usage varies from low to average for the sector. Cultivation of protein crops is not a priority – neither to the policy, nor to the farmers.

The small farms of Romania, Poland, and Greece are not largely applying ecological schemes that are connected to the application of the Common Agricultural Policy.

Even their permanent crops farmers are maintaining the good agricultural practice of natural nitro-fixing.

Polish farmers keep the usage of pesticides, fertilizers and energy on low levels. Romania`s could not do this with the crop protection products only, while Greek`s – with the fertilizers.

CONCLUSIONS

The top successful MS in the measured farm sustainability through CSI do not posses the largest farms, but just around the EU average permanent crop garden, so there is no dependency on the physical farm size (production scale). This is confirmed by the lowest results which do not belong to the smallest farms of Slovenia and Cyprus.

The CAP instruments are neglecting the sectoral needs or are just focused on another sector, which affect permanent crops farmers' sustainability in all the dimensions reflected in this study.

The level of production intensity in the permanent crops sector is one of the highest in agriculture. This is the reason very few MSs to perform over the average farm sustainability (CSI) level of the European Union – Austria, Italy and Spain.

Austria is a special case where a social variable indicates a methodology shortcoming in the ecological pillar measurement. Around half of Austrian production is organically certified which means that the own factors of production are not taken into account correctly as environmentally friendly and respectfully the ecological sustainability is underestimated.

The most of EU sector farms are comparatively low economic and social sustainability rates. Furthermore, Bulgarian farms are at the bottom of EU concerning the socio-economic indicators expressed in this observation.

About 60% of the Member States are not increasing the share of their own land and more of them are selling some farmland to survive, while the sector is characterized by comparatively high share of own land assets relative to a rather limited cultivation area. Between 7% and 18% are the highest rates of decreased own land respectively in Spain and Denmark (about ha 1 and 3 ha) and Italy on the other side (less than 2 ha). Estonian farmers lower their coefficient by 11% which is around 4 ha while for the Greek farmers 13% is lower than a hectare as the decline is for the other MS. On the other hand, Belgium, French, German and Croatian holdings acquire new plots and their farmers add between 7% and 10% to their farm areas. Bulgarian farmers downgrade the total farm area by 10% (1ha) and the half seems to be sold, while Romanian have no change in the cultivation volume but 4% fewer assets.

Most of the European Union founding Member States (without Italy), engaged in permanent crops production, are the top users in terms of detrimental factors of production including energy. The rates of Belgium and the Netherlands are several times higher than the sectoral average (up to five times).

Concerning ecological effects, this methodology could not separate organic out of non-organic fertilizers and crop protection products. Furthermore, CAP after 2022 is oriented for promoting environmentally

friendly inputs aiming to protect and conserve the soil health. That measure led to increase in farmer`s cost for organic fertilization and its transportation but on the other hand, the crop protection expenditures could be reduced by lack of need for most of them.

To further alleviate the climate change effects on farming systems, CAP could undertake more new measures to promote specific climate adapting good agricultural practices. Organic or non-organic, some innovative crop protection preparations might strengthen the contemporary management strategies. Such an example could be the product, which decelerates the vegetation process in the early spring in order to avoid the morning frosts and temperature extremums, protecting the potential yields of permanent crops.

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PERCEPTION OF SMALL AND MEDIUM-SIZED PORK PRODUCERS IN THE REPUBLIC OF MOLDOVA ON FOOD SAFETY REGULATIONS AND ECONOMIC SUSTAINABILITY

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Abstract

The paper analyzes the perceptions of local pork producers and consumers in the Republic of Moldova about the regulations governing food safety and their role in economic development. The study refers to the importance of complying with standards, the impact of implementing standards on production costs, and the analysis of the competitiveness of the Republic of Moldova's market, which is currently in the process of gradual alignment with European Union norms. Through a mixed approach, data were collected through structured questionnaires and semi-structured interviews with the main actors: small and medium-sized producers, traders and consumers. The quantitative data were statistically analyzed, and the qualitative data were thematically coded to highlight major attitudes and challenges. The results show that although most producers recognize the importance of compliance, they consider the implementation of regulations to be costly and insufficiently supported institutionally. Consumers associate compliance with standards with higher product quality, but show limited information. The study concludes that institutional support, targeted training, and consumer education are essential for balancing regulatory enforcement with long-term economic sustainability in the pork sector in the Republic of Moldova.

Key words**:** *food safety, pork producer sector, regulation, sustainability*

INTRODUCTION

Pig breeding is a sector of the livestock industry within the national economy. The pig breeding sector has diversified its animal selection and breeding technologies. It has visibly increased the efficiency of feed utilization and animal slaughter. The quality of pork, in terms of albumin content and degree of its assimilation, is close to that of other animal species, and in terms of caloric content it is much higher. New capital investments are being made in the sector to modernize production and labor organization. At the same time, this sector is strictly regulated from the point of view of food safety [3, 15]. The literature points out that the implementation of these regulations can have different effects on farms of different sizes, especially on small and medium-sized producers, who often face financial and institutional constraints (Baltag, Henson & Humphrey, 2010) [2, 16].

Food safety has become a central concept in modern agri-food policies, being defined as the set of measures aimed at ensuring that food products do not pose risks to the health of consumers. According to the World Health Organization and World Organisation for Animal Health (WHO, 2020, WOAH, 2022), food safety is essential for protecting public health and maintaining consumer confidence in the food system. [31, 32] In the European Union, the legislative framework on food safety is mainly governed by Regulation (EC) No. 178/2002, which establishes the general principles of food legislation and the responsibilities of operators in the agri-food chain [11,12].

This regulatory framework supports the principle of traceability, the empowerment of producers and the implementation of food

safety management systems, such as HACCP (Hazard Analysis and Critical Control Points).
In the specialized literature in the economic and agricultural fields, the application of food safety standards is frequently examined in relation to agri-food value chains and the level of competitiveness of producers. According to Jaffee, Henson and Rios (2011), these standards can have a significant role in increasing product quality and facilitating access to international markets, but, at the same time, they can create barriers for small producers who do not have the resources to comply with these requirements [18]. Compliance costs can include investments in infrastructure, quality monitoring systems, certification and staff training. In the livestock sector, these costs can be particularly high, as biosecurity and veterinary control standards are complex and require significant investment [27].
In the case of the pig sector, food safety is closely linked to animal health, growing conditions and meat processing. Studies by McGlone (2013) show that modern pork production systems are under increased pressure to comply with strict standards on animal welfare, hygiene and product traceability. These requirements are motivated both by consumer concerns and by the need to prevent zoonotic diseases and food contamination. At the same time, McGlone in his research mentions that the sustainability of pork production systems highlights that economic efficiency, environmental protection and social acceptability are fundamental factors for the sustainable development of the sector in the long term (McGlone et al., 2013) [20].
In the Republic of Moldova, the application of food safety standards is largely determined by the process of harmonizing the national legislative framework with the acquis communautaire of the European Union. According to studies conducted by Litvin et al (2018) and Caisin (2025), the modernization of the Moldovan agri-food sector is closely linked to the adoption of European food quality and safety standards. These standards can contribute to increasing the competitiveness of Moldovan agri-food products on international markets, but can generate difficulties for small producers, who face limitations in terms of access to capital, technology and information. (Caisin et al., 2025) [4, 19].
The research carried out by Turcan (2020) highlights the role of traceability systems and sanitary-veterinary control in ensuring food safety in the Republic of Moldova. (Turcan et al., 2020) [28]. The National Food Safety Agency (ANSA) is the state control body that ensures and monitors the implementation of the aforementioned systems [1]. At the same time, studies show that the level of compliance with food safety regulations varies significantly depending on the size and economic capacity of farms [13,14]. Large commercial farms are generally better prepared for the implementation of standards, while small farms and individual households have difficulty complying with legal requirements.
Producers' perception of food regulations is an important aspect in the analysis of the effectiveness of public policies. The literature emphasizes that the success of the implementation of standards depends not only on the legislative framework, but also on the level of acceptance and understanding of these regulations by manufacturers (Henson et al., 2006) [17]. If farmers perceive regulations as overly complex or costly, there is a risk that they will only be partially or formally implemented. Conversely, when manufacturers recognize the economic and reputational benefits of compliance, the level of adoption of standards increases significantly.
In the pig sector, farmers' perceptions are influenced by several factors, including the size of the farm, level of education, professional experience and access to markets. Studies conducted in Central and Eastern Europe show that smallholder farmers are often sceptical about the economic benefits of food standards, as the initial costs of implementation can outweigh the short-term benefits (Popescu, 2020, Popescu et al, 2021) [24, 25]. At the same time, research indicates that institutional support, training programs, and government subsidies can help increase

farmers' capacity to implement these standards.

Another important aspect analyzed in the literature is the relationship between food safety and the economic sustainability of farms [5, 23]. Economic sustainability implies the ability of farms to generate stable incomes and maintain competitiveness in the long term. According to the OECD and FAO (2022), the adoption of food quality and safety standards can contribute to increasing the added value of agri-food products and access to premium markets. However, the economic benefits of these standards depend on the ability of farmers to integrate these requirements into their production and marketing strategies [22].

In this context, this study investigates the perception of small and medium-sized pork producers in the Republic of Moldova regarding food safety regulations and their impact on the economic sustainability of their activity.

MATERIALS AND METHODS

The study was designed as an exploratory research with a mixed approach, combining quantitative and qualitative elements, with the aim of highlighting how producers perceive regulatory requirements, the difficulties encountered in the compliance process and the economic implications generated by them.

Small and medium-sized producers in the pig sector served as the basic sample of the research. To ensure balanced results, producers from the North, Center and South regions of the Republic of Moldova were selected. They represent an important segment of the national livestock sector, having a significant role in ensuring domestic pork production and supporting the rural economy. The selection of study participants was carried out through a targeted sampling method, so that the respondents would be actively involved in the pork production activity and have direct experience in applying food safety requirements.

Data collection was carried out through a structured questionnaire, applied to a sample of 50 producers in the field of pork production. The questionnaire was developed in such a way as to allow the assessment of producers' perceptions, experiences and attitudes towards food safety regulations, as well as the analysis of the economic impact of their implementation on production activities. The research instrument included both closed-ended questions, which allowed the quantification of general opinions and trends, and open-ended questions, which offered the possibility of obtaining additional information on specific problems encountered by producers.

The questionnaire was structured into several thematic sections. The first section aimed to collect general information about the holdings, such as farm size, production capacity, experience in pig farming and the size of the economic activity. The second section aimed at the level of knowledge and understanding of food safety regulations, including the familiarization of producers with national legislative requirements and sanitary standards applicable to the sector. The third section analyzed the degree of compliance and operational difficulties, such as the costs of implementing hygiene measures, veterinary controls, product traceability and other requirements imposed by the regulatory framework. The last section followed the perception of economic sustainability, assessing how compliance with regulations influences production costs, market competitiveness and long-term development prospects of farms.

Before application, the questionnaire was analyzed to ensure the clarity and relevance of the questions formulated. Participation in the study was voluntary, and respondents were guaranteed the confidentiality of the data provided. The distribution of the questionnaires was carried out through direct contact with producers and through professional networks in the livestock sector.

Data was collected during November 2025 and were analyzed using descriptive statistical methods, which allowed the identification of the main trends and patterns in the perceptions of producers. Frequencies and percentages were calculated to highlight the distribution of responses within the analyzed sample. At the

same time, the responses to the open questions were interpreted through a thematic analysis, which allowed highlighting the main problems related to compliance with food safety regulations, financial constraints and adaptation strategies adopted by producers.

Through this methodological approach, the study provides a comprehensive picture of how food safety regulations are perceived and managed by producers. At the same time, it highlights the relationship between compliance with regulations and the economic sustainability of activities in the livestock sector.

RESULTS AND DISCUSSIONS

In the Republic of Moldova, the pig sector faces a number of structural challenges, including fragmentation of production, low investment levels and volatility of agricultural markets.

The World Bank report (2020, 2021) highlights that modernizing the livestock sector requires significant investments in infrastructure, production technologies, and quality control mechanisms.

From this perspective, food safety regulations can significantly contribute to boosting the modernization process of the sector, but it is essential to maintain a balance between regulatory requirements and the economic capacity of farmers to comply with them. The systematic analysis of the Republic of Moldova's food safety legislation allowed the research team to identify the applicable regulatory acts, their degree of updating and their internal coherence [29, 30].

A significant number of legislative documents were examined, as well as a number of technical norms and orders issued by the National Food Safety Agency (ANSA) [1].

The Legislation on red meat was analyzed in detail, which includes normative acts establishing sanitary and veterinary requirements for the production, processing, marketing and official control of meat from large animals (cattle, pigs, sheep), with an emphasis on hygiene, traceability and public health protection [21, 26].

The result of this activity was the development of a legislative database of relevant documents, organized by thematic areas – sanitary control, traceability, labelling, hygiene, certification and import/export.

The analysis highlighted the fact that a significant part of the national legislative framework is already aligned with European Union regulations, especially in the field of food hygiene and traceability of products of animal origin (Table 1). However, areas were also identified where regulatory framework remains fragmented or outdated, especially regarding internal audit procedures of food operators and sanctions for non-compliance.

Table 1. Comparative analysis of the legislation of the Republic of Moldova and the European legislation in the field of food safety

Legislative aspect	Republic of Moldova	European Union
Basic legislative framework	Law no. 306/2018 on food safety	Regulation (EC) no. 178/2002 – "From farm to fork"
Product traceability	Regulated, But the implementation is being strengthened	Mandatory, with integrated IT systems and rigorous control
Food labelling	Partial transposition of Regulation (EU) no. 1169/2011	Complete, clear labelling with nutritional and origin information
Official controls	Law no. 50/2013 and recent harmonization projects	Regulation (EU) no. 2017/625 on official controls and delegated rules
Use of pesticides /additives	Regulated, but with the need to align with EU doses and methods	Strict regulations on permissible limits and continuous monitoring
Laboratory certification	In the process of accreditation and modernization	Only accredited laboratories can perform official tests
Responsible institutions	National Agency for Food Safety, Ministry of Agriculture, Ministry of Health	EFSA, the national competent authorities of each Member State

Source: developed by the authors based on sources [1, 22, 26].

The next activity aimed at comparing Moldovan regulations with international standards, in particular with those of the European Union and Codex Alimentarius. The process was structured around five key areas: food quality control, traceability, chemical residues, product labelling and requirements for the hygiene of technological processes.

For each area, the project team created a comparative matrix in which national regulations were reported to EU Directives

and Regulations, as well as to FAO/WHO international standards.

The analysis revealed that, on average, approximately 72% of national provisions are aligned with international requirements, but significant differences persist in terms of the terminology used, certification procedures and the level of sanctioning of deviations. A concrete example is the regulations on food additives, where Moldovan legislation uses a limited list, different from the one adopted at EU level. Also, the labelling standards do not require the indication of the origin of all ingredients, which may affect transparency for consumers and the access of domestic products to foreign markets.

Based on the comparison, an in-depth analysis of the significant differences between Moldovan and international regulations was carried out. The process involved a qualitative assessment of the inconsistencies, classifying them into three categories: technical, conceptual and implementation.

- Technical inconsistencies concern the lack of clear standards for maximum permitted limits of chemical residues and for laboratory testing methods.
- Conceptual ones derive from different interpretations regarding the definition of the terms “safe food” and “compliant product”.
- Regarding implementation aspects, differences were found between the authorities responsible for control, the lack of a single platform for reporting non-conformities and difficulties in inter-institutional coordination.

These findings were documented and refer to the updating of control mechanisms and the strengthening of cooperation between regulatory institutions. The need to implement European good practices was also mentioned, such as:

1. The EU Farm to Fork System:

• Integration of all stages of the food chain: production, processing, distribution, consumption.

• Rigorous control of hygiene, traceability and use of chemicals.

• Promotion of sustainability and healthy eating.

2. Transparent and informative labelling:

• Clear labels on origin, composition, allergens, nutritional value.

• Implementation of QR codes for quick access to additional information.

3. Certification of laboratories and personnel:

• Exclusive accreditation of laboratories that comply with ISO standards.

• Continuous training for health inspectors and quality control specialists.

4. Monitoring of residues and contaminants:

• Centralized IT systems for tracking residues in food products.

• Risk assessment by independent institutions such as BfR (Germany) [6, 7, 8, 9,10].

The application of these good practices and reforms will bring the Republic of Moldova closer to European standards and, at the same time, support the protection of public health, contributing to strengthening the competitiveness of the agri-food sector and facilitating the access of Moldovan products to the European single market. Harmonizing national legislation with European Union norms in the field of food safety constitutes a strategic investment in the health of the population, in economic performance and in strengthening institutional trust. Therefore, food safety must be treated not only as a technical aspect of public governance, but as a national strategic priority, with direct effects on the health of the population, economic competitiveness and citizens' trust in state institutions.

The analysis of the data collected through the questionnaire reveals that the majority of respondents work in the primary sector of the agri-food chain, namely in the field of animal husbandry. This reality highlights the specific configuration of the pig sector in the Republic of Moldova, where most pig breeding activities are carried out in small and medium-sized farms, with a relatively low level of vertical integration of the value chain. The results indicate that the main activity of the majority of the enterprises analyzed is pig breeding, while a smaller number of economic operators are involved in activities such as slaughtering, meat processing or marketing of meat products. This distribution suggests the existence of a fragmentation of the production

chain, which may reduce the capacity of producers to generate added value and to amortize the costs associated with the compliance with food safety regulatory requirements. In the context of the integration of the agri-food market and the alignment of national legislation with European standards, the lack of vertical integration may represent a structural limitation for the competitiveness of local producers.

The distribution of enterprises by size highlights the predominance of micro enterprises, with a small number of employees. The majority of respondents fall into the category of enterprises with fewer than 10 employees, while small and medium-sized enterprises are represented to a lesser extent. This economic structure is particularly relevant for the analysis of the impact of food safety regulations. The implementation of modern food safety management systems, such as HACCP or ISO 22000, involves investments in infrastructure, operational procedures, staff training and monitoring of technological processes. For small enterprises, these requirements can generate relatively high costs in relation to their financial capacity.

The results therefore suggest that food safety regulations can have a disproportionate impact on small enterprises, affecting their competitiveness compared to larger economic operators, which have more consistent resources to implement regulatory requirements.

Food safety regulations play a key role in protecting public health and ensuring the quality of food products. However, the implementation of these regulations can generate additional costs for producers, especially for small and medium-sized enterprises.

The data obtained from the questionnaire suggest that compliance with sanitary and veterinary standards involves significant investments in the modernization of infrastructure, adaptation of technological processes and development of internal control systems. In the absence of effective institutional or financial support mechanisms, these requirements may diminish the competitiveness of domestic producers on the domestic market.

Instead, compliance with food safety standards can generate significant long-term benefits. The implementation of food safety management systems contributes to increasing consumer confidence, improving product quality and facilitating access to foreign markets.

Figure 1 shows the level of implementation of systems such as HACCP or ISO 22000 among the analyzed producers.

The results show that a significant proportion of the respondents (30 person) have not yet implemented a formal food safety management system, but plan to do so in the future. At the same time, a smaller proportion of enterprises (10 person) have fully implemented these systems or are in the process of implementing them.

These finding indicate the existence of structural and financial barriers to the adoption of international food safety standards, especially in the case of small and micro enterprises.

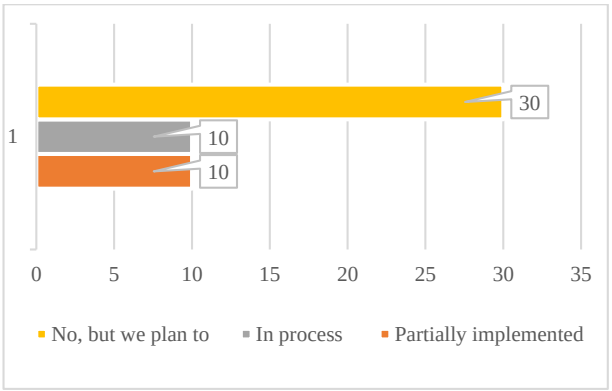

Fig. 1. Food safety management system implementation (Number of respondents)
Source: Developed by the authors based on the survey results.

Figure 2 highlights the main difficulties faced by producers. The most frequently mentioned obstacles are: high compliance costs; complex administrative requirements; lack of qualified personnel; lack of support or information from authorities. These results suggest that the problem is not only financial, but also institutional and administrative, which highlights the need for more effective support programs for the agri-food sector.

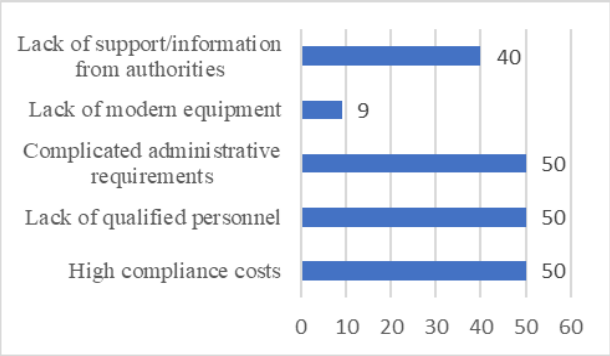

Fig. 2. Main obstacles in compliance with food safety regulations (Number of respondents)
Source: Developed by the authors based on the survey results.

Figure 3 highlights the perception of producers on the costs generated by the implementation of regulations. The results show that the majority of respondents believe that the regulations have significantly increased production costs. This aspect is particularly important for the competitiveness of local producers, especially in relation to imported products.

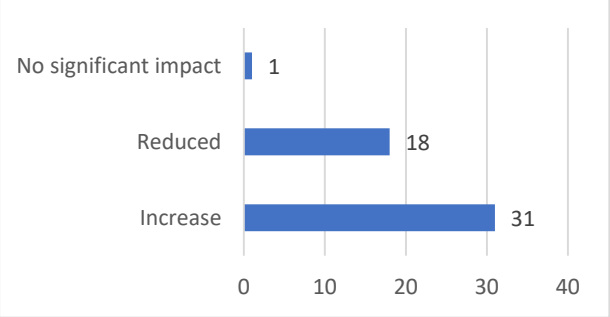

Fig. 3. Impact of food safety regulations on production costs (Number of respondents)
Source: Developed by the authors based on the survey results.

The analysis of the diagram regarding the question "Do you think that full alignment with EU standards is realistic for small meat producers in the Republic of Moldova by 2030?" reveal a predominantly reserved attitude among producers. A majority of responses, namely 36 farmers, consider that full harmonisation with European Union standards by 2030 is not an achievable objective for small producers in the meat sector. At the same time, 14 farmers stated that they cannot assess this perspective, which suggests a significant level of uncertainty regarding the sector's ability to meet European requirements.

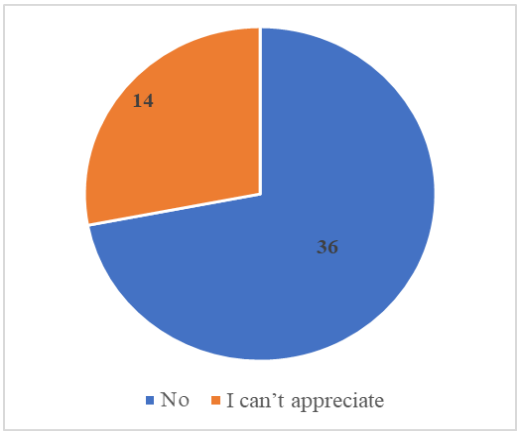

Fig. 4. Perceived feasibility of full alignment with EU standards by 2030 (Number of respondents)
Source: Developed by the authors based on the survey results.

These results suggest the existence of significant challenges, such as limited financial resources, insufficient infrastructure and difficulties in implementing food safety standards.

CONCLUSIONS

The research highlights the significant role of food safety regulations in shaping the competitiveness of local pork producers in the Republic of Moldova. The analysis of data obtained through the questionnaire applied to producers shows that the sector is dominated by small and micro enterprises, which operate predominantly in primary livestock activities and have limited financial and administrative resources to implement complex food safety management systems.

The results of the study indicate that food safety regulations are perceived simultaneously as a necessity to ensure product quality and protect consumer health, but also as an economic and administrative challenge for producers. The main difficulties identified in the compliance process include high implementation costs, the complexity of administrative requirements, the lack of qualified personnel and limited access to information and technical support.

The research also shows that the implementation of food safety standards, such

as HACCP systems, is still at an early stage for a significant part of producers, which reflects the need to strengthen institutional capacities and support mechanisms for the agri-food sector. In parallel, a portion of respondents consider that adherence to these regulations may enhance long-term competitiveness through improvements in product quality, greater consumer trust and easier entry into more demanding markets. Overall, food safety regulations represent a key component of the sustainable development of the agri-food sector in the Republic of Moldova, however their effect on producer's competitiveness is largely determined by the capacity of business to adjust to emerging requirements and by the availability of effective public support policies. Strengthening training programs, facilitating access to financing for infrastructure modernization and improving communication between public institutions and producers can significantly contribute to increasing the level of compliance and strengthening the competitiveness of local producers on the agri-food market.

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INTEGRATION OF THE MOLDOVAN AGRI-FOOD SECTOR INTO THE EU MARKET IN THE CONTEXT OF THE DCFTA AGREEMENT: FROM NATURAL ADVANTAGES TO COMPETITIVENESS

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Abstract

Together with the DCFTA agreement in 2014, the Moldovan foreign trade pattern with agri-food products has shifted its directions from CIS market to the EU. Thus, the paper aims to analyse how the Moldovan agri-food trade has integrated into the EU market since 2015 and how its competitiveness has enhanced over the analysed years. The paper is based on the analysis of secondary data on foreign trade and calculation of the Revealed Comparative Advantage indicator for competitiveness with respect to EU countries, Revealed Comparative Advantage indicator for specialization, Agri-food trade intensity index, and the Grubel–Lloyd Index. The empirical analysis reflected a consolidation of the Moldova's position on the EU market, observed through the increase of trade intensity with EU. The RCA presents highly competitive advantages for raw agri-food products, while for processed ones it still remains limited. The findings point on the need of diversification of the range of products exported to EU, continuous modernization of the value chains, and increase in processing. Thus, natural advantages will be transformed into sustainable competitive advantages on the EU market.

Key words**:** *foreign trade, RCA, agri-food trade intensity, Grubel-Lloyd index, Republic of Moldova, EU, DCFTA*

INTRODUCTION

The signing of the DCFTA Agreement between EU and Moldova has successfully contributed to the shift of the Moldovan economy and foreign trade towards the European market (Hagemejer & Dabrowski, 2025; Stratan, Lucasenco & Ceban, 2023) [10, 14] and a deeper economic integration into it (Nielsen & Šiljak, 2025) [12]. At the same time, a positive trend is noted in export of processed agri-food products (Stratan & Fala, 2022) [15], although the exports of primary production still hold the lion's share. Furthermore, as a result of beginning the negotiation process with EU, Moldova intends to fully benefit from the EU potential enlargement (Malic, 2024) [11] as the other countries have previously done (Beyer, Li &Weber, 2025) [3]. In this regard, foreign trade with EU is of particular importance for the developments in the future relationship of the two parties.

The recent regional geopolitical turbulences have had a negative effect on the Moldovan agricultural sector (Dabrowski et al, 2025; Busch & Codreanu, 2022) [7, 4]. Embargoes imposed by the Russian Federation (Calus, 2014) [5] and the Russian-Ukrainian war (Ferreira, & Critelli, 2023) [8] have impacted the supply chains, input availability, logistical aspects and products affordability. Therefore, the successful trade relations with EU represent a safety net for the Moldovan agri-food products in these times of uncertainty and risks. The aim of the paper is to analyse how the Moldovan agri-food trade has integrated into the EU market since 2015 and how its competitiveness has enhanced over the analysed years. Leveraging comparative advantages with respect to the EU market (Cojocaru & Cimpoies, 2025) [6] would bring additional benefits for the Moldovan agricultural sector and will impact the process of meeting the EU accession criteria (Antoci, 2025) [1].

MATERIALS AND METHODS

Analysis of the trade evolution between Moldova and EU countries is mainly based on the 2-digit data provided by UN Comtrade database (UN Comtrade, 2026) [16] and covers the period 2015 – 2024. Secondary data on foreign trade was used for calculation of the trade balance, Revealed Comparative Advantage indicator for competitiveness with respect to EU countries, Revealed Comparative Advantage indicator for specialization, Agri-food trade intensity index, and the Grubel–Lloyd Index [9].

RCA for competitiveness (Moldovan exports vs EU imports) was based on the formula of the standard RCA (Balassa, 1965) [2], but adjusted by Obermeier (Obermeier, 1982) [13].

$$RCA_c = \frac{\frac{Xi,MD-EU}{Xtotal,MD-EU}}{\frac{Mi,EU,world}{Mtotal,EU,world}} \quad \text{.....(1)}$$

where:

$X_{i,MD\text{-}EU}$ marks the exports of the Moldovan *i* product to the EU market

$X_{total,MD\text{-}EU}$ – total exports of Moldovan products to the EU market

$M_{i,EU,world}$ points on the imports of EU countries of the *i* product from the world market

$M_{total,EU,world}$ – total imports of EU countries from the world market.

RCAc determines the competitiveness of the Moldovan products on the neighbouring EU market. In case when RCAc values are greater than 1, Moldova holds a relative comparative advantage with respect to the EU market. This signifies the importance of Moldova in providing certain products on this specific market, meaning that it is higher than the average values of the providers from the world. The authors accept that the classical method of Balassa is more commonly used in order to assess the real competitiveness of the Moldovan products on the EU market. Nevertheless, the selection of Obermeier's approach is more tailored to the Moldova – Eu trade relationship and brings added value to the findings of the paper.

RCA for specialization (Moldova vs. EU on the world market) is closer to the original Balassa RCA indicator, using the exports of Moldova and EU, both with respect to the world market. It was calculated based on the following formula:

$$RCA_S = \frac{\frac{Xi,MD}{Xtotal,MD}}{\frac{Xi,EU}{Xtotal,EU}} \quad \text{.....(2)}$$

where:

$X_{i,MD}$ – Moldova's exports of the *i* product to the world market

$X_{total,MD}$ – Moldova's total exports of goods to the world market

$X_{i,EU}$ –exports of EU countries of the *i* product to the worldwide market

$X_{total,EU}$ –total exports of EU countries to the worldwide market.

Generally, this indicator determines whether Moldova's economy is more dependent on a certain sector, in this case the agricultural one, rather than the EU economy is. Thus, the obtained results show that the Moldovan economy presents some differences with respect to the EU economy and for some products with RCAs>1, means that Moldova is more specialized in these products than the EU on the world market.

Trade intensity index is based on the following formula:

$$TII = \frac{\frac{xijk}{Xik}}{\frac{xwjk}{Xwk}} \quad \text{.....(3)}$$

Where:

x_{ijk} – Moldova's exports of the product *k* to EU

X_{ik} – Moldova's total exports of the product *k*

x_{wjk} – world total export of the product *k* in EU

X_{wk} – world total export of the product *k.*

It is intended mainly for analysing markets, by pointing to the fact that a country exports more in percentage terms to a certain partner, compared to the exports on the world market. If the obtained value is greater than 100, then there is demonstrated a more intense correlation than with the world's indicators

(World Bank, International Trade Unit, 2013) [17].

The Grubel–Lloyd Index is intended for measuring the intra-industry trade using export and import data and varies between 0 and 1. Therefore, in case a country only imports or only exports goods, there is inter-industry trade and the values are either close to 0 or even equal to 0. On the other hand, in case the values are equal to 1 or are being close to 1, then the intra-industry trade is present (Grubel & Lloyd, 1975) [9] which means a deep economic integration.

The indicator was calculated based on the formula:

$$Gli = 1 - \frac{|Xi-Mi|}{Xi+Mi} \quad \text{.....(4)}$$

Where: X_i is represented by export values, while M_i - the import values of a certain good. The use of these methods provides the empirical evidence for the carried-out analysis, allowing the observation of the dynamic of the evolution of trade between Moldova and EU countries.

RESULTS AND DISCUSSIONS

In terms of the analysis of imports, exports and trade balance, Moldova has consistently maintained a positive trade balance in agri-food products with the EU countries during the analysed period, which indicated on the targeted orientation of cereals, oil seeds, fruits, nuts and wines on the EU market.

The export values increased from 405.5 mil. USD in 2015 to 1,047.7 mil. USD in 2024, reaching a maximum level of 1,194.9 mil. USD in 2023. The most intense increase from 649.1 mil. USD to 1,158.2 mil. USD has occurred in 2022, as a result of the strong support from EU in the context of the Russian – Ukrainian war. At the same time, imports from EU countries increased from 206.6 mil. USD in 2015 to 672.3 mil. USD in 2024.

The trade balance has been positive through the entire period, fluctuating between 198.1 mil. USD in 2021 to 599.9 mil. USD in 2022 (Figure 1).

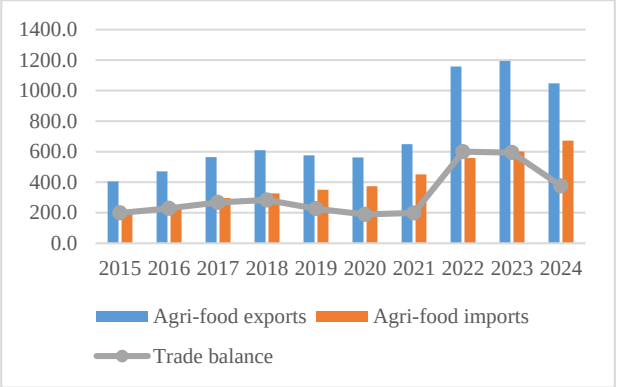

Fig. 1. Agri-food trade with EU countries, 2015 – 2024, mil. USD

Source: authors' calculations based on UN Comtrade (2026) [16].

In terms of the share in the total exports of goods with EU countries, the share of agri-food exports varies between 37.6% in 2015 to 43.8% in 2024, with a maximum share of 45.6% in 2022. The main determinants that have caused these increases are due to the implementation of the DCFTA which have boosted the Moldovan agri-food exports to EU, as well as the occurrence of geopolitical events from 2022 – 2024, which diminished the share of exports to CIS countries on the one hand, and enhanced the presence of new European partners, on the other. At the same time, imports of agri-food products from EU as a share of the total imports of goods from EU ranged between 11 – 15%, with a slight upward trend in the last 2 years (Figure 2).

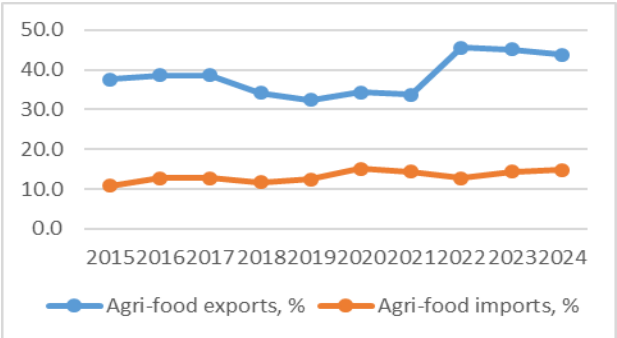

Fig. 2. Share of agri-food exports and imports in the total exports and imports of goods with EU, 2015 – 2024, %

Source: authors' calculations based on UN Comtrade (2026) [16].

Therefore, generally, during 2014 – 2024 a deepening of the trade relation between Moldova and EU occurred, which was

reinforced by the DCFTA, expansion of tariff quotas for key products like fruits, as well as the declared path towards the European integration. This confirms the reliability of the Moldova - EU partnership that contributes to stable relations, positive trade balance and increase of resilience of the agri-food sector, being in alignment with the current negotiation process for accessing the EU membership status. Taking into account the existence of the natural advantages of the agricultural sector and the path towards enhancing its competitiveness, a series of indicators have been analysed in order to evaluate the existing advantages for the Moldovan side in the framework of the trade with EU. The Moldova-EU trade is further analysed in the framework of some trade-specific indices like Revealed Comparative Advantage for competitiveness and for specialization, Trade intensity index and Grubel-Lloyd index.

The calculated ***RCA for competitiveness*** indicators can be grouped in several categories according to the strength of the comparative advantages. Thus, the first group is comprised of commodity groups with *strong and sustained comparative advantage*, which are:

-***Oil seeds and oleaginous fruits***, the RCA of which increased from 15 to 29 during the analysed period. It reflects the specialization of the country in sunflower seeds and rapeseed, together with the demand on EU's side for oil seeds.

-***Cereals***, with RCA increase from 12 to 22. The expanded quotas and the EU market access played a beneficial role in this regard.

-***Animal or vegetable fats and oils***, with RCA values fluctuating between 5 to 15, mainly due to the production of sunflower oil.

Within this group, two commodity groups are of primary products, while just one belongs to the added value category.

Emerging advantages group is composed of:

-Edible fruits and nuts, with RCA values between 5 and 9;

-Sugars and sugar products, that have RCA values between 1 and 15;

-Processed fruits and vegetables with RCA oscillating between 4 and 9;

- Beverage and spirit products, including vinegar, with RCA between 4 and 7.

-Dairy, eggs and honey, with RCA values between 0 and 1, but with further development potential due to the increase of quality of products and permission of export of certain products of animal origin to EU.

Table 1. RCA for competitiveness, Moldova with respect to EU countries, 2015 – 2024

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
01 - Live animals	0	-	-	-	-	-	-	0	-	-
02 - Meat and edible meat offal	-	0	0	0	-	0	0	0	-	0
03 - Fish and crustaceans	0	0	0	-	-	0	0	0	0	0
04 - Dairy, eggs and honey	1	1	1	1	1	1	1	1	0	0
05 - Products of animal origin	0	0	0	0	0	0	0	0	0	0
06 - Live trees and other plants	0	0	0	0	0	0	0	0	0	0
07 - Edible vegetables	0	0	0	0	0	0	0	0	0	0
08 - Edible fruit and nuts	9	7	9	7	7	6	5	5	6	8
09 - Coffee, tea	0	0	0	0	0	0	0	0	0	0
10 - Cereals	12	17	16	19	13	6	14	19	25	22
11 - Products of the milling industry	1	1	0	1	1	1	1	2	3	3
12 - Oil seeds and oleaginous fruits	15	19	20	20	19	18	16	26	21	29
13 - Lac	-	-	-	0	0	0	0	0	0	0
14 - Vegetable plaiting materials	5	0	0	0	2	3	3	5	6	5
15 - Animal or vegetable fats and oils	11	5	5	6	7	8	8	15	13	5
16 - Preparations of meat and fish	-	0	0	-	-	-	0	-	-	0
17 - Sugars and sugar confectionery	3	15	8	4	2	2	4	2	1	1
18 - Cocoa and cocoa preparations	1	1	1	1	1	1	1	1	1	0
19 - Preparations of cereals, flour	2	2	2	1	1	2	2	1	1	1
20 - Preparations of vegetables, fruit	7	5	8	4	6	7	6	5	5	9
21 - Miscellaneous edible preparations	0	0	0	0	0	0	0	0	1	1
22 - Beverages, spirits and vinegar	5	6	6	5	5	7	6	6	4	5
23 - Residues and waste from the food	0	1	0	0	0	0	0	2	3	1
24 - Tobacco and manufactured tobacco	1	1	0	0	0	0	0	0	0	0

Source: authors' calculations based on UN Comtrade (2026) [16].

Namely this group has the most potential of passing through the natural advantages to competitiveness, as result of the increased added value of the food industry products.

Weak or no comparative advantage have the rest of the products with values close to 0 (Table 1).

Thus, the competitiveness of Moldovan agri-food products on the EU market remains highly concentrated in primary products like cereals, oil seeds and fruits while lower figures for processed products point on some shortcomings with respect to quality standard compliance or limited capacity of processing.

RCA for specialization compares the export specialization of Moldova in a certain product at the global level to the EU's export specialization at the world level with the same products. Therefore, strong specialization advantages are presented with the following commodity groups: Oil seeds and oleaginous fruits, with sunflower and rapeseed among the highest values, with RCA values between 25 – 39; Cereals (wheat and maize) with values between 9 and 24; Fresh fruits and nuts (apples, plums, grapes and walnuts) with figures between 12 and 17; Vegetable plaiting materials (1 to 16); Animal or vegetable fats and oils – mainly sunflower oil - (4 to 14). These categories are the one that are highly raw commodities determined by the existing seasonal advantages. A moderate specialization with RCAs values between 1 and 10 has been recorded for: Processed vegetables and fruits with RCA values between 4 and 6; Beverages, spirits, and vinegar (with a fluctuation from 5 to 7); Sugars and sugar products (dispersed values from 1 to 9); Residues and waste from food industries (with less dispersion in the range of 1 to 3); Tobacco and manufactured tobacco: (0 to 3) and Live animals (with RCA from 1 to 2).

Table 2. RCA for specialization on the global market, Moldova with respect to EU countries, 2015 – 2024

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
01 - Live animals	2	2	1	2	2	2	1	1	1	2
02 - Meat and edible meat offal	0	0	0	0	0	0	0	0	0	0
03 - Fish and crustaceans	0	0	0	0	-	0	0	0	0	0
04 - Dairy, eggs and honey	1	1	1	1	1	1	1	0	0	0
05 - Products of animal origin	0	0	0	0	0	0	0	0	1	1
06 - Live trees and other plants	0	0	0	0	0	0	0	0	0	0
07 - Edible vegetables	1	1	1	1	1	0	0	0	1	1
08 - Edible fruit and nuts	17	13	16	14	14	14	13	12	13	14
09 - Coffee, tea	0	0	0	0	0	0	0	0	0	0
10 - Cereals	11	17	19	22	20	9	24	17	20	20
11 - Products of the milling industry	1	0	1	1	0	0	0	1	1	2
12 - Oil seeds and oleaginous fruits	35	36	36	34	35	29	27	31	25	39
13 - Lac	0	0	0	0	0	0	0	0	0	0
14 - Vegetable plaiting materials	16	1	6	14	15	10	8	8	9	8
15 - Animal or vegetable fats and oils	8	5	4	6	6	9	7	14	11	6
16 - Preparations of meat and fish	0	0	0	0	0	0	0	0	0	0
17 - Sugars and sugar confectionery	9	9	5	3	2	2	3	1	1	1
18 - Cocoa and cocoa preparations	1	1	1	1	1	1	1	1	1	1
19 - Preparations of cereals, flour	1	1	1	1	1	1	1	1	1	1
20 - Preparations of vegetables, fruit	5	4	6	4	5	6	5	5	5	6
21 - Miscellaneous edible preparations	1	1	1	1	1	0	0	1	1	1
22 - Beverages, spirits and vinegar	7	7	7	7	7	7	6	5	5	6
23 - Residues and waste from the food	2	2	1	2	2	2	2	2	3	1
24 - Tobacco and manufactured tobacco	2	2	2	3	3	1	1	1	1	0

Source: authors' calculations based on UN Comtrade (2026) [16].

The group with no specialization or weak specialization includes the remaining commodity groups (Table 2).

Therefore, the Moldovan RCAs values are higher than the EU ones at the global level for some products like oil seeds, cereals, fruits, nuts, oils and wine presenting a contrast with the EU profile that is more specialized in processed agri-food products.

Trade intensity index measures how intensively Moldova exports a certain product to EU countries, compared to the world

exports to EU. Most of the calculated values exceed the benchmark of 100, fact that confirm the intense agri-food trade between Moldova and EU in many commodity groups. Thus, there have been developed the following grouping of the results:

Very high trade intensity with an average TII approximately of 200 – 400: Cereals (with TII varying between 188–401); Oil seeds and oleaginous fruits (with values clustered between 199 to 454); Animal or vegetable fats and oils: (in the range from 210 to 327); Products of the milling industry: (spanning 147 to 375); Edible fruit and nuts (with a variability between100 to 162); Edible vegetables (41 to 160, with a strong increase in 2024); Vegetable plaiting materials with high peaks of 260–482 in the recent years; etc.

Moderate to high intensity trade with average values of TII between 50 – 150: Dairy, eggs, honey: with TII values between 84–160; Miscellaneous edible preparations: (33–132) etc.

Some groups like Live animal, Meat and edible meat offal, Products of animal origin, Live trees and other plants etc. present a low intensity trade (Figure 3).

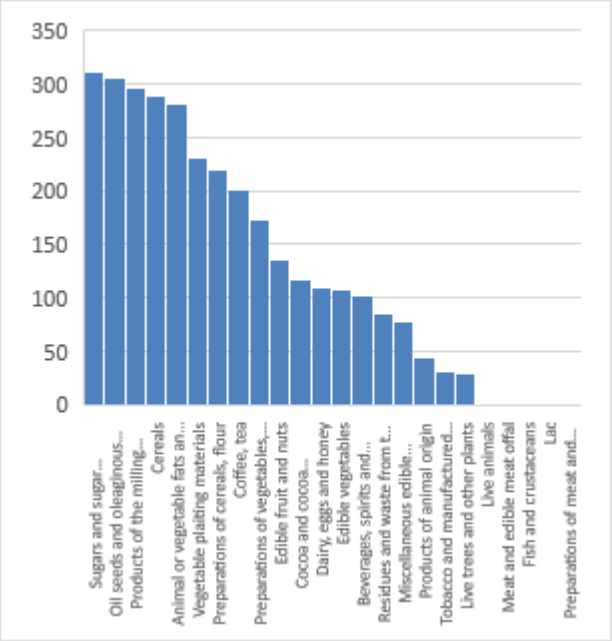

Fig. 3. Trade intensity index, average values for 2015-2024

Source: authors' calculations based on UN Comtrade (2026) [16].

Thus, there is noted an intense Moldova – EU agri-food integration with TII values >100 in most of the categories, which present that Moldova exports in a more proportional manner to the EU than to the other countries. The recent years present more intense figures, pointing on a European reorientation of products, but also has some shortcomings related to the high dependence on one market.

For Grubel-Lloyd index, a value closed to 1 means that Moldova exports and imports almost similar volumes of a certain commodity to and from EU, while values near 0 point on the presence of inter-industry trade, where Moldova is either an importer or exporter of a specific product. The index results can be grouped in:

-Sectors with high intra-industry integration (values close to 1): preparations of cereals and flour with an increase from 0.3 in 2015 to 0.9 in 2024; sugars and sugar products which were almost every year over 0.7, with a peak near 0.98; beverages, alcoholic drinks and vinegar with an increase up to 0.8 in 2024; products of the milling industry with an observed upward trend, etc.

-Medium inter-industry trade: Preparations of vegetables, fruit, nuts with an average of 0.5 for the period 2015 – 2024; Dairy products, eggs and honey – 0.5; Residues and waste from the food industry - 0.4; Edible fruit and nuts (fresh or dried) - 0.3; Oil seeds and oleaginous fruits - 0.3; Edible vegetables - 0.3; Cereals - 0.3; Coffee, tea, mate and spices - 0.3.

-Sectors characterized by inter-industry trade (values close to 0): Vegetable plaiting materials - 0.2; Tobacco and manufactured tobacco - 0.2; Animal/vegetable fats and oils - 0.2; Miscellaneous edible preparations – 0.2. At the same time, some of the primary sectors are near zero: live animals (0.0), meat (0.006), fish/crustaceans (0.008), products of animal origin (0.030), live trees/plants (0.037) (Table 3). These data present Moldova's comparative advantage in exporting or importing some raw agricultural goods while importing almost none. A certain degree of success of DCFTA may be confirmed by some sectors with added value like processed and semi-processed commodities. Important shifts are noted for

some sectors like the milling industry with a considerable increase while tobacco and dairy with some declines. Moldova has passed over the traditional export of raw products to some food processing areas, but high levels of GLI are not yet achieved for most important processing sectors.

Table 3. Grubel-Lloyd index with respect to EU countries, 2015 – 2024

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
01 - Live animals	0.0	-	-	-	-	-	-	0.0	-	-
02 - Meat and edible meat offal	-	0.0	0.0	0.0	-	0.0	0.0	0.0	-	0.0
03 - Fish and crustaceans	0.0	0.0	0.0	-	-	0.0	0.0	0.0	0.0	0.0
04 - Dairy, eggs and honey	0.7	0.5	0.7	0.6	0.5	0.3	0.3	0.3	0.2	0.2
05 - Products of animal origin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
06 - Live trees and other plants	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
07 - Edible vegetables	0.3	0.5	0.3	0.4	0.4	0.1	0.2	0.1	0.3	0.3
08 - Edible fruit and nuts	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.3	0.3
09 - Coffee, tea	0.4	0.4	0.4	0.4	0.3	0.2	0.2	0.1	0.1	0.1
10 - Cereals	0.3	0.2	0.2	0.2	0.3	0.6	0.3	0.2	0.1	0.2
11 - Products of the milling industry	0.3	0.4	0.3	0.5	0.5	0.5	0.5	0.6	0.8	0.9
12 - Oil seeds and oleaginous fruits	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.2	0.3	0.2
13 - Lac	-	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.1
14 - Vegetable plaiting materials	0.0	0.7	0.5	0.7	0.1	0.1	0.1	0.0	0.1	0.0
15 - Animal or vegetable fats and oils	0.1	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.3
16 - Preparations of meat and fish	-	0.0	0.0	-	-	-	0.0	-	-	0.0
17 - Sugars and sugar confectionery	1.0	0.4	0.6	0.7	1.0	0.9	0.7	1.0	1.0	0.4
18 - Cocoa and cocoa preparations	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.5
19 - Preparations of cereals, flour	0.9	0.9	1.0	1.0	0.9	0.8	0.7	0.6	0.6	0.5
20 - Preparations of vegetables, fruit	0.4	0.5	0.4	0.6	0.5	0.4	0.6	0.6	0.6	0.4
21 - Miscellaneous edible preparations	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3
22 - Beverages, spirits and vinegar	0.6	0.5	0.6	0.5	0.6	0.4	0.6	0.6	0.7	0.8
23 - Residues and waste from the food	0.2	0.5	0.2	0.3	0.2	0.2	0.2	0.8	0.8	0.7
24 - Tobacco and manufactured tobacco	0.7	0.5	0.2	0.1	0.1	0.2	0.2	0.0	0.0	0.0

Source: authors' calculations based on UN Comtrade (2026) [16].

CONCLUSIONS

As a result of entering into force of the DCFTA, Moldova's agri-food trade has successfully turned towards EU market, with noticeable export growth of more than 2.5 times during 2014 – 2024. The positive trade balance with agri-food products confirm the status of net exporter towards EU.

The RCA calculations present some trends mainly confirming that high RCA values for cereals and oil seeds represent the picture of domination of raw products in the export structure, while emerging advantages appear for fruits, nuts, preparations of fruits and vegetables and beverages. The RCA for specialization also confirms the still high specialization of Moldova in primary products than the EU average. At the same time, the Grubel-Lloyd indices closer to 1 for sugars, milling industry or beverages suggest for a growing phenomenon of the intra-industry trade and represent among the first stages towards enhancing the added value of the exported products.

The presented patterns point on the need for diversification of added value production in order to sustain the competitiveness in the long term and a better alignment with the CAP provisions.

Quality compliance issues supported by the modest RCA figures and low Grubel-Lloyd indices for products of animal origin present the need for better processing capacities in order to transform natural advantages into competitive ones.

In order to enhance this process, it is recommended to modernize continuously the value chains with a prioritization of processing infrastructure, alignment with the sanitary provisions of EU and standards of the CAP, export diversification through collective activities and continuous monitoring mechanisms based on empirical evidence in order to evaluate annually the progress.

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OPTIMIZATION OF AGRICULTURAL HOLDINGS THROUGH SUSTAINABLE PRACTICES - CASE STUDY OF SACOSU TURCESC COMMUNE, TIMIȘ COUNTY, ROMANIA

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Abstract

Since ancient times, agriculture has been a vital area of human activity, being the main source of food, an important supplier of raw materials for industry, and the basic activity of the rural population. In this context, the optimization of agricultural holdings in the Romanian rural area represents an essential condition for increasing competitiveness and ensuring sustainable development, under current economic, climatic and structural pressures. The paper analyzes how sustainable agricultural practices, combined with investments aimed at increasing added value and vertical integration of the production process, contribute to improving the technical and economic performance of an agricultural holding. The research methodology is based on the use of methods for collecting, processing and interpreting statistical data, as well as on the case study method, applied to a crop farm in Sacosu Turcesc commune. The evaluation of economic performance is carried out by determining financial indicators and applying cost-benefit analysis. The conclusions confirm the economic viability of an integrated model for optimizing agricultural holdings, applicable to small and medium-sized farms in Romanian rural area.

Key words**:** *rural area, sustainable agriculture, sustainable practices, cost-benefit analysis, agricultural holdings*

INTRODUCTION

Rural development is a multidimensional and multisectoral process that includes not only the current changes in agriculture and forestry but also those in other economic and social areas existing in the rural area. However, agriculture remains the main sector of activity in the rural area [13]. This sector provides jobs for a significant part of the population and, after decades of difficulties, still has a huge development potential. Every effort must be made to ensure that the development of a more productive agricultural sector generates benefits for farmers and rural areas [10]. Romania still has a high percentage of the rural population who, for their subsistence, rely to some extent on small and fragmented plots of land and on the use of communal or state-owned pastures [1]. These small farmers have very limited resources, with modest growth potential. In many cases, smallholder farmers provide virtually all the national agricultural production [8]. Products derived from smallholdings are often mainly intended for subsistence or semi-subsistence [2]. Marketing any surplus is even more difficult due to limited links to organized markets and a degraded and damaged rural infrastructure [5, 11].

Rural space is a particularly complex concept, which has generated a great diversity of opinions regarding its definition, scope and components. Thus, there are specialists who define rural space in opposition to urban space, one of them being Robert Badouin, who in his Rural Economics course, defines rural spaces: "...areas characterized by a relatively low population density and by the preponderance of agricultural activities. Rural

space, contrary to urban space, does not involve strong concentrations of people. Agglomerations are limited to the size of the village or the town. It is represented by a dispersed habitat in the form of hamlets or farms scattered in nature. Rural space is suitable for agricultural activities..." [14].

The concept of development is often identified with that of growth, although the two are not synonymous [16]. Growth means the expansion of all economic activity in a territory and is measurable by the increasing number of jobs, by increasing the income of the population. The programs that generate this growth emphasize the immediate creation of jobs, generally with support from the state. Development aims at the sustainable increase of individual, community and institutional productivity, which can lead to ensuring higher incomes for individuals [15].

Sustainable development must ensure an improvement in people's standard of living and well-being while allowing for the long-term preservation and use of environmental resources. Thus, sustainable development represents a long process of slow changes [11].

The concept of sustainable rural development began to take shape after the United Nations Conference on the Human Environment (Stockholm, 1972) and the creation of the World Commission Environment and Development (WCED, 1987). Based on the Brundtland Report, sustainable development is defined as that "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [17].

From an economic perspective, sustainable development must be achieved under profitable conditions and should support the viability of agricultural holdings, since agriculture remains the determining element of rural development in most rural areas [3].

From an economic perspective, the principles of sustainable development of rural areas must be consistent with economic and social development and avoid environmental degradation. Environmental protection is the fundamental element of sustainable development and must be consistent with the principles of practicing sustainable agriculture [9, 14].

The practice of sustainable agriculture aims to: maintain soil quality and ensure an optimal correlation between the quantity and quality of food, human health and maintaining the quality of the environment. The achievement of these equilibrium correlations can be ensured by practicing an alternative agriculture whose objective function is determined by ecological and production restrictions [18]. As directions of action, the following activities are necessary: crop rotation; recycling of crop residues and manure; use of chemical fertilizers, pesticides and other chemical substances in restricted doses; expansion of soil protection and improvement crops including nitrogen-fixing legumes (soybeans, peas, alfalfa, etc.); integrated disease and pest control [4].

There is a significant debate in the literature on the relationship between sustainability and the economic performance of agricultural holdings. On the one hand, the adoption of sustainable agricultural practices is often seen as a source of additional costs and technological constraints in the short term. On the other hand, numerous recent contributions show that sustainability can become a factor of competitiveness, by reducing agronomic risks, using resources more efficiently, stabilizing production and increasing the capacity to adapt to market volatility and climate change [6, 7].

However, the literature frequently treats farm economic efficiency, sustainable agricultural practices and investments in agricultural infrastructure separately, without sufficiently analyzing how these components act together in the process of optimizing agricultural holdings. In particular, in the case of small and medium-sized farms in Romania, there are relatively few applied studies that highlight, based on a case study, the link between the adoption of sustainable practices, increased profitability and the vertical integration of complementary economic functions to the farm.

In this paper, efficiency is understood as improving the ratio between the resources used and the economic results obtained at the

level of the current activities of the farm. Optimization has a broader meaning and aims to configure an operating model that maximizes the performance of the farm in the medium and long term, by integrating sustainable practices, logistical investments and complementary economic functions. Also, sustainability is not assimilated to profitability: profitability is an economic indicator of performance, while sustainability involves an integrated approach, which includes economic, ecological and social dimensions.

From a social perspective, sustainable rural development involves ensuring decent living conditions in all localities and regions where human activity is present. Not all regions offer the same conditions for economic and social development [9].

Differences arise due to natural conditions and due to the level of development of the region from an economic point of view [14].

Sustainable development of rural regions cannot be conceived without considering finding viable solutions for the multitude of problems identified in social terms, without a rural infrastructure that allows and outlines a minimum of comfort for the members of a community.

Thus, the Romanian rural area faces numerous structural, economic and social challenges, generated by the fragmentation of agricultural holdings, the volatility of agricultural markets, climate change and alignment with EU sustainability standards. In this context, simply streamlining the economic activities of a farm is not enough, an integrated approach to optimizing agricultural holdings is necessary, which includes both the technical-economic dimension and the social and environmental one.

The specialized literature in the domain states that small and medium-sized farms can become competitive in the market by diversifying their activities, through economic integration and through adaptability to market requirements. In Romania, recent studies highlight the urgent need for a transition from subsistence or semi-subsistence agriculture to market-oriented, sustainable and resilient agricultural holdings [6,7].

In this context, the paper is part of the debate on the extent to which sustainable agricultural practices, correlated with investments aimed at increasing added value and strengthening post-harvest functions, can contribute not only to increasing economic efficiency, but to optimizing agricultural holdings. The objective of the paper is to highlight, based on an applied case study, how sustainable agricultural practices and logistics investments can contribute to increasing economic performance, reducing farm vulnerabilities and consolidating a competitive and sustainable agricultural model. The specialized literature deals with these aspects: sustainability, efficiency and infrastructure, but mostly separately. Also, there are relatively few integrated studies at the level of small/medium farms in Romania. Thus, the paper aims to fill an existing gap in the specialized literature through an integrated analysis of the relationship between sustainability, economic efficiency and functional optimization of a farm in the Romanian rural environment.

MATERIALS AND METHODS

The research undertaken for the purpose of this study was structured on two distinct methodological components: quantitative research and qualitative research, integrated into an applied case study approach.

The choice of the case study was based on its relevance for the category of small and medium-sized agricultural holdings in the Romanian rural area, which are in a process of transition from a traditional production model to one oriented towards sustainability, diversification and increased added value. The farm under analysis is considered analytically relevant due to the size of the holding, the crop structure, the limited access to resources and the need to adapt to economic, climatic and commercial pressures, characteristics frequently encountered in Romanian agriculture.

Therefore, the case study does not aim at a statistical generalization of the results at the level of all agricultural holdings, but at the formulation of analytical and applicative

conclusions relevant to farms with a similar profile. In this sense, the selected case is illustrative for understanding how sustainable practices and infrastructure investments can influence the optimization process of an agricultural holding.

Quantitative research (theoretical documentation). This stage consisted of analyzing the relevant specialized literature for the field of sustainable agriculture and rural development, using national and international academic sources. Concepts such as sustainable rural development, optimization of agricultural holdings, economic efficiency and vertical integration in agriculture were analyzed. At the same time, statistical data and recent studies were used to substantiate the theoretical framework, according to the selected bibliography.

Qualitative research (case study). The empirical component of the paper was based on the case study method applied to an agricultural holding located in the Sacosu Turcesc commune, Timiș County. The study was carried out within a research project entitled "Studies on the efficiency of the technical and economic activity of P.N. PFA farm and development possibilities in the context of sustainable agriculture".

Data collection was carried out through:

- direct observations within the agricultural holding;
- analysis of the farm's economic and financial documents;
- discussions with the farm administrator;
- the use of data generated through digital technologies.

The analysis also has an internal comparative component. It is based on comparing the economic results obtained in two stages of development of the same farm: on the one hand, the operating model in 2024, characterized by a more restricted productive structure and conventional practices, and on the other hand, the model applied in 2025, after the introduction of sustainable practices, the expansion of the cultivated area and the development of logistical investments. In this way, the study allows to capture the differences between the streamlining of current activities and the broader optimization of the farm.

The following methods were used to evaluate economic performance and investment efficiency:

- Cost-Benefit Analysis (CBA), to determine the profitability of sustainable practices;
- economic indicators: total profit, incremental benefit (ΔB), incremental cost (ΔC);
- Benefit-Cost Ratio (B/C), used to evaluate the efficiency of investments;
- Payback Period (PP), used to estimate the investment recovery period.

This methodological framework enables an integrated assessment of the impact of sustainable practices on economic performance and on the process of optimizing the agricultural holding.

It is important to note that the comparative analysis carried out between 2024 and 2025 presents certain methodological limitations. Thus, the differences observed in the economic performance of the agricultural holding cannot be attributed exclusively to the introduction of sustainable agricultural practices, as they are also influenced by other external factors, such as the evolution of the prices of agricultural products, the climatic conditions specific to each agricultural year or the expansion of the cultivated area. In this sense, the analysis rather reflects a correlation between the adoption of sustainable practices and the economic results obtained, without allowing the establishment of a strict causal relationship. However, the methodology used provides a relevant picture of the direction of development of the holding in the context of the transition to a sustainable model.

RESULTS AND DISCUSSIONS

The farm presented in this article is an individual agricultural holding covering 24 hectares, operating in the crop sector (wheat, corn, rapeseed), from the Sacosu Turcesc commune, Timiș County. Based on the economic results obtained in 2024, it became necessary for the holding to undergo a transition towards sustainable agriculture to improve its technical and economic performance. The main crops of the farm are

the following: wheat, corn and rapeseed (Table 1, year 2024). Thus, the farm increased its area to 45 hectares (by leasing), and sustainable agricultural techniques were introduced, with a positive impact on both the economic activity of the farm and the environment: In order to ensure proper crop rotation, new crops were introduced: alfalfa for seed, sunflower and soybean (Table 1, year 2025).

Table 1. Technical and economic data of the analyzed crop farm, 2024 and 2025

No.	Crops	Cultivated area	Average production	Sale price
	Unit of measurement	(ha)	(kg/ha)	(lei/kg)
1	**Year 2024**			
2	Wheat	10	4,500	0.8
3	Corn	8	6,000	0.9
4	Rapeseed	6	2,400	2.0
5	**Total**	**24**	-	-
6	**Year 2025**			
7	Wheat	10	4,700	1.1
8	Corn	8	6,200	1.3
9	Rapeseed	6	2,500	2.4
10	Alfalfa (seed)	7	700	10.0
11	Sunflower	7	2,800	2.2
12	Soybean	7	2,300	2.0
13	**Total**	**45**	-	-

Source: own according to the documents of the farm analyzed.

The sustainable agricultural techniques introduced are crop rotation, minimum tillage, the use of organic fertilizers instead of chemical ones, efficient irrigation (especially during drought periods), digitalization of agricultural processes using modern monitoring technologies, including satellite-based NDVI indices for assessing vegetation status. These measures were implemented within a research project entitled "Studies on the efficiency of the technical and economic activity of the P.N. PFA farm and development possibilities in the context of sustainable agriculture" and part of the results have been disseminated in previous research outputs.

The economic results obtained in 2025 indicate significant improvements in performance were observed, demonstrating the efficiency of the farm's activity in the context of the development of sustainable agriculture [12].

The results obtained show that a clear demarcation between efficiency and optimization is necessary. Efficiency aims to improve the performance of individual farm activities, by increasing yields, reducing costs or making better use of resources. In contrast, optimization involves a higher level of organization, namely the configuration of an operating model that correlates agricultural production, sustainable practices, logistics infrastructure and production marketing to maximize economic performance and ensure medium and long-term stability. From this perspective, efficiency is a component of optimization, without being confused with it.

Cost-benefit analysis is a type of analysis that evaluates the economic efficiency of a farm that moves from traditional agricultural practices to sustainable agricultural practices, by comparing the increase in profit obtained due to the new practices introduced (incremental benefits, ΔB) and the additional expenses generated by the application of sustainable practices (incremental costs, ΔC).

From an economic point of view, an implemented measure is considered profitable if the benefit-cost ratio is greater than 1 ($B/C > 1$) and if the investment payback period is short.

For the 24 ha, the comparison of the years 2024–2025 shows that the application of sustainable practices in 2025 leads to a significant increase in total profit, from 27,800 lei to 58,780 lei. The incremental benefit is 30,980 lei/year, obtained with an additional cost of 9,200 lei/year

The benefit-cost ratio calculated for the implementation of sustainable agricultural practices is 3.37, a value indicating that each leu invested generates a benefit of 3.37 lei (Table 2).

For the 45 ha, the total profit at the level of the year 2025, in the amount of 92,100 lei clearly exceeds the reference profit of 52,125 lei (reference profit corresponding to the baseline scenario). The incremental benefit is 39,975 lei/year, obtained with an incremental cost of 17,600 lei/year.

The calculated benefit-cost ratio for implementing sustainable agricultural practices is 2.27, with a payback period of 5.3 months, indicating high profitability and a relatively fast recovery of the investment. The

expansion of the area amplifies the positive effects of sustainable practices on the profitability of the farm.

Table 2. Cost benefit analysis

Year 2024 (24 ha)		
Total Profit (PrT)	**PrT=V-C**	**27,800 lei**
Year 2025 (24 ha)		
Total Profit (PrT) under sustainable practices	PrT= V-C	58,780 lei
Incremental Benefit (ΔB)	$\Delta B = PrT_{2025} - PrT_{2024}$	30,980 lei/year
Incremental Cost of Sustainability (ΔC)	$\Delta C = C_{sustainable} - C_{traditional}$	9,200 lei/year
Benefit/Cost Ratio (B/C)	B/C= ΔB/ ΔC	3.37
Payback period (PP)	PP= ΔC/ ΔB	0.30 years, respectively 3.6 months
Year 2025 (45 ha)		
Total Profit (PrT) 2025	PrT= V-C	92,100 lei
Reference profit (PrTR)	PrTR= V-C	52,125 lei
Incremental Benefit (ΔB)	ΔB= PrT-PrTR	39,975 lei/year
Incremental Cost of Sustainability (ΔC)	$\Delta C = C_{sustainable} - C_{traditional}$	17,600 lei/year
Benefit/Cost Ratio (B/C)	B/C= ΔB/ ΔC	2.27
Payback period (PP)	PP= ΔC/ ΔB	0.44 years, respectively 5.3 months

Source: own according to the analyzed farm documents.

It is necessary to specify that part of the increase in profitability recorded in 2025 is also determined by the favorable evolution of the prices of agricultural products, an aspect highlighted in Table 1. Thus, the increase in prices of the main crops contributes significantly to the increase in the total income of the holding. Consequently, the economic performance obtained cannot be attributed exclusively to the implementation of sustainable agricultural practices but must be interpreted in the combined context of technological and market factors. However, the restructuring of production and the diversification of crops contribute to a better adaptation of the holding to market conditions, representing an essential element of the optimization process.

The implementation of sustainable agriculture **practices leads to significant increases in profit, with short investment recovery periods**, demonstrating the economic viability of the transition to a sustainable agricultural model, both for small and medium-sized farms.

Another essential aspect in assessing the performance of the agricultural holding is the dimension of agricultural risk. The sustainable agricultural practices implemented, such as crop rotation, diversification of the production structure and the use of modern monitoring technologies, contribute not only to increasing profitability, but also to reducing agronomic and climatic risks. Crop diversification reduces the farm's dependence on the evolution of a single market or the performance of a single crop, thus reducing income volatility. Also, the use of digital technologies, such as monitoring through satellite images, allows for the early identification of plant stress and the optimization of technological interventions. In this context, sustainability can be interpreted not only as an instrument of economic growth, but also as a mechanism for stabilizing income and increasing the resilience of the farm to external risks.

The results obtained in the case study are consistent with the conclusions of the specialized literature, which highlights the fact that the adoption of sustainable agricultural practices contributes significantly to increasing the economic efficiency of agricultural holdings [12,3]. At the same time, crop diversification and compliance with crop rotation confirm the conclusions of other studies, according to which sustainable agriculture can reduce agronomic risks and stabilize production in conditions of climatic and economic volatility [9,18].

Furthermore, the results on improving farm profitability support the idea that sustainability is not only an ecological constraint, but also an economic opportunity for small and medium-sized farms, in line with recent studies on the need for Romanian agriculture to transition towards market-oriented, competitive and resilient agricultural models [1,12].

Also, to optimize the farm's activity, in addition to sustainable agricultural practices, investments were introduced to increase added value and vertically integrate the technological flow.

This stage is also important from a conceptual point of view, as it shows that the optimization of the agricultural holding is not limited to improving the marketing of

production, but also includes the consolidation of the post-harvest, logistical and commercial functions of the farm. Therefore, the investments made do not represent only a physical expansion of the material base, but a strategic component of the transition from a strictly production-oriented farm to an integrated holding, with greater capacity for capitalization and control over its own economic flow.

Thus, the farm diversified its activity by purchasing a 3,000 sq m plot of land, on which it built a 300 sq m storage hall, a 280 sq m agricultural hangar and which also includes a 60-ton weighing scale. These investments aimed to reduce post-harvest losses, improve product storage management and increase negotiation capacity in the product marketing process.

The construction of the storage hall (300 sq m) directly contributes to the efficiency of the post-harvest chain, by ensuring the conditions for storage and separation of batches, reducing the risks of qualitative depreciation (humidity, contamination, physical losses) and reducing the pressure to sell immediately after harvest, when prices are often unfavorable. In practice, the storage space offers the farm commercial flexibility, allowing the timing of sales and orientation towards times with higher demand or more advantageous prices, which is reflected in the increase in gross margin and profitability per hectare.

The agricultural shed (280 sq m) plays an essential role in operational optimization, by protecting and organizing the fleet of machinery, inputs and materials. Sheltering the machinery reduces accelerated wear and maintenance costs, decreases work preparation times and minimizes the risks of interruptions during critical periods (sowing campaigns, treatments, harvesting). In addition, the existence of a dedicated space allows for better planning of activities, more efficient internal logistics and more rigorous control of consumption (fuel, parts, materials), with a direct effect on production costs. The integration of the 60t scale represents a tool for economic control and commercial transparency, through the possibility of accurately weighing production upon leaving the farm. It reduces dependence on external weighing points, reduces logistical costs (travel, downtime) and limits the risks associated with measurement errors or commercial disputes. Furthermore, the scale facilitates precise quantitative records on lots and crops, providing useful data for performance analysis (production/ha, yields, losses) and for management decisions (planning, contracting, stock sizing).

At a strategic level, the investment in the 3,000 sq m plot and the development of the logistics infrastructure position the farm as a more competitive player in the market, by increasing operational autonomy and the capacity to capitalize on the production. By storing, handling and weighing in-house, the farm can move from an “as needed” sales model (immediately after harvest) to a market-oriented model, based on a sales calendar, selection of distribution channels and more advantageous contractual negotiation. Moreover, the created infrastructure opens opportunities for complementary income, such as providing logistics services for other farmers (weighing, temporary storage, handling), contributing to diversifying income sources and reducing vulnerability to price and production fluctuations.

The value of the investment is significant (approximately 200,000 Euros), financed through a bank loan and a significant contribution from the farmer’s own funds.

The investment was made in the current year, while its economic benefits are expected to materialize over time.

The forecast indicates the main sources of annual benefits generated by this investment:

- internal farm benefit resulting from the storage of production and price control, depending on supply and demand, not having to sell immediately after harvest;
- reduction of losses caused by the qualitative depreciation of production, due in previous years to the improper storage of production;
- logistical savings: elimination of many transport routes, reduction of dead times, and external weighing;

- income from services for other farmers: weighing, storage, handling.

The payback period is not very long, a maximum of 5 years, if the infrastructure is used as a local service point for third parties (weighing + storage), which confirms the economic efficiency of the investment (Table 3).

Table 3. Cost benefit analysis forecasts for hall investment and facilities

Indicator	Calculation formula	Value
Investment	Land acquisition + equipment	1,000,000 (200,000)
Total annual benefit (ΔB)	Own B + Third-party B	260,000 lei/year
Annual operating costs (ΔC)	Logistics costs	70,000 lei/year
Net annual benefit	ΔB - ΔC	190,000 lei/year
Benefit/Cost ratio (B/C)	B/C= ΔB/ ΔC	3.71
Payback period (PP)	PP= **Investment** / Net annual benefit	5.26 years,

Source: own according to the analyzed farm documents.

Estimates of the economic benefits generated by investments in logistics infrastructure assume the efficient use of the created capacities and the existence of local demand for the services offered (storage, weighing, handling). However, the results obtained may vary depending on the actual degree of use of the infrastructure, the level of local competition and the capacity of the holding to attract external customers. In this regard, alternative development scenarios can be outlined: an optimistic scenario, characterized by full use of capacities and rapid recovery of the investment, and a conservative scenario, in which the degree of use is lower, which will lead to the extension of the recovery period. Thus, the investment analysis must be interpreted in a dynamic manner, dependent on the economic conditions and the managerial capacity of the holding.

In conclusion, by acquiring the land and building the hall, hangar and scales, the farm introduced an investment component with high added value, which complements sustainable practices by improving post-harvest efficiency, reducing operational costs, increasing managerial control and strengthening the negotiating position in the production value chain.

These results are also supported by the specialized literature, which emphasizes that investments in logistics infrastructure and in the vertical integration of technological flow contribute to increasing the competitiveness of agricultural holdings, by reducing dependence on intermediaries and by improving the capacity to capitalize on production [5, 11]. In this sense, the analyzed case highlights the fact that the farm optimization is not limited to the production stage, but also includes the consolidation of the post-harvest and commercial functions of the farm.

CONCLUSIONS

The analysis carried out in this study highlights that the optimization of agricultural holdings in rural Romania can be achieved efficiently through an integrated approach, which combines sustainable agricultural practices with investments aimed at increasing added value and vertical integration of technological flow. The case study of the P.N. PFA farm in Sacosu Turcesc commune demonstrates that the transition from a traditional agricultural model to a sustainable one leads to significant improvements in economic performance, without compromising environmental objectives.

The results of the cost–benefit analysis indicate that the implementation of sustainable agricultural practices generated substantial increases in profitability, both at the level of the initial 24-hectare farm and under the scenario of land expansion to 45 hectares. The high values of the benefit/cost ratio and the short investment recovery periods confirm the economic viability of this production model, demonstrating that sustainability is not an economic constraint, but a factor of competitiveness. The introduction of diversified crops, adapted to local pedoclimatic conditions, together with strict adherence to crop rotation principles, contributed to production stability, reduced agronomic risks, and enhanced the efficiency of natural resource use. In addition, these measures created the premises of a more resilient agriculture, capable of responding to

the challenges generated by the volatility of agricultural markets and climate change.

The investments made in the logistics infrastructure – storage hall, agricultural hangar and scale – have added a new dimension to the optimization process, by improving post-harvest management, reducing qualitative and quantitative losses and increasing the farm's autonomy in the production capitalization process. These investments contribute to increasing the farmer's negotiating capacity and allow the transition from an immediate sales model to a strategically market-oriented one.

The investment analysis shows that, under the conditions of using the infrastructure and providing services to other farmers, the payback period of the invested capital is reasonable, and the annual economic benefits are significant. Thus, the analyzed farm assumes an expanded functional role within the local economy, becoming a potential agricultural and logistics services hub at the commune level.

The results should be interpreted within the methodological limits inherent to the case study approach, which does not allow statistical generalization to all agricultural holdings in Romania. However, the study provides a relevant analytical framework for understanding the relationship between sustainable practices, economic performance and logistical investments in the context of small and medium-sized farms undergoing transition towards a sustainable and integrated model. Future research could extend the analysis to a broader sample of holdings and incorporate quantitative models for assessing the impact of climatic and economic risks on farm performance.

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ANALYSIS OF FOOD ACCESS IN BULGARIA AS A BASIS FOR FOOD SECURITY

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Abstract

The article examines one of the four elements of food security, namely access to the necessary amount of quality food. In recent years, it has spread extremely widely, the advice of military conflicts and disruption of supply chains dictated by measures against the spread of Covid 19 have made production and this is difficult and often managers, commercial organizations and people to be carried out in the face of various challenges. In the first quarter of the 21st century, food security is faced with the difficulty of ensuring access to food products for political, economic and social reasons. Data from the Global Food Security Index (GFSI) were analyzed. The analysis included indices of real income, real expenditure and prices, the relative share of the poor by gender and age group, and the population at risk of poverty or social exclusion by gender and age. The aim is to assess the population's access to food in Bulgaria. Achieving a balance between food accessibility, trade in agricultural goods, and the fight against low incomes and inequality is key to a sustainable food system.

Key words**:** *food security, GFSI, real income, real expenditure, average price, poverty*

INTRODUCTION

In modern science, food security is of paramount importance and is strongly influenced by geopolitical, economic, social and natural factors. To study it in depth, a multidisciplinary approach must be used and a rich set of analytical tools must be used.

The FAO definition is as follows: Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. (World Food Summit, 1996) [11].

Given population growth and rising incomes, food demand is expected to increase by 70 to 100 percent by 2050. To meet this need, the United Nations estimates that production in developing countries will need to nearly double (USDA, 2025) [8].

According to the World Bank, physical and economic access to food and adequate supply are the main factors that affect food security at the agricultural level. Fears of insufficient access to food have led to a greater policy focus on income, expenditure, markets and prices in achieving food security goals. (World Bank, 2023) [10].

Access to food resources is one of the four main measures of food security, along with availability, quality and safety, and resilience and adaptation, and they are inextricably linked.

Access to food can be hampered by poor harvests due to extreme weather conditions, or by food being unavailable in markets due to high inflation, or by people being unable to reach these markets because they live in areas affected by conflict and disaster. Access can also be limited by gender, ethnicity, or other factors (WPF, 2025) [12].

Reduced food availability as a result of reduced yields due to climate change has further direct consequences for access to food. As food becomes increasingly scarce, prices rise and food becomes unaffordable for a growing portion of the population (Vrabcheva, 2016) [9].

Access to food has never been more important. As the COVID-19 pandemic spreads across the world, identifying ways to

ensure local access to the global supply chain for essential goods and services, such as food, water, and shelter, is a top priority. (O'Hara and Toussaint, 2021) [6].

Food access and logistics, where food affordability is achieved by ensuring economic and physical access to food, especially for vulnerable groups (children, the elderly, the sick, and people with low incomes) and combating poverty and inequalities that limit access to quality food, can be changed through social programs and subsidies for people with low incomes (Kasova, 2025) [2].

Accessibility is a right according to which every person should have physical and economic access to basic food products. People should have access to adequate resources (rights) to acquire appropriate foods for a nutritious diet. Rights are defined as the set of all bundles of goods over which a person can establish control, taking into account the legal, political, economic and social arrangements of the community in which they live (including traditional rights such as access to common resources) (Sidova, 2023) [7].

The aim of this study is to examine access to food in Bulgaria by tracking changes in average food expenditure, the share of the population below the poverty line, and the income of citizens. Customs tariffs and trade freedom will be examined, as well as control over food quality. The study will cover household purchasing power, average prices of basic food items purchased by households, and indices of real income, real expenditure, and prices for the period 2019-2024, as well as key poverty indicators. The impact of Covid 19 and the war in Ukraine on access in Bulgaria will be examined.

MATERIALS AND METHODS

The scientific article is based on accessibility as part of Bulgaria's food security. The need for information to obtain Bulgarian food security is the basis of this study. Articles by scientists from Bulgarian and foreign authors were studied and various free-access Internet sources were used. The research period is five years, covering the time frame from 2019 to 2024.

Retrospective, comparative and descriptive analysis were applied. The information used is mainly from FAO, Economist Impact, World Trade Organization, World Bank and World Development Indicators, NSI and agrostatistics. The current article cites excerpts from Bulgarian and foreign authors. Conclusions and generalizations were made. Part of the data is presented through tables and graphs.

RESULTS AND DISCUSSIONS

According to the prestigious Economist Impact publication, Bulgaria is in the upper middle income group, the prevalence of malnutrition is 3%, the percentage of stunted children is 6.4%, the percentage of underweight children is 1.9%, the prevalence of obesity is 27.4%, and the human development index is 0.82. According to it, the overall global food security index for our country in 2022 was estimated at 73 points, which ranks us 29th in the world, 18th in Europe, and 3rd in the upper middle income group, with only Costa Rica and China ahead of us. Neighboring countries such as Turkey, Greece, Romania, and Serbia are ranked lower than our country, and the Republic of North Macedonia did not participate in the study (Economist Impact, 2022) [1]. (Figure 1)

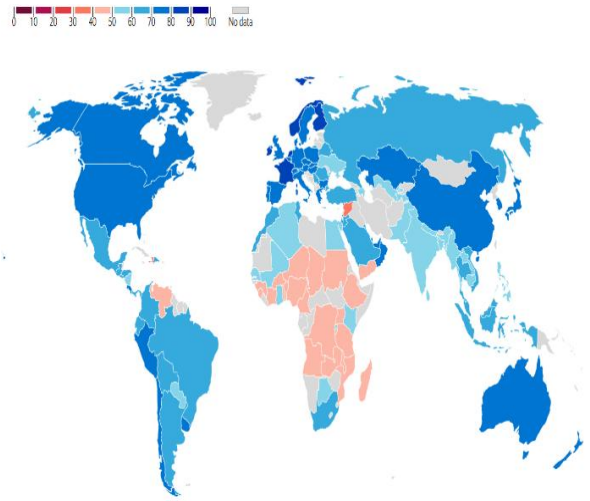

Fig. 1. Map of the world according to the Global Food Security Index
Source: (Economist Impact, 2022) [1].

In terms of food accessibility, according to the Global Food Security Index, Bulgaria ranks 34th with a score of 85.8.
The creation of the accessibility assessment index includes:
• *Accessibility*
-Change in average food expenditure
-Share of population below poverty line
-Income inequality index
• *Trade in agricultural products*
-Tariffs on agricultural imports
-Trade freedom
• *Food safety net programs*
-Existence of food safety net programs
-Financing of food safety net programs
-Coverage of food safety net programs
-Functioning of food safety net programs
(Economist Impact, 2022) [1].

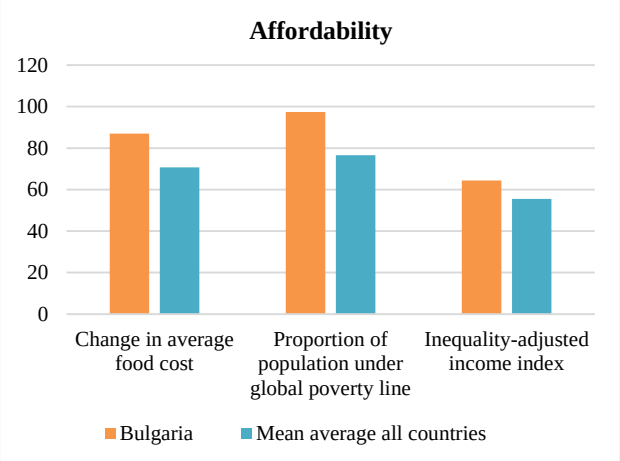

Fig. 2. Affordability in Bulgaria (GFSI)
Source: (Economist Impact, 2022) [1].

The change in average food costs is reflected by the Consumer Price Index for Food, which tracks changes in the price of an average basket of food products since 2015, using data from the FAO (Economist Impact, 2022) [1].
Bulgaria's score on this item is 87 points, which exceeds the average for all countries - 70.7. The share of the population below the poverty line is calculated as the percentage of the population living on less than $ 3.2 per day at 2011 purchasing power parity exchange rates, and the source of information is the World Bank and World Development Indicators. (Economist Impact, 2022) [1]. Our country is wonderfully positioned in this segment of the study, with a maximum score of 100, we are at 97.4 and significantly ahead of the world average, which is 76.6.
The inequality-adjusted income index is a measure of individual income (GNI per capita at 2011 PPP) adjusted for levels of inequality, the publication used the UN Information Program (Economist Impact, 2022) [1] as the source of information. Bulgaria is rated 64.4, which is higher than the average for all countries - 55.5 (Figure 2).
Economist Impact calculates the values of Trade in Agricultural Products using data from the EIU (Economist Impact, 2022) [1].
Figure 3 shows that the values are again higher in favor of Bulgaria than the average. Customs tariffs for agricultural imports are estimated using the average Most Favoured Nation (MFN) tariff applied to all imports of agricultural products, using data from the World Trade Organization (Economist Impact, 2022) [1]. Bulgaria's score is relatively good -72.2, ahead of the average indicators. Trade freedom is measured using an indicator that assesses the level of tariff and non-tariff barriers affecting the import and export of goods and services. The Freedom Index calculates the free trade score based on two inputs: the average trade-weighted tariff rate and non-tariff barriers. With a global average score of 71.3, Bulgaria has a score of 79.2, which places it well on the global map (Figure 3).
The Economist Impact publication conducts its own study using public data on the existence, financing, scope and functioning of food safety programs.

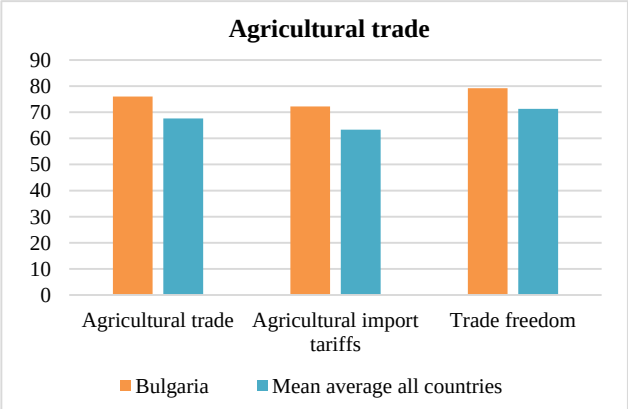

Fig. 3. Agricultural trade in Bulgaria *(GFSI)*
Source: (Economist Impact, 2022) [1].

In all categories, Bulgaria has a maximum score of 100 points. It is ahead of the average values, which is an indicator of excellent work in the field of food safety and control (Figure 4).

Dynamic price indices based on data from the Household Budget Survey

The change in prices of food and non-food goods purchased by households is characterized by calculating dynamic price indices based on information from the Household Budget Survey. These indices measure the average relative change in prices for the structure of purchased goods from the base period. For the period 2019 - 2024, the price index increases by over 40% (NSI, 2025) [5].

The price index is calculated by the formula:

$$I=\frac{\sum p1q0}{\sum p0q1} \quad \text{.....(1)}$$

where:

p0 - average price of goods during the base period;

p1 - average price of goods during the current period;

q0 - quantity of goods bought during the base period.

These indices are not comparable with the consumer price indices that take into account inflation in the country, since different methodologies were used in their calculation. The price index was developed using the consumer basket of goods formed based on data from the Household Budget Survey. When determining the indices in Table 1.

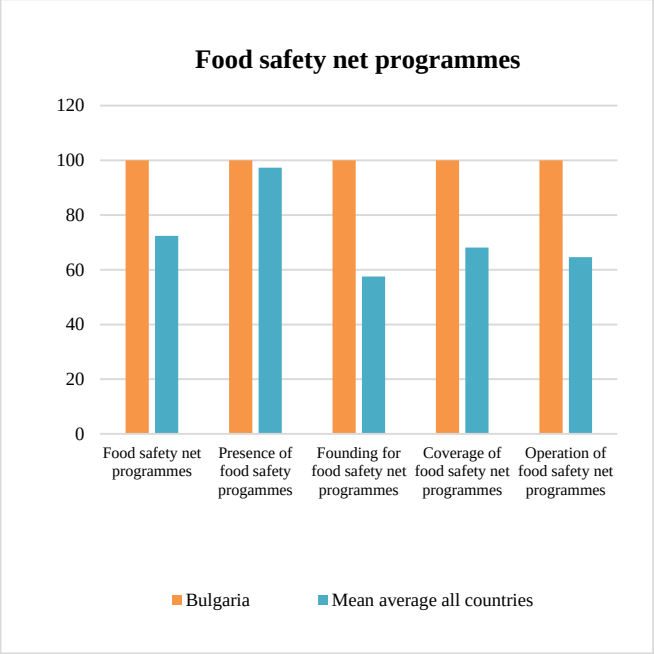

Fig. 4. Food safety net programmes in Bulgaria (GFSI)
Source: (Economist Impact, 2022) [1].

Only the goods for which the Household Budget Survey has data on the purchased quantities were taken into account - 117 items for food and 45 for non-food goods (NSI, 2025) [5].

Table 1. Dynamic price indices according to data from the Household Budget Survey in Bulgaria 2018-2024

Years	Base year						
	2018	2019	2020	2021	2022	2023	2024
2018	100						
2019	104.9	100					
2020	109.3	103.1	100				
2021	112.4	108.3	104.9	100			
2022	124.0	128.5	124.5	118.2	100		
2023	132.5	140.2	135.8	129.1	109.1	100	
2024	136.6	144.1	139.6	132.8	112.1	103.2	100

Source: (NSI, 2025) [5].

Indices of real total income per person in a household

From Table 2 it can be seen that total real income for the period under review increased by 52.7%. In 2024, compared to the previous year, the increase was 15.7%, for 2023 it was 10%, for 2022 it was 1.4%, for 2021 it was 6.5%, for 2020 it was 4.4% and for 2019 it was 6.3%, which shows that the highest growth was in the last two years.

Table 2. Indices of real total income average per capita in Bulgaria 2018-2024

Years	**Base year**						
	2018	2019	2020	2021	2022	2023	2024
2018	100						
2019	106.3	100					
2020	111.1	104.4	100				
2021	118.3	111.3	106.5	100			
2022	120.0	112.8	108	101.4	100		
2023	131.9	124.1	118.8	111.5	110.0	100	
2024	152.7	143.6	137.5	129.0	127.3	115.7	100

Source: (NSI, 2025) [5].

Indices of real total expenses per person per household

In real expenses, a constant increase is also observed, with only a decrease in 2020 compared to the previous year. For the period under review, the increase was over 44%, with the highest being in 2024 with 13.8% (Table 3).

Table 3. Indices of real total expenditure average per capita in Bulgaria 2018-2024

Years	Base year						
	2018	2019	2020	2021	2022	2023	2024
2018	100						
2019	104.4	100					
2020	102.8	98.4	100				
2021	112.7	107.9	109.6	100			
2022	116.4	111.5	113.2	103.3	100		
2023	127.3	121.9	123.8	113.0	109.4	100	
2024	144.9	138.8	141.0	128.6	124.5	113.8	100

Source: (NSI, 2025) [5].

Figure 5 shows the growth trend in all three indices.

The largest growth is in income with over 50%, followed by expenses with 44.9%. A slight decline is observed in real expenses in 2020, after which the curve begins to grow again.

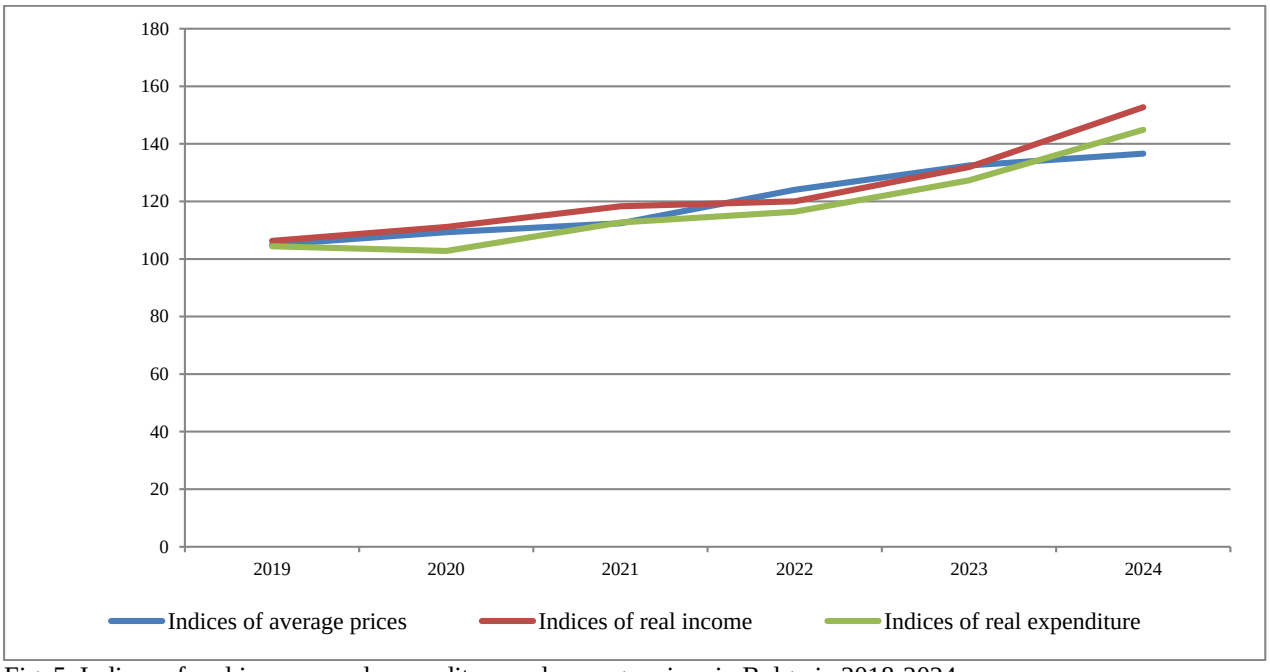

Fig. 5. Indices of real income, real expenditure and average prices in Bulgaria 2018-2024
Source: (NSI, 2025) [5].

The movement of the price indices, the real total income indices and the real total expenditure indices is relatively uniform with small fluctuations (Figure 5).

Household purchasing power, calculated using the average total income per person, for the period 2019 – 2024

Household purchasing power indicators are calculated using data from the Household Budget Survey.

Purchasing power is the amount of a certain type of good that can be purchased with the annual cash or total income of the household, if it were spent only on the purchase of that good.

The data are presented as absolute values in Table 4 (NSI, 2025) [5].

Table 4. Household purchasing power, calculated using the average total income per person, for the period 2019 – 2024

Goods	MU	2019	2020	2021	2022	2023	2024
White bread	Kg	4,094	4,244	4,257	3,866	4,445	5,205
Rice	Kg	2,770	2,714	2,723	2,772	2,955	3,366
Dry beans	Kg	1,682	1,675	1,739	1,823	2,123	2,440
Potatoes	Kg	5,634	6,669	7,554	7,149	6,695	7,792
Tomatoes	Kg	2,943	3,044	3,107	2,944	3,199	3,622
Cucumbers	Kg	3,109	3,197	3,251	3,128	3,327	3,838
Peppers	Kg	3,416	3,416	3,350	3,276	3,652	3,956
Apples	Kg	4,610	4,168	4,586	4,949	5,343	5,871
Grape	Kg	4,337	4,432	4,329	4,643	4,463	3,849
Milk	Liters	4,146	4,168	4,250	4,042	4,033	4,658
Yoghurt	Kg	2,879	2,942	3,045	2,896	3,081	3,642
White cheese	Kg	853	841	879	791	809	941
Yellow cheese	Kg	525	544	583	536	562	670
Pork	Kg	844	820	958	1,008	1,011	1,175
Poultry meal	Kg	1,439	1,415	1,440	1,335	1,407	1,599
Perishable sausages	Kg	1,036	990	1,043	1,059	1,089	1,195
Sausages	Kg	442	443	465	489	507	559
Eggs	Number	27,467	29,175	32,104	27,297	24,650	29,900
Sugar	Kg	5,110	5,037	5,277	4,209	4,220	5,818
Butter	Kg	393	464	480	440	514	594

Source: (NSI, 2025) [5].

Main indicators of poverty

The indicators of poverty and social inclusion are part of the common indicators of the European Community for monitoring the progress of countries in the fight against poverty and social exclusion. The main source of statistical data for calculating the indicators is the annually conducted survey "Statistics on Income and Living Conditions (SILC)"(NSI, 2023) [3].

The poverty line shifts upwards from 413.04 BGN at the beginning of the research period to 763.83 BGN in 2024, with the largest increase in the last year compared to 2023. The shift of the poverty line is due to increasing wages and inflation. Persons below the poverty line in 2019 were 1,586, and for the next year they increased to 1,660, which is the highest value, after which a gradual decline is observed until 2023 with 1,326 - the lowest values, and in 2024 there is an increase again. The dynamics of the relative share as a percentage of the population initially increases in 2020, then decreases to the lowest values in 2023, and in the last year it again shows a slight increase. The relative share of the poor before receiving social transfers as a percentage of the population is high and the trend is to increase. The lowest level is 42.2% in 2019, and the highest is in 2024.

The trend is similar for the poor before receiving social transfers, including pensions. The ratio between the incomes of the poorest and the richest shows minimal improvement until 2023, after which there is an increase. The values are high, which is a sign of strong inequality. A similar movement is observed for the Gini coefficient (Table 5).

Table 5. Main indicators of poverty in Bulgaria 2019-2024

Indicators	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Poverty line-average monthly amount-BGN	413.04	451.00	504.33	525.92	637.92	763.83
Persons below the poverty line - thousand	1,586	1,660	1,532	1,572	1,326	1,401
Relative share of the poor - % of the population	22.6	23.8	22.1	22.9	20.6	21.7
Relative share of the poor before receiving social transfers - % of population Relative share of the poor before receiving social transfers, including pensions - % of population	42.2	41.7	44.3	44.2	45.3	46.1
Relative share of the poor before	29.6	29.9	31.5	30.3	28.5	30.0
Ratio between the income of the poorest and richest 20% of the population (S80/20)	8.1	8.0	7.4	7.3	6.6	7.0
Gini coefficient	40.8	40.0	39.7	38.4	37.2	38.4

Source: (NSI, 2023 and NSI, 2024) [3 and 4].

CONCLUSIONS

In terms of accessibility, Bulgaria is well positioned in a global context. The change in average food costs is assessed positively and exceeds the world average, with room for improvement. The income inequality index is at an average level, which is also proven by the study of poverty and social inclusion indicators.

Import tariffs and trade freedom are above average, largely due to our membership in the European Union. Food safety programs are highly developed, unlike many countries around the world.

The prices of food and non-food goods purchased by households, real income and real expenses are increasing with relatively equal intensity, which means that there is no decrease in purchasing power.

The purchasing power of households, calculated by the total average income per person during the study period, is increasing, with only a

second year of decline in 2022, which is most likely due to the increase in prices, disruption of the supply chain as a result of the war in Ukraine

The poverty line in the country is shifting upwards, due to the depreciation of the currency, increasing food prices and the growth of both the minimum and average wages. Despite the reduction in the number of people below the poverty line, the figures remain very high. The relative share of the poor is too high, although there is a decreasing trend. The same applies to the Gini coefficient and the ratio between the incomes of the poorest and richest 20% of the population. (S80/20), which are indicators of inequality in society. Bulgaria lags behind EU countries.

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STUDIES ON THE STRUCTURE AND SCALE OF CONTRACTUAL RELATIONS IN BULGARIAN AGRICULTURE

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Abstract

This study analyzes the structure and scale of contractual relations in Bulgarian agriculture, focusing on land leasing as the main mechanism governing land use. Based on official regional data for 2020, the analysis employs indicators such as the share of leased land, average leased area per holding, an index of institutionalization, and land concentration. The results show a highly institutionalized system, with over 90% of utilized agricultural land operated under lease. Strong regional differences are observed: Northern Bulgaria is dominated by large-scale, corporate leasing and high concentration, while Southern and mountainous regions retain fragmented ownership and small-scale farming. A positive relationship between leasing intensity, land concentration, and land prices is identified. The findings underline a trade-off between economic efficiency and social and territorial polarization in Bulgarian agriculture.

Key words**:** *contractual relations, land relationship, lease structure, land markets*

INTRODUCTION

The structural organization of contractual relations in agriculture plays a key role in shaping the economic and territorial landscape of the sector, particularly in the context of Bulgaria, a country characterized by diverse regional conditions and a transition toward free market-oriented agricultural practices (World Bank, 2010) [25]. The theoretical foundation of this study is grounded in New Institutional Economics (NIE), which emphasizes the role of institutions in the form of formal rules, contracts, and enforcement mechanisms that shape economic behaviour and outcomes (North, 1990) [20]. In agricultural land markets, institutions determine how access to land is organized, how rights are allocated, and how economic benefits are distributed between landowners and users. Where ownership is highly fragmented and land markets are imperfect, contractual arrangements such as leasing emerge as dominant mechanisms for coordinating land use (Coase, 1937; Kopeva, 2002; FAO, 2004) [5], [16], [7]. In post-planned economies, including Bulgaria, land restitution policies resulted in extreme fragmentation of land ownership, creating high transaction costs for land exchange through markets (Kopeva, 2002; FAO, 2004; Janus, 2023) [16], [7], [14]. Under such conditions, leasing contracts function as institutional substitutes for ownership that foster less cost-intensive land relationships, enabling operational consolidation without transfer of property rights (Bachev, 2011; Georgiev, 2024, Bachev, 2025,) [2], [10], [3]. The prevalence of leased land therefore reflects not merely market preference but an institutional response to historical and legal constraints, including the specific legal design of lease contracts (KGMP Legal, 2020; Georgiev, 2024; Marinova, 2024; Bashev, H, 2025) [15], [10], [18], [4].

Consolidation via contractual land use has become the dominant mechanism for access to land, as the land sales market remains institutionally and financially more rigid; consequently, leasing has displaced owner-operated land use across large areas, particularly in Northern Bulgaria but the process is prominent for the country as whole (Bachev, 2011; Eurostat, 2024; NSI, 2023)

[2], [6], [21]. From this perspective, the share of leased agricultural land can be interpreted as an indicator of the degree to which land use is governed through formalized institutional arrangements rather than through owner-operated farming. Following North (1990) [20], higher levels of institutionalization are expected to reduce uncertainty, lower transaction costs, and facilitate long-term investment. Accordingly, regions characterized by widespread use of formal land-lease contracts are expected to exhibit more stable and scalable agricultural structures.

Williamson (1985) [24] argues that economic agents choose governance structures - markets, contracts, or hierarchies - that minimize transaction costs arising from asset specificity, uncertainty, and frequency of transactions. Within this framework, regional variation in farm size and land concentration reflects differences in transaction costs associated with geography, parcel structure, and institutional enforcement. Plains with large, contiguous parcels and lower monitoring costs favor large-scale contractual consolidation, while mountainous and peripheral regions face structural constraints that limit the expansion of lease-based farming (World Bank, 2010; Georgiev, M., Gandeva, R., 2025; Georgieva, 2025) [25], [11], [9].

The study also takes into consideration the theory of farm structure and economies of scale, which explains differences in farm size as outcomes of technological requirements, factor markets, and policy environments (Hayami & Ruttan, 1985) [12]. Modern mechanized agriculture, especially cereal and oilseed production, exhibits significant scale economies, making large operational units more cost-efficient. This pattern is further confirmed by specialised studies on farm structures, which demonstrate that a very small number of large holdings control the predominant share of agricultural land - a result of long-term lease contracts and cooperative arrangements (Georgieva, 2025) [9]. This process is further reinforced by CAP design as part of the EU institutional framework, particularly through area-based payments and investment support (World Bank, 2010; Fi-compass, 2020; Ivanov, 2020) [25],[8],[13].

Research has consistently shown that in environments where leasing is widespread, farm structures tend to polarize, with a small number of large farms controlling the majority of agricultural land (Schultz, 1964; Eurostat, 2024) [23] [6]. This pattern is particularly pronounced in post-planned economies, where leasing enables rapid consolidation following restitution-induced fragmentation among a large number of owners (Kopeva, 2002; FAO, 2004) [16], [7]. The indicators used in this study - average leased area per farm and land concentration per tenant - serve as operational measures of scale and structural differentiation within agriculture.

The relationship between land leasing, land concentration, and land prices is theoretically rooted in classical and modern land rent theory. According to Ricardo's theory of differential rent, land values reflect differences in productivity and economic returns (Ricardo, 1817/2001) [22]. In contemporary agricultural economies, policy instruments - especially area-based subsidies - are capitalized into land rents and prices (Alston & James, 2002; Ivanov, 2020; Georgieva, 2025) [1], [13], [8]. Secure leasing arrangements facilitate this capitalization process by stabilizing expected income streams from land. As a result, regions with high shares of leased land and concentrated land use tend to exhibit higher land prices, as subsidies and productivity gains are bid into rents by competitive tenants (Marinov P., 2023; NSI, 2023; Eurostat, 2024) [19], [21], [6].

Finally, the study is informed by theories of structural dualism and regional political economy, which highlight how economic development produces spatially uneven outcomes (Lewis, 1954) [17]. In the Bulgarian context, the coexistence of a corporate, lease-based agricultural model in northern regions and a fragmented, owner-operated model in southern and mountainous areas reflects such structural dualism (Georgieva, 2025; World Bank, 2010) [9], [25]. While the former promotes productivity

and economic efficiency, the latter preserves social embeddedness but limits scale expansion. Beyond institutional norms, factors such as social structure, population decline, geographical characteristics, and soil fertility also exert a significant influence on the structure and scale of contractual relations in Bulgarian agriculture (Bachev, 2025) [3]. The main objective of this study is to analyse the structure and scale of contractual relations in Bulgarian agriculture through a quantitative assessment.

The main research tasks include:

-Identifying regional patterns of lease-based land relations;

-Measuring the degree of land concentration through leasing arrangements;

-Comparing the structure of agricultural holdings according to the scale of land use;

-Developing a typology of regions based on the characteristics of contractual land relations.

Based on the theoretical framework of land market development and contractual land relations in post-planed agricultural systems, the study formulates the following hypotheses regarding the relationship between contractual land-use structures and agricultural land prices.

H1: The share of leased agricultural land positively influences agricultural land prices.

Regions with a higher proportion of leased land are expected to have more developed land markets and stronger demand for agricultural land, leading to higher land prices.

H2: The scale of leased land per farm positively affects agricultural land prices.

Larger average leased areas per farm indicate greater structural consolidation and economies of scale, which increase land demand and contribute to higher land values.

H3: Higher institutionalization of contractual land relations leads to higher agricultural land prices.

Regions characterized by more structured and formalized lease markets are expected to demonstrate higher land values due to lower transaction costs and improved market efficiency.

H4: Regions with higher land concentration tend to exhibit higher agricultural land prices.

Strong concentration of agricultural land use among a limited number of operators increases competition for land and contributes to the capitalization of agricultural profitability into land prices.

MATERIALS AND METHODS

The study is based on official statistical data for 2020 at the regional (NUTS3) and statistical region levels from FSS, NSI and Bulgarian cadastre. The analysis includes the following variables:

-Utilised Agricultural Area (UAA);

-Owned land and land rented under lease or tenancy agreements;

-Number of farms by type of land tenure;

-Number of lessees and the average size of leased parcels.

For the purpose of this research 4 main indicators were composed.

(1)Share of Leased Agricultural Land (DAZ)

This indicator measures the percentage of the total utilised agricultural area (UAA) that is cultivated under lease, rental agreements, or other contractual land-use arrangements.

$$DAZ = \frac{\text{Leased land area } (ha)}{Total\ utilized\ land\ area\ (ha)} x\ 10 \quad \text{.....(1)}$$

Economic significance

The higher the value of DAZ, the more institutionalised the land-use system becomes. A lower DAZ indicates that land is primarily cultivated by its owners, reflecting a smallholder or owner-operated agricultural model.

Interpretation of values

- 80% → dominant lease-based agricultural model
- 50–80% → mixed land-use model
- < 50% → predominantly owner-operated land use and informal agreements

(2)Average Size of Leased Area per Farm (SRA1) and (SRA2) Average Size of Leased Area per Number of Leases

This indicator measures the average scale of leased land per farm operating under contractual arrangements.

$$SRA = \frac{\text{Leased land area } (ha)}{Holdings\ with\ leased\ land\ (ha)} \quad \text{.....(2)}$$

$$SRA2 = \frac{\text{Leased land area } (ha)}{\text{Number of Leases } (number)} \quad \text{.....(3)}$$

Economic significance

The indicator reflects the degree of land concentration and the intensity of land use. Higher values of SRA indicate a stronger presence of large-scale agricultural enterprises that operate predominantly through lease-based land management.

Example interpretation

-SRA ≈ 200–300 ha → industrial agricultural model (large lease operators, grain production)

-SRA ≈ 40–100 ha → mixed agricultural model, often associated with agricultural cooperatives

-SRA < 20 ha → smallholder or family farming model

Economic significance for SRA2

(3)Institutionalization Index (II)

This index measures the extent to which agricultural land use is institutionalised through formal contractual arrangements and the presence of active lease operators.

$$\text{II} = \frac{Number\ of \text{lessees}}{Number\ of\ farms} x\ DAZ \quad \text{.....(4)}$$

This index measures the extent to which agricultural land use is institutionalised through formal contractual arrangements and the presence of active lease operators.

Economic logic

The index combines:

- a quantitative dimension (number of lessees), and
- a structural dimension (share of leased agricultural land).

A higher value of the index indicates more structured and formalised contractual land relations, where a large share of agricultural land is operated by a relatively limited number of users through long-term lease contracts.

Lower values reflect fragmented or informal practices, with a predominance of individual landowners managing their own land.

Interpretation

- II > 70 → high level of institutionalization
- 40 ≤ II ≤ 70 → moderate institutionalization
- II < 40 → low institutionalization

(5)Land Concentration Index (SC)

This indicator measures the average amount of leased agricultural land managed by a single lessee.

$$SC = \frac{Leased\ land\ area\ (ha)}{Number\ of\ lesess} \quad \text{.....(5)}$$

This indicator measures the average amount of leased agricultural land managed by a single lessee.

Economic logic

The indicator reflects the distribution of land use among lessees and serves as a measure of structural land concentration. High SC values indicate that a small number of lessees manage large areas of land (high concentration). Low SC values indicate that many lessees cultivate relatively small parcels (fragmented land use).

Interpretation

-SC > 200 ha → highly concentrated land use

-SC = 50–200 ha → moderate concentration

-SC < 50 ha → low concentration, predominance of small-scale farming

Table 1. Relationships Between Indicators

Relationship	Interpretation
DAZ ↔ II	A higher share of leased land corresponds to a higher level of institutionalization.
SRA1 ↔ SC	The indicators are proportional: larger leased areas per farm lead to higher land concentration.
DAZ ↔ SC	High shares of leased land are often associated with high land concentration, typical of industrialised agricultural regions.
II ↔ economic efficiency	Higher institutionalization levels are often associated with greater productivity and higher agricultural gross value added (GVA).

Source: Created by the authors.

RESULTS AND DISCUSSIONS

The evolution of contractual land relations in Bulgarian agriculture over the past two decades reflects a profound institutional and structural transformation, characterized by a transition from predominantly owner-operated land use to a lease-based agricultural system. An analysis of data for the period 2003–2020 reveals a steady expansion of agricultural land cultivated under contractual arrangements, accompanied by a gradual decline in the area of owner-operated land. As illustrated in Figure 1**,** the area of owner-operated land decreased from approximately 601 thousand hectares in 2003 to about 409 thousand hectares in 2020**,** while the area cultivated under lease or rental agreements increased substantially during the same period. In 2003**,** leased agricultural land amounted to approximately 2.3 million hectares, whereas owner-operated land accounted for about 0.6 million hectares**.** By 2020, the area under lease had increased to over 4.15 million hectares, while owner-operated land had declined to approximately 0.41 million hectares**.**

Fig. 1. Land owned and leased in Bulgaria
Source: own calculations based on NSI data [21].

This represents an increase of more than 80% in leased land and a reduction of over 30% in owner-operated land**,** confirming the consolidation of the contractual model of land use. By 2020, approximately 4.155 million hectares**,** or 91% of the utilised agricultural area (UAA) in Bulgaria, were cultivated under lease, rental agreements, or other forms of contractual land use, while owner-operated land accounted for only 9% of the total agricultural area**.** These trends clearly demonstrate the central role of contractual land relations as the primary mechanism for land consolidation and agricultural production in Bulgaria, reflecting a highly institutionalized system of land use and the development of a stable market for agricultural land contracts (Figure 1).

Relationship between land prices and indicators of contractual land relations

The relationship between agricultural land prices and the indicators describing contractual land relations reveals several important structural patterns in the Bulgarian agricultural land market. Although the share of leased land (DAZ) is uniformly high across all NUTS3 regions, ranging from 84.15% in Plovdiv to 95.72% in Montana, its variation appears to have a limited direct effect on regional land prices. The widespread prevalence of leasing indicates that contractual land use has become the dominant institutional mechanism for accessing agricultural land, but because the indicator shows relatively small regional variation, it does not strongly differentiate land price levels between regions.

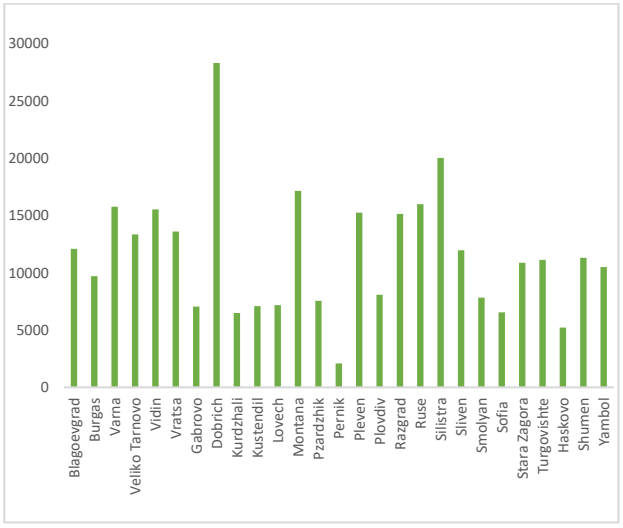

Fig. 2. Land prices in Bulgaria (BGN/ha)
Source: own calculations based on NSI data [21].

More pronounced relationships can be observed when examining indicators related to the scale and concentration of leased land, particularly SRA and SC, which measure the

average leased land per lessee and the degree of land concentration among operators. Regions characterized by larger farm structures and highly concentrated land use often demonstrate relatively higher land values. For example, Dobrich, which records very high levels of concentration (SRA and SC = 648.79 ha) and large operational farm sizes (SRA2 = 93.30 ha), also exhibits the highest agricultural land price in the dataset (28,320 BGN/ha). Similarly, regions such as Silistra (20,040 BGN/ha), Montana (17,150 BGN/ha), and Ruse (15,990 BGN/ha) combine relatively large operational farm sizes with high land prices, suggesting that larger agricultural enterprises operating through lease agreements can increase demand for agricultural land. The relationship between land concentration and land prices is not uniform across all regions. Some regions with high levels of concentration demonstrate relatively moderate land values. For instance, Veliko Tarnovo, despite exhibiting the highest concentration indicator (1,001.99 ha), shows only moderate land prices (13,350 BGN/ha), while Yambol, with relatively large farm structures (504.80 ha), records lower land values (10,500 BGN/ha). This suggests that structural concentration alone does not determine land prices and that other factors such as soil fertility, agricultural productivity, crop specialization, and regional market accessibility play a crucial role in shaping land values. The SRA2 indicator, which reflects the average leased land per holding operating under lease arrangements, also provides insight into the operational structure of agricultural farms. Regions with higher SRA2 values, such as Pleven (108.09 ha), Dobrich (93.30 ha), and Varna (83.32 ha), tend to demonstrate relatively high land prices, indicating that larger operational farm units may contribute to stronger land market demand. Conversely, regions characterized by very small farm structures, such as Kurdzhali (6.84 ha) and Smolyan (7.18 ha), display relatively low land values (6,500 BGN/ha and 7,840 BGN/ha respectively), reflecting more fragmented agricultural structures and lower levels of market pressure on land resources. The Institutionalization Index (II) shows moderate variation across regions and highlights the role of formalized contractual relations in shaping land market dynamics. Regions with higher levels of institutionalization, such as Varna (0.38), Razgrad (0.29), and Stara Zagora (0.23), generally demonstrate relatively stable land markets and moderate to high land prices. Nevertheless, the relationship between institutionalization and land prices remains indirect, suggesting that while formalized lease markets contribute to the stability and organization of land use, they do not independently determine land price levels.

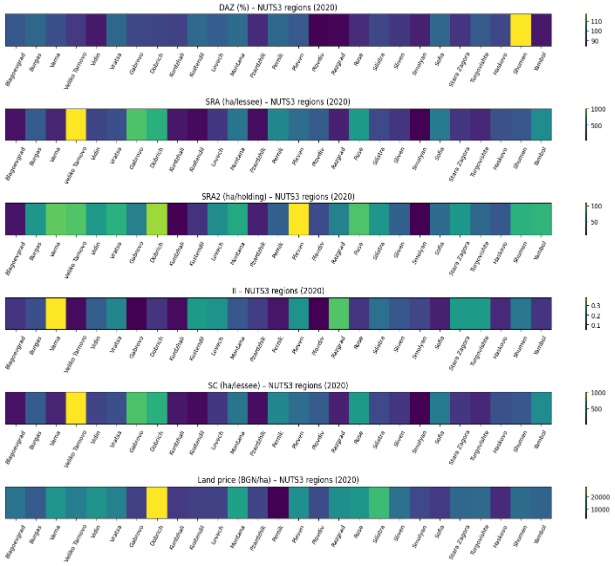

Fig. 3. Regional distribution of contractual land-use indicators and agricultural land prices across Bulgarian NUTS3 regions (2020). Source: own calculations based on NSI data [21].

Figure 3 presents heatmaps for the main indicators describing contractual land relations, including the share of leased land (DAZ), average leased area per lessee (SRA), average leased land per holding under lease (SRA2), institutionalization index (II), land concentration (SC), and agricultural land prices. Each panel uses an independent scale to highlight regional variation. The visualization illustrates substantial spatial differences in farm size, land concentration, and institutional organization of lease markets across Bulgarian regions.

Share of Leased Agricultural Land (DAZ)

The share of leased agricultural land (DAZ) reflects the extent to which agricultural land is

cultivated through contractual arrangements rather than owner-operated farming. The results indicate that leasing represents the dominant form of land use across all Bulgarian NUTS3 regions, with values ranging from 84.15% in Plovdiv to 95.72% in Montana.

The highest levels of leased land are observed in Montana (95.72%), Vratsa (95.25%), Burgas (95.23%), Pernik (95.13%), and Sofia (95.03%), indicating a highly institutionalized system of contractual land relations. In these regions, agricultural production is largely organized through lease agreements that enable the consolidation of fragmented land ownership into larger operational units.

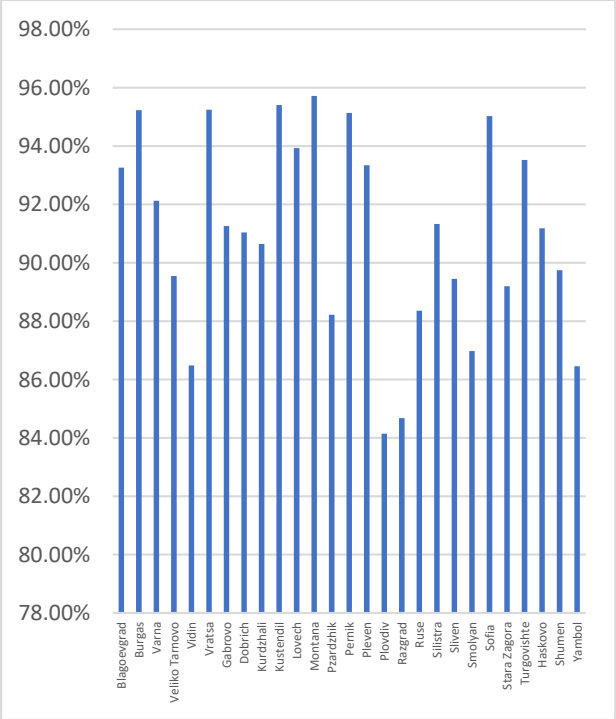

Fig. 4. Share of Leased Agricultural Land (DAZ)
Source: own calculations based on NSI data [21].

Slightly lower values are observed in Plovdiv (84.15%), Razgrad (84.68%), and Yambol (86.45%), where owner-operated land still maintains a somewhat greater presence within the agricultural structure. However, even in these regions, the share of leased land remains very high, confirming that contractual land use has become the predominant mechanism for accessing agricultural land in Bulgaria. The results demonstrate a high level of institutionalization of land use through leasing, reflecting the post-socialist process of land consolidation and the development of a functioning agricultural land market.

Average leased land per lessee (SRA) and (SRA2)

The indicator SRA measures the average area of leased agricultural land per lessee and serves as a proxy for the scale of agricultural operations and the degree of land concentration among agricultural operators.

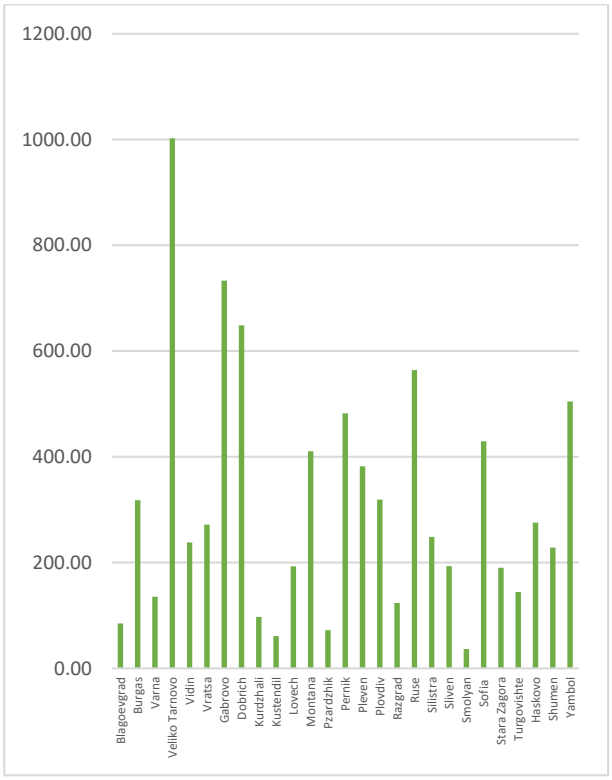

Fig. 5. Average leased land per lessee
Source: own calculations based on NSI data [21].

The highest values are recorded in Veliko Tarnovo (1,001.99 ha), Gabrovo (733.26 ha), Dobrich (648.79 ha), and Ruse (564.06 ha), indicating the presence of large-scale agricultural enterprises managing extensive land areas through lease agreements. These regions are characterized by highly consolidated farming systems and a strong orientation toward large-scale commercial agriculture. Moderately high values are observed in Yambol (504.80 ha), Pernik (482.42 ha), Sofia (429.21 ha), Montana (410.43 ha), and Pleven (382.24 ha), suggesting the presence of large farms but with somewhat more diversified land-use structures. In contrast, the lowest values are recorded in Smolyan (36.62 ha), Kyustendil

(61.11 ha), and Pazardzhik (72.40 ha), reflecting regions with smaller-scale agricultural operations. These areas are often characterized by mountainous terrain, mixed farming systems, and a greater presence of small family farms. SRA indicator demonstrates the significant heterogeneity in farm size across Bulgarian regions, highlighting the coexistence of highly consolidated agricultural enterprises and smaller regional farming systems.

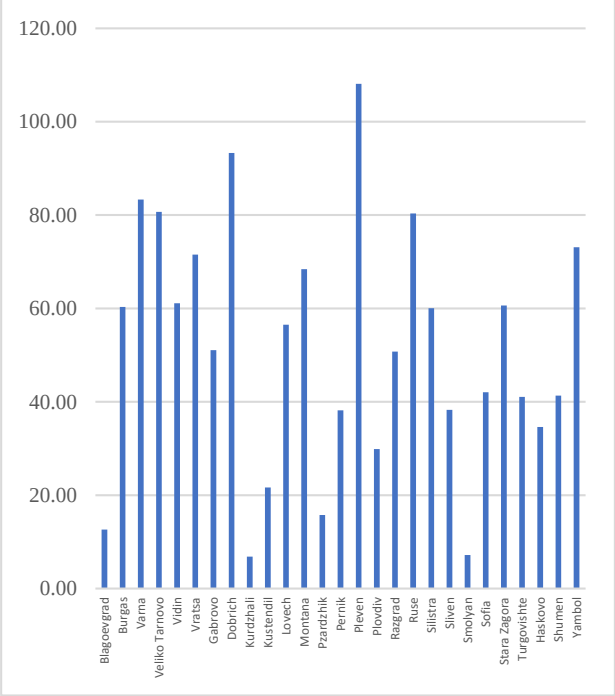

Fig. 6. Average leased land per holding that operates under lease
Source: own calculations based on NSI data [21].

The SRA2 indicator measures the average amount of leased land per holding that operates under lease arrangements, providing additional insight into the structure of farms relying on rented land. The highest values are observed in Pleven (108.09 ha), Dobrich (93.30 ha), Varna (83.32 ha), Veliko Tarnovo (80.69 ha), and Ruse (80.34 ha). These regions are characterized by relatively large operational farm units, reflecting a high level of farm consolidation and specialization. Moderate values are recorded in Yambol (73.09 ha), Vratsa (71.53 ha), Montana (68.41 ha), Vidin (61.12 ha), and Stara Zagora (60.64 ha), indicating the presence of medium-sized agricultural enterprises operating leased land. The lowest values are observed in Kurdzhali (6.84 ha) and Smolyan (7.18 ha), where agricultural land use remains highly fragmented and dominated by small-scale farms. These patterns are largely influenced by geographical constraints, particularly mountainous terrain and fragmented land ownership. SRA2 indicator confirms the considerable diversity in the operational scale of farms that rely on leased land across Bulgarian regions.

Institutionalization of contractual land relations (II)

The institutionalization index (II) measures the extent to which agricultural land use is organized through formal contractual arrangements involving active lease operators. Higher values of the index indicate more structured and formalized land markets.

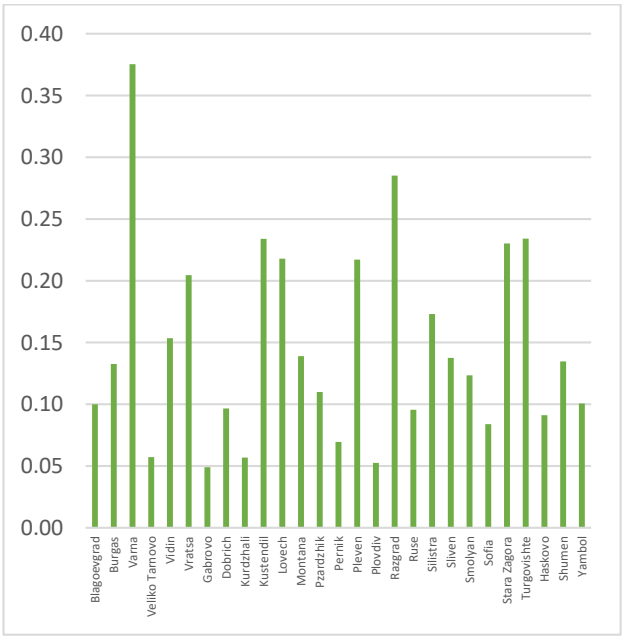

Fig. 7. Institutionalization of contractual land relations
Source: own calculations based on NSI data [21].

The highest levels of institutionalization are observed in Varna (0.38) and Razgrad (0.29), followed by Kyustendil (0.23), Stara Zagora (0.23), and Targovishte (0.23). These regions demonstrate relatively well-developed lease markets with a higher level of formal organization in contractual land relations. Moderate levels of institutionalization are recorded in Pleven (0.22), Lovech (0.22), Vratsa (0.20), and Silistra (0.17), indicating stable contractual frameworks that facilitate

agricultural land use. Lower values are observed in Gabrovo (0.05), Plovdiv (0.05), and Veliko Tarnovo (0.06). These lower levels may reflect either a greater concentration of land in fewer operators or variations in the structure of contractual relationships. The results indicate that the institutional organization of land-use relations varies across regions, reflecting differences in ownership structures, agricultural specialization, and regional land market dynamics.

Land concentration (SC)

The land concentration indicator (SC) measures the average leased land area per lessee and reflects the distribution of agricultural land among lease operators.

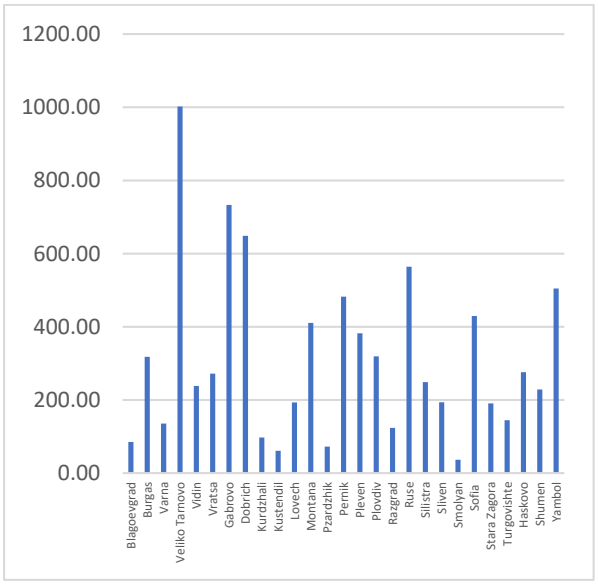

Fig. 8. Land concentration
Source: own calculations based on NSI data [21].

The highest levels of land concentration are observed in Veliko Tarnovo (1,001.99 ha), Gabrovo (733.26 ha), Dobrich (648.79 ha), and Ruse (564.06 ha). These regions are characterized by highly concentrated agricultural structures where large enterprises manage extensive areas of leased land. Moderate levels of concentration are observed in Yambol (504.80 ha), Pernik (482.42 ha), Sofia (429.21 ha), Montana (410.43 ha), and Pleven (382.24 ha), indicating the presence of large farms but with somewhat more distributed land management. The lowest concentration levels are recorded in Smolyan (36.62 ha), Kyustendil (61.11 ha), and Pazardzhik (72.40 ha), where agricultural production is dominated by smaller farms and fragmented land use patterns. SC indicator highlights the strong regional differentiation in the concentration of agricultural land use, reflecting differences in production specialization, natural conditions, and the historical evolution of land ownership structures.

Integrated interpretation of contractual land-use indicators

The combined analysis of the indicators DAZ, SRA, SRA2, II, and SC provides a comprehensive picture of the structural organization of contractual land relations in Bulgarian agriculture at the NUTS3 regional level. Together, these indicators reveal a land-use system characterized by a high level of institutionalization and widespread reliance on lease agreements, combined with significant regional differences in farm size, operational structure, and land concentration. The share of leased land (DAZ) is consistently high across all regions, ranging from 84.15% in Plovdiv to 95.72% in Montana, confirming that leasing has become the dominant mechanism for accessing agricultural land in Bulgaria. This pattern reflects the structural transformation of the agricultural sector following land restitution, where fragmented ownership has been consolidated through lease agreements that allow agricultural operators to cultivate large areas without acquiring ownership. The uniformly high DAZ values indicate that contractual land relations are deeply embedded in the functioning of the Bulgarian agricultural land market. Despite the similar levels of leased land across regions, substantial differences emerge when examining the scale of leased land use, as captured by the indicators SRA and SC. Regions such as Veliko Tarnovo (1,001.99 ha), Gabrovo (733.26 ha), Dobrich (648.79 ha), and Ruse (564.06 ha) demonstrate extremely high values for both indicators, reflecting highly concentrated agricultural structures dominated by large agricultural enterprises. These regions represent areas where agricultural production is organized through large-scale lease

operations capable of managing extensive land resources. In contrast, regions such as Smolyan (36.62 ha), Kyustendil (61.11 ha), and Pazardzhik (72.40 ha) exhibit much smaller operational scales, indicating more fragmented agricultural systems characterized by smaller farms and more diversified production structures. These differences highlight the strong influence of geographical conditions, historical land fragmentation, and production specialization on regional farm structures. The indicator SRA2, which measures the average leased land per holding under lease arrangements, further illustrates the diversity of operational farm sizes. High values in regions such as Pleven (108.09 ha), Dobrich (93.30 ha), Varna (83.32 ha), and Veliko Tarnovo (80.69 ha) indicate relatively large farm units operating leased land, suggesting advanced levels of consolidation and professionalized agricultural management. Conversely, extremely low values in Kurdzhali (6.84 ha) and Smolyan (7.18 ha) reflect small-scale agricultural systems with fragmented land structures and a greater presence of family-based farming. The Institutionalization Index (II) complements these structural indicators by capturing the extent to which agricultural land use is organized through formal contractual relationships between landowners and operators. Higher values of the index in regions such as Varna (0.38), Razgrad (0.29), Stara Zagora (0.23), and Turgovishte (0.23) suggest more developed and structured lease markets, where contractual relations are more formalized and widely used. In contrast, lower values in regions such as Gabrovo (0.05), Plovdiv (0.05), and Veliko Tarnovo (0.06) may indicate either a higher concentration of land in fewer operators or variations in the organization of lease arrangements. Taken together, the indicators reveal a dual structure of agricultural land use in Bulgaria. On one hand, the agricultural system is characterized by a highly institutionalized lease market, where the majority of land is cultivated under contractual arrangements. On the other hand, significant regional differences persist in terms of farm size, land concentration, and the organization of contractual relations. These variations reflect the interaction of natural conditions, historical land fragmentation, regional agricultural specialization, and the evolving institutional framework of the land market. The integrated analysis therefore demonstrates that while contractual land relations provide the institutional foundation for agricultural land use in Bulgaria, the structural characteristics of regional farming systems remain highly heterogeneous.

CONCLUSIONS

This study examined the structure and scale of contractual land relations in Bulgarian agriculture and their relationship with regional agricultural land prices at the NUTS3 level. Using a set of indicators that capture different dimensions of contractual land use—namely the share of leased land (DAZ), the average leased area per lessee (SRA), the average leased land per holding under lease arrangements (SRA2), the institutionalization index (II), and the degree of land concentration (SC)—the analysis provides a comprehensive picture of the institutional and structural characteristics of the agricultural land market in Bulgaria.

The results confirm that Bulgarian agriculture operates within a highly lease-based land-use system, where contractual arrangements represent the dominant mechanism for accessing agricultural land. The consistently high values of the DAZ indicator across all regions demonstrate that leasing has become the primary institutional framework through which fragmented land ownership is consolidated into operational farming units. This reflects the long-term structural transformation of Bulgarian agriculture following the land restitution process and the gradual development of a functioning agricultural land market. At the same time, the analysis reveals substantial regional differences in farm structure, land concentration, and operational farm size. Indicators related to the scale of leased land use, particularly SRA and SC, highlight the presence of highly consolidated agricultural systems in several regions, such as Veliko Tarnovo, Dobrich, Gabrovo, and Ruse, where

large agricultural enterprises manage extensive land areas through lease agreements. In contrast, regions such as Smolyan, Kyustendil, and Kurdzhali are characterized by significantly smaller operational farm sizes and more fragmented agricultural structures. These patterns demonstrate that although leasing is widespread across the country, the structural organization of agricultural production varies considerably between regions, reflecting differences in natural conditions, production specialization, and historical land fragmentation. The indicator SRA2 further illustrates the diversity in operational farm structures by showing that the average leased land per holding varies significantly across regions. Higher values observed in regions such as Pleven, Dobrich, and Varna indicate the presence of larger operational farm units, while significantly lower values in mountainous regions highlight the persistence of small-scale agricultural production systems. In parallel, the institutionalization index (II) reveals regional differences in the degree to which land-use relations are organized through formal contractual arrangements, suggesting that the institutional organization of lease markets is not uniform across the country.

The analysis of the relationship between land prices and the indicators of contractual land relations shows that land prices are influenced more strongly by structural characteristics of agricultural production than by the simple prevalence of leasing. While the share of leased land remains consistently high across all regions, indicators reflecting farm size and land concentration demonstrate a more visible relationship with agricultural land prices. Regions characterized by larger operational farm structures and higher land concentration, such as Dobrich, Silistra, and Montana, tend to exhibit higher land prices, reflecting stronger demand for productive agricultural land. Nevertheless, the relationship is not uniform, as land prices are also shaped by factors such as soil fertility, agricultural productivity, infrastructure, and regional market conditions.

From the perspective of the research hypotheses, the results provide partial support for the proposed relationships between contractual land-use indicators and agricultural land prices. Hypothesis H1, which assumes that a higher share of leased land leads to higher agricultural land prices, is only weakly supported, as the indicator shows limited variation across regions and therefore has a relatively small explanatory role in differentiating land values. Hypotheses H2 and H4, which link land prices to the scale and concentration of leased land (SRA and SC), receive stronger support, as regions with larger operational farm structures and higher land concentration often demonstrate higher land values. Hypothesis H3, which suggests that higher levels of institutionalization of contractual land relations contribute to higher land prices, is only partially confirmed, since the relationship between institutionalization and land prices appears to be indirect and influenced by broader structural and economic conditions.

The findings highlight that the Bulgarian agricultural land market is characterized by a highly institutionalized lease-based system combined with significant regional heterogeneity in farm structure and land concentration. The results contribute to a better understanding of the role of contractual land relations in shaping the organization of agricultural production and the dynamics of land markets in post-socialist agricultural systems. Future research could further refine the analysis by incorporating additional variables related to soil quality, crop specialization, and regional economic development in order to better explain the spatial variation in agricultural land prices.

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TRENDS IN ROMANIAN AGRITOURISM DURING 2019-2024: A PRE- AND POST-COVID-19 ANALYSIS

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Abstract

Human population needs outdoor recreational periods to reduce their stress accumulated during work periods. Agritourism is a suitable method for connecting with nature and farm products both bringing benefits for human health. The aim of this work was to analyse a six-year period (2019-2024) of touristic statistics for Romania, to identify the share of agritourism and the magnitude of COVID-19 impact on this type of tourism. The source of data was the database of National Institute of Statistics, from which the overnight stays were selected for the target years. The results indicate that agritourism had a 16% share of total tourism, which is related to guesthouses especially. While the pandemic period decreased drastically the number of tourists in 2020, in the same year the tourists in guesthouses increased slightly. This indicate a preference of tourists for accommodation that provide more fresh air and recreational activities in nature. In general, the number of tourists in guesthouses is reduced comparatively with hotels, and most of the time they belong to one single group. Compared to 2019, the trend of tourism recovery showed 24% less tourists in 2021, 10% in 2022 and similar values in 2023 and 2024. The post COVID-19 period for agritourism showed improvements in hospitality and redefining of this concept.

Key words**:** *hospitality, overnight stays, touristic specificity, tourism recovery, food and services quality*

INTRODUCTION

Climate change, accelerated depletion of natural resources and biodiversity loss are the result of the intensification of anthropogenic activities and constitute some of the most serious environmental challenges of the contemporary era, having significant negative effects on the balance of ecosystems and on the quality of life (Safarov et al., 2024) [18].
In the context of the succession of crises in recent years, the tourism industry has been strongly affected, especially by the economic crisis and the COVID-19 pandemic, which have led to economic losses (Simak et al., 2020) [21].
Tourism occupies an important place in the global economy (Zawadka et al., 2022) [24], is characterized by a high development dynamic and contributes to economic growth through employment and the promotion of cultural interactions at the international level (Moyle et al., 2010) [13].
The vulnerability of the tourism industry is an important characteristic because it can be influenced by various external factors (Wang et al., 2022; Kusune, 2020; Scott et al., 2019) [23, 11, 20].
Recognized as one of the most serious health crises (Duro et al., 2021) [7] the COVID-19 pandemic has had major effects on the tourism industry causing profound disruptions in the global tourism industry (Aldao, et al., 2021) [2].
Tourist flows have been affected by travel restrictions and quarantine measures, generating negative effects especially on tourism-dependent businesses (Gössling et al., 2020; Khalid et al., 2021) [8] [10].
The tourism sector is a very vulnerable one and the COVID-19 pandemic has accentuated this but has also accelerated the transition to alternative tourism models, especially rural tourism and agrotourism (Brune et al., 2023) [3]. The need to spend time in nature has become an essential priority for people, so the

pandemic has not only caused changes in the tourism sector but also changes in the population's lifestyle and consumption preferences (Ingrassia et al., 2023; Wang et al., 2022; Chin and Pehin Dato Musa, 2021) [9, 23, 4].

The rural environment offered tourists an increased sense of safety during the COVID-19 pandemic (Robina-Ramírez et al., 2023) [17], but even after its end, interest in agritourism increased significantly, this form of tourism becoming a preferred one, following substantial increases in the incomes of rural communities (Adom et al., 2021) [1].

The specialized literature highlights an increased academic interest in agritourism and rural tourism in the post-pandemic period, which justifies the relevance and necessity of a comparative analysis between 2019-2024 (Popescu and Plesoianu, 2021) [16].

MATERIALS AND METHODS

The data used in this research comes from official tourism statistics in Romania published by the National Institute of Statistics [14]. The analyzed interval was between 2019-2024, which includes the time of the COVID-19 pandemic but also the stage of recovery after it.

The analysed indicators included: the structure of overnight stays in agrotourism guesthouses by comfort category; the structure of Romanian and foreign tourists' overnights stays in total overnight stays in agrotourism guesthouses. Data analysis was performed using the number of overnights from the NSI database, with the calculation of percentages for accommodation comfort, the share of Romanians and foreigners and their preference for one or other type of comfort. At the same time, a comparative analysis was carried out to emphasize the effect that the pandemic has caused in the field of agritourism.

RESULTS AND DISCUSSIONS

The study, from the analysed period 2019-2024, highlights the dynamics of agritourism in Romania and the capacity of this sector to adapt due to the situation caused by the COVID-19 pandemic.

In 2019, before the start of the pandemic, tourism in our country experienced a significant evolution, namely

A total of 30.08 million overnight stays were recorded for the entire 2019 year, of which 2.51 million were in agrotourism guesthouses, representing 8.37% of the total.

The outbreak of the COVID-19 pandemic in 2020 caused a sharp decline in tourist flows globally. In Romania, the overnight stays decreased to approximately 14.57 million, which represents only 60.16% of the 2019 level.

Table 1. The number of overnight stays in agrotouristic guesthouses compared to total overnight stays in Romania in the period 2019-2024

Year	2019	2020	2021	2022	2023	2024
Total Overnight stays in Romanian tourist units of accommodation	30,086,091	14,579,140	22,747,562	27,044,372	29,691,592	30,837,328
Overnight stays in agrotouristic guesthouses	2,518,605	1,515,305	2,089,781	2,265,633	2,529,052	2,559,867
% overnight stays in agrotouristic guesthouse of total overnight stays in Romanian tourism	8.37	10.39	9.19	8.38	8.52	8.30
% of 2019		60.16	137.91	108.41	111.63	101.22
Absolute difference of overnight stays in agrotouristic guesthouses compared to 2019		-1,003,300	-428824	-252972	10447	41262

Source: Own calculation based on the data from NIS, 2026 [14].

However, the agritourism sector has proven more resilient compared to other forms of tourism. In 2020, agritourism guesthouses hosted 1.51 million overnight stays, in agrotouristic guesthouses and the share of agritourism in total tourism increased to 10.39%. This increase in the share of agritourism can be explained by the change in

tourist behaviour during the pandemic. They began to prefer less crowded destinations, natural areas, and outdoor activities, which favoured rural tourism and agritourism. Similar trends have been observed in other countries, where rural tourism has demonstrated a greater capacity to adapt to crisis situations (Chin and Musa, 2021; Gössling et al., 2020) [4, 8].

In the period 2021–2024, tourism entered a phase of progressive recovery. The number of overnight stays in agrotourism guesthouses has increased steadily: 2021 – 2.08 million overnight stays, 2022 – 2.26 million overnight stays 2023 – 2.53 million overnight stays 2024 – 2.56 million overnight stays.

In 2024, the number of overnight stays in agritourism guesthouses slightly exceeds the level recorded before the pandemic, which indicates a complete recovery and consolidation of interest in agritourism.

This result confirms the conclusions of recent studies showing that, in the post-pandemic period, tourists show an increased interest in authentic experiences, local products and activities carried out in nature, characteristic elements of agritourism (Matiza and Kruger, 2024; Robina-Ramírez et al., 2023; Ingrassia et al., 2023; Dogru-Dastan et al., 2022; Sánchez-Sánchez and Sánchez-Sánchez, 2022) [12, 17, 9, 6, 19]. The analysis of the evolution of tourism indicators shows that the decrease in 2020 was the most pronounced in the analysed period, reflecting the impact of mobility restrictions and economic uncertainties generated by the COVID-19 pandemic. However, the agritourism sector was less affected compared to other forms of tourism, maintaining a relatively stable share in total tourism activity.

A gradual recovery of tourist flows is observed in the period 2021–2024, both in general tourism and in the agritourism sector. In 2024, the number of overnight stays in agritourism guesthouses slightly exceeds the level recorded before the pandemic, which indicates a consolidation of interest in this type of tourism.

Table 2 highlights the distribution of nights spent in agrotourism guesthouses by comfort category, where significant trends in the evolution of the tourism sector appear infrastructure in rural areas. In 2019, the largest share was recorded for 4- and 5-star guesthouses, which indicates a relatively high level of quality of services offered in the agrotourism sector.

During the pandemic, some comfort categories experienced fluctuations, reflecting the economic difficulties faced by tour operators.

However, after 2021, a stabilization of the guesthouse structure is observed, which suggests the adaptation of the agritourism sector to the new conditions of the tourism market. The lower categories had lower shares: 2 flowers – 14.92%, 1 flower – 0.71%.

Table 2. Distribution of overnight stays by comfort category of agrotourism guesthouses in the period 2019-2024 (%)

Year/Category	2019	2020	2021	2022	2023	2024
5 flowers	2.65	3.46	4.75	4.24	3.97	3.38
4 flowers	17.66	18.83	18.60	19.09	19.79	20.31
3 flowers	62.29	62.08	60.81	61.79	61.81	62.55
2 flowers	16.77	14.92	15.04	14.18	13.74	13.03
1 flower	0.64	0.71	0.80	0.69	0.69	0.73

Source: Own calculation based on the data from NIS, 2025 [14].

Some structural changes were observed during the pandemic. In 2020, the share of 5-flower guesthouses decreased to 3.46%, which may reflect the temporary difficulties encountered by tourist units with premium services in the context of economic and health uncertainty.

Subsequently, starting in 2021, the agritourism sector began to stabilize. In 2024, the structure of guesthouses looks like this: 5 flowers – 3.38%, 4 flowers – 20.31%, 3 flowers – 62.55%, 2 flowers – 13.03%, 1 flower – 0.73%. This distribution indicates a trend of modernization and increase in the

quality of tourist services in rural areas. Agritourism operators are increasingly investing in infrastructure, comfort and diversification of tourist experiences (Ongsakul,et al, 2022) [15].

According to Brune et al. (2023) [3], improving the quality of services and diversifying tourism offers are essential strategies for maintaining the competitiveness of agritourism in times of crisis.

In Table 3 it can be observed the percentage of foreign tourists in the overnight stays in the total number of overnight stays accommodated in agrotourism guesthouses during 2019-2020, separated by comfort categories.

Table 3. The percentage of foreign tourists' overnight stays in the total number of overnight stays in agrotourism guesthouses during 2019-2020, separated by comfort categories

Guesthouse Category	Origin	2019	2020	2021	2022	2023	2024
5 flowers	**Romanians**	60,918	51,291	96,704	92,583	96,033	80,563
	Foreigners	5,817	1,064	2,643	3,557	4,280	5,912
4 flowers	**Romanians**	418,173	281,973	380,224	418,923	483,490	498,769
	Foreigners	26,507	3,331	8,384	13,564	16,953	21,245
3 flowers	**Romanians**	1,451,198	927,964	124,3804	135,0503	1,493,494	1,522,687
	Foreigners	117,662	12,770	26,986	49,497	69,718	78,488
2 flowers	**Romanians**	372,463	222,280	304,437	306,260	314,648	311,076
	Foreigners	49,816	3,859	9,938	15,054	32,967	22,520
1 flower	**Romanians**	15,500	10,708	16,551	15,680	16,033	18,111
	Foreigners	551	65	110	12	1,436	496
Total Romanians		2,318,252	1,494,216	2,041,720	2,183,949	2,403,698	2,431,206
Total Foreigners		200,353	210,89	48,061	81,684	125,354	128,661
Total number of overnight stays in agroturistic guesthouses		2,518,605	1,515,305	2,089,781	2,265,633	2,529,052	2,559,867
Percentage of total overnight stays %		7.95	1.39	2.30	3.61	4.96	5.03

Source: Own calculation based on the data from NIS, 2025 [14].

Agritourism in Romania is largely dominated by Romanian tourists as highlighted in the research.

In 2019, the structure of Overnight stays was as follows: Romanians overnight stays – 2.31 million, foreigners' overnight stays – 200,353. The share of foreigners' overnight stays in total overnight stays in agrotourism guesthouses was 7.95 % of the total number overnight stays in agrotourism guesthouses. In 2020, mobility restrictions and border closures strongly affected international tourism. The number of foreign tourists' overnight stay decreased dramatically to 21,089, representing only 1.39% of the total number of tourists' overnight stays. This decline is in line with the trend observed in international tourism during the COVID-19 pandemic (Aldao et al., 2021) [2].

After restrictions were eased, the number of foreign tourists' overnight stays began to gradually increase: in 2021 – 48,061, in 2022 – 81,684, in 2023 – 125,354, in 2024 – 128,661. However, the share of foreign tourists' overnight stays remains below the level recorded before the pandemic, which indicates that Romanian agritourism is mainly oriented towards the domestic tourism market. This pattern is commonly found in rural tourism in many European countries, where most visitors come from within the country (Dogru et al., 2019) [5].

The results obtained highlight the important role of agritourism in the economic development of the rural environment. The main implications identified are:

Agritourism is more resilient than general tourism in times of crisis. The pandemic has accelerated tourists' preference for natural destinations and authentic experiences.

Domestic tourism is the main driver of agritourism development. Increasing the quality of services in agritourism guesthouses contributes to the competitiveness of rural destinations. These results confirm that agritourism can be an effective tool for

diversifying the rural economy and generating additional income for farmers and local communities (Adom et al., 2021; Ingrassia et al., 2023) [1, 9].

CONCLUSIONS

The results of the study highlight that agritourism can represent an important tool for the sustainable development of the rural environment, contributing to improving rural areas through job creation and economic growth.

The evolution of the tourism sector can be achieved through various means such as financing, resource allocation, and marketing to highlight local traditions.

The analysis of tourism statistics from 2019–2024 highlights the dynamic evolution of agritourism in Romania and its ability to adapt to external shocks such as the COVID-19 pandemic. Although the pandemic generated a significant decrease in tourism activity at the national level, the agritourism sector was less affected and even increased its share in total tourism during the crisis.

The recovery observed after 2021 confirms the growing importance of rural tourism in the post-pandemic tourism landscape. Agritourism guesthouses are becoming increasingly attractive to tourists due to their authentic experiences, contact with nature and reduced levels of crowding.

In addition, the predominance of Romanian tourists suggests that tourism development policies should pay increased attention to promoting agritourism on the domestic market. Overall, agritourism represents an important opportunity for the sustainable development of the rural environment, contributing to job creation, the valorisation of local products and the preservation of cultural traditions.

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RURAL POLICY OR ECONOMIC FUNCTIONALITY? A COMPARATIVE ANALYSIS OF RURAL DEVELOPMENT IN BULGARIA AND THE USA (THE CASE OF NEBRASKA)

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Abstract

Rural areas are taking an important and significant share of the territory in both Europe and the United States, providing food security and economic stability. This research`s main goal is to make a comparative analysis of the rural development strategies in Bulgaria and the USA (focusing on the state of Nebraska). The article is examining the different definitions of "rural" and how each region is supporting its agricultural sector. Based on policy analysis and macroeconomic statistical information, the results are showing a big difference: Bulgaria is following the European Union's area-based approach, while Nebraska relies on a market-driven model focused on specific agricultural programs. Even with these different types of governance, both regions are facing similar problems like demographic decline and the need for modernization. The conclusion is related to finding successful practices from both models that can be used to improve the future development of rural areas.

Key words**:** *rural governance, regional disparities, agricultural policy*

INTRODUCTION

Rural areas are an important part of the economies in Europe and the USA. They are the main drivers for food production, natural resources management, and regional development. Despite their great importance, rural municipalities on both continents are having big structural problems, such as fast population decline, aging, and economic lag compared to the urban centers [1]. While the problems of rural decline look similar, the governance models and policies used to solve them are very different between the European Union (EU) and the United States (USA).

The main goal of this article is to compare and analyze both rural development strategies. It will review the area-based approach of the EU, which is implemented in Bulgaria, and compare it with the market-driven model of the USA, through the case of Nebraska. A big difficulty in making a comparative analysis of rural policies is the difference in how we define a "rural" territory. In the EU, rural areas are defined mostly by territory and demography using the Degree of Urbanization (DEGURBA) and NUTS classifications, which are looking at population density [3]. On the other hand, the US Department of Agriculture (USDA) is using Rural-Urban Continuum Codes (RUCC) to define nonmetropolitan counties depending on their population size and distance to metropolitan areas [12].

By reviewing these different policies and the main macroeconomic indicators, this research tries to evaluate the strengths and the weak points of both systems. The analysis will help to answer if long-term rural development is achieved better through general territorial policies or through specific economic functionality programs.

To understand the difference between the two regions, it is important to review their main funding mechanisms: the EU's Common Agricultural Policy (CAP) and the US Farm Bill.

The European Union's approach to rural development is based on the idea of "territorial cohesion". Through the second pillar of the CAP, the EU provides structural funds to achieve balanced territorial development, environmental protection, and socio-economic support for rural communities

[2], [8], [9]. An important part of this European model is the LEADER approach, which supports community-led local development (CLLD) strategies. By distributing area-based subsidies and financing local action groups, the EU is trying to keep the population in rural areas and prevent smaller settlements from falling behind. In this case, rural policy works like a social safety net. The main priority is to preserve the rural landscape and population instead of only maximizing the agricultural production [1]. In Bulgaria, this means that rural municipalities are highly dependent on EU structural funds to maintain their infrastructure and support small farmers.

On the opposite side, the United States is using a market-driven governance model, regulated mainly by the Farm Bill. The US model is focused on economic efficiency, global market competitiveness, and managing the risk for producers. Unlike the EU's territorial focus, most of the US federal agricultural funds go to commodity support programs and crop insurance, which stimulate production volume and market integration [11]. The Farm Bill also has a Rural Development title managed by the USDA, but these programs are very different from the European subsidies. US rural development programs are working mostly as competitive grants or targeted loans for specific infrastructure projects (like internet expansion, electrification, and water) or for rural business development, rather than giving universal support based on area [5].

Because of this, in states with strong agriculture like Nebraska, the policy helps to create large, highly capitalized agricultural businesses. These companies have high economic efficiency on the global markets, but they need fewer workers because of the high level of mechanization. As a result, the development of the broader rural community in the US depends mostly on local economic success and local taxes, rather than on federal demographic preservation policies.

This theoretical difference shows the main debate between "rural policy" and "economic functionality". The EU looks at rural areas as living landscapes that need constant demographic stabilization. If we look on this problem from another angle, the US model looks at them mostly as centers for agricultural and economic production. Understanding how these funding models work is very important for analyzing why regions like Bulgaria and Nebraska are experiencing rural decline and poverty in very different ways.

MATERIALS AND METHODS

To evaluate the results of the different rural policies in Bulgaria and the USA (Nebraska), this research is using a comparative analysis method, combining theoretical policy review with quantitative socio-economic statistical information. The period of the quantitative research is focused on the years after 2020 (specifically 2020-2023) to capture the recent demographic changes and the economic situation after the global disruptions.

The theoretical part of the research is based on an institutional analysis of the main legislative documents for rural development in both regions. For Bulgaria, the research is reviewing the implementation of Pillar II of the EU’s Common Agricultural Policy (CAP) and the LEADER approach, with a focus on their area-based funding and territorial cohesion goals [2]. For Nebraska, the analysis is reviewing the US Farm Bill and USDA Rural Development programs, highlighting their focus on agricultural innovations, commodity support, and specific grants instead of broad territorial subsidies.

The quantitative part evaluates the practical results of these policies by comparing three main macroeconomic indicators: demographic changes (population growth or decline), economic functionality (poverty rates and income per capita), and agricultural employment dynamics. The statistical information for Bulgaria is collected from the Eurostat regional database, using the urban-rural typology to select the predominantly rural regions [3]. The data for Nebraska is taken from the USDA Economic Research Service (ERS) State Fact Sheets and the US Census Bureau’s Small Area Income and Poverty Estimates (SAIPE). The data is

aggregated at the county level based on nonmetropolitan (RUC codes 4-9) and metropolitan (RUC codes 1-3) classifications [10, 13]. Processing the data this way allows us to make a standard assessment of rural development across two completely different governance models.

It is important to note a methodological difference in how the EU and the USA define and measure poverty and economic vulnerability. Because there is no single global standard for these specific regional typologies, this research is using the official statistical frameworks of each governing body.

In Europe, the main indicator used is the "at-risk-of-poverty rate" (AROP), provided by Eurostat [3]. The EU measures poverty as a relative concept. The AROP indicator shows the percentage of people with an equivalized disposable income below the at-risk-of-poverty threshold, which is 60% of the national median income [3]. This means the European metric is mostly measuring income inequality and social exclusion in Bulgaria, which reflects the EU's policy to reduce the gap between rich and poor.

On the other hand, the quantitative analysis for Nebraska is using the US Census Bureau's Small Area Income and Poverty Estimates (SAIPE) [10]. The United States measures poverty as an absolute concept. The Census Bureau uses fixed income thresholds based on family size and composition to calculate who is in poverty. If a family's total income before taxes is less than the specific dollar threshold, the family is considered to live in poverty [10]. This absolute measure is focused on basic material deprivation instead of relative income differences.

While these two indicators, relative inequality (EU) and absolute deprivation (US), are capturing slightly different socio-economic trends, they are the most accurate official metrics to evaluate the economic functionality of rural populations in both regions. By comparing them, we are getting a good picture of how effectively each policy model provides financial stability for the rural citizens.

RESULTS AND DISCUSSIONS

After processing the data, the comparative analysis shows that the different policy frameworks in the EU and the USA are leading to different socio-economic results, although both regions have a common problem with rural decline.

In the European model, the area-based payments of the CAP are designed specifically to maintain rural population density and territorial cohesion. However, the demographic statistical information from Eurostat shows that these policies are not very successful in stopping the outgoing migration from Bulgaria. On the other hand, the US model in Nebraska is showing a highly market-driven approach. The US Farm Bill is giving big subsidies for agricultural production through crop insurance and commodity programs, which makes states like Nebraska global leaders in agricultural exports. However, this system leads to fast farm consolidation and requires high capital investments [7].

Table 1. Comparative socio-economic indicators (Bulgaria vs. Nebraska)

Indicator	Region Classification	Bulgaria (EU Policy Model)	Nebraska (US Policy Model)
Population Change (%)	Urban / Metropolitan	+0.72% (2021-2023)	+1.55% (2020-2023)
	Rural / Nonmetropolitan	-2.16% (2021-2023)	-0.52% (2020-2023)
Poverty Rate (2023)	Urban / Metropolitan	13.8% (Relative, AROP)	9.94% (Absolute, SAIPE)
	Rural / Nonmetropolitan	27.7% (Relative, AROP)	10.79% (Absolute, SAIPE)
Unemployment Rate (2023)	Urban / Metropolitan	4.10%	2.36%
	Rural / Nonmetropolitan	7.60%	2.11%

Source: Authors' calculations based on Eurostat [3], SAIPE [10], and USDA ERS data [13].

The empirical data highlights a very important difference between agricultural success and rural economic functionality, which is summarized in Table 1. Between 2020 and

2023, the metropolitan population in Nebraska increased by 1.55%, while its nonmetropolitan (rural) population had a small decrease of 0.52%.

When analysing the data from Figure 1, this demographic decline is much smaller than the one in the European model. The data from Eurostat is showing that Bulgaria's predominantly rural regions had a serious decline of 2.16% for a similar period. This means that passive area-based subsidies alone are not enough to keep the population in rural areas if there is no strong economic vitality.

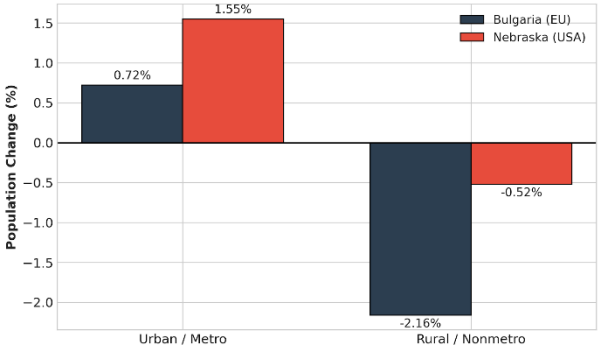

Fig. 1. Population change (%) in urban and rural regions.
Source: Authors' calculations based on Eurostat [3] and USDA ERS data [13].

The economic indicators are giving more information about the weak points of a purely territorial policy. As it is shown in Figure 2, there is a big structural gap in Bulgaria. The at-risk-of-poverty rate in rural areas in 2023 reached 27.7%. This is exactly double compared to the 13.8% rate in the urban centers. In the Nebraskan model, there is a very small difference in poverty between urban and rural areas (9.94% vs. 10.79%). This shows that the disparity is well contained compared to the European framework in Bulgaria. This big structural gap means that while the EU's CAP and cohesive subsidies are trying to help rural areas, they are failing to create equal economic functionality and to close the income gap in Bulgaria as effectively as the market-driven mechanisms in the US [6].

This comparison illustrates a structural income gap in Bulgaria (rural poverty is double the urban rate), whereas Nebraska maintains relative parity.

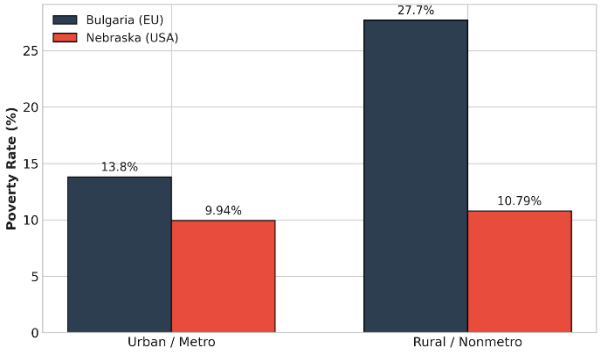

Fig. 2. Poverty Rate (%) by regional typology (2023)
Source: Authors' calculations based on Eurostat [3] and SAIPE [10].

Data from the Small Area Income and Poverty Estimates (SAIPE) for 2023 shows that even with low absolute poverty, there is still an income difference. The median household income in rural Nebraska was $63,936, which is nearly $13,000 less than the metropolitan median of $76,890. This brings us to the "employment paradox" of the American rural model. The statistical information for 2023 reveals that nonmetropolitan unemployment in Nebraska was very low at 2.11%, which is even better than the metropolitan rate of 2.36%. Basically, the rural population is fully employed, but they are still in a worse economic position compared to urban residents. The high functionality of the agricultural sector is not leading to equal wealth distribution for the whole rural community.

If we compare this with Bulgaria, as illustrated in Figure 3, the European model is showing a traditional gap in unemployment: the rural unemployment rate is 7.6%, which is almost double the 4.1% rate in the urban and suburban regions. This proves that passive territorial subsidies have not been successful in creating enough job opportunities to stabilize the local labor market, unlike the highly efficient agricultural business in the US.

When we put them side by side, the Bulgarian (EU) and Nebraskan (US) models are showing a trade-off. The EU system is providing a better social safety net and territorial support,

but it has problems with agricultural competitiveness and innovation.

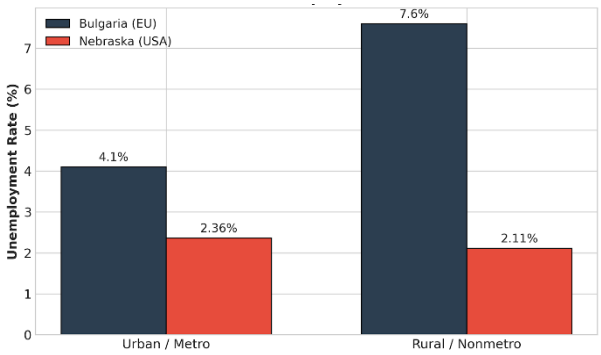

Fig. 3. Unemployment Rate (%) by regional typology (2023)
Source: Authors' calculations based on Eurostat [3] and USDA ERS data [13].

The US system is generating very high productivity and global market integration, but it is increasing social stratification and depopulation in the exact communities that are producing the wealth [1], [4], [5].

CONCLUSIONS

Based on the collected statistical information, this comparative analysis is showing that the structural problems of rural areas, mostly depopulation and economic lagging, are still present in both the European Union and the United States, even though they use completely different policy models.
The European model, which is used in Bulgaria, depends highly on area-based subsidies from the Common Agricultural Policy (CAP) to achieve territorial cohesion. However, the data suggests that this policy is failing to keep the rural population and to reduce the economic gaps. Rural regions in Bulgaria are facing a serious migration out of the rural areas (a population decline of 2.16% between 2020 and 2023) and a very high poverty rate of 27.7%, which is two times higher than in the urban centers. Also, the rural unemployment rate is almost double (7.6%) compared to the urbanized areas (4.1%). This is a clear indicator that passive subsidies without targeted economic stimulation cannot generate stable rural development or create new jobs.
On the other hand, the US model in Nebraska is working on a highly market-driven approach supported by the Farm Bill. This system is creating high agricultural productivity and global competitiveness, but it leads to the "employment paradox". Even though the rural population in Nebraska is fully employed (2.11% unemployment) and poverty is at low levels (10.79%, very close to the urban rates), the median household income is still much lower than in the metropolitan areas. The fast consolidation and the need for capital in the agribusiness sector are securing the food systems, but they are slowly reducing the rural population demographically (-0.52% decline).
We can conclude that to achieve successful long-term rural development, it is necessary to combine the positive sides of both models. Bulgaria can take an example from the American approach by changing the rural funding from passive area-based subsidies to targeted grants that can stimulate high-value agricultural innovations, local entrepreneurship, and job creation. At the same time, the US model can adopt some European-style structural funds focused on community infrastructure and local wealth retention. This will ensure that the big capital generated by the rural agribusinesses is invested back into the local economy instead of being extracted by large corporate companies. In conclusion, the rural policy must evolve from just subsidizing the agriculture to actively supporting the overall economic success of the rural municipalities.

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ECONOMIC EFFICIENCY OF REARING AND FATTENING LOW-WEIGHT PIGLETS AT EARLY WEANING WITH THE ADDITION OF A PORK MEAL SUBSTITUTE IN THE FIRST WEEK OF REARING

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Abstract

The article presents a comprehensive economic evaluation of reducing the suckling period from 28 to 21 days at a purebred pig farm using Landrace and Large White breeds. The analysis covered annual weaning output, the share of replacement gilts, the amount of surplus young stock for fattening, as well as revenue, cost, profit, and profitability of integrated production. Shortening the suckling period increased the annual number of weaned piglets in both breeds (Landrace: +3.0%; Large White: +5.5%) due to faster reproductive recovery in sows. This resulted in higher product sales per sow: +6.1% (+413.62 EUR) in Large White and +1.2% (+80.64 EUR) in Landrace. Economic indicators improved as revenue growth exceeded cost increases. The annual profit rose markedly in Large White by 7.0% (+210.35 EUR), while remaining nearly unchanged in Landrace (–0.1%). Profitability of integrated production increased by 1.16% (up to 82.23%) in Large White, but slightly decreased in Landrace (–1.71%). Overall, reducing the suckling period to 21 days is economically justified, enhancing sow productivity, increasing both breeding and meat output, and maintaining stable profitability. The most substantial positive effect was observed in the Large White breed.

Key words**:** *over-repair young stock, landrace, large white, profitability, economic efficiency*

INTRODUCTION

The critical role of replacement gilts in maintaining a high-performance sow herd is widely acknowledged [31, 42, 50, 51]. The effective organization of their rearing directly influences sow survival, longevity, and the overall economic efficiency of pig production. A key strategic issue for modern swine systems is the financial feasibility of rearing replacement gilts internally versus purchasing them from genetic suppliers [7, 26, 30, 38]. The frequency of herd replacement significantly impacts production costs and biosecurity risks. As pointed out [15, 42], gilt cost is among the most sensitive parameters in the financial model. Data from [2, 17] indicate that a 10–15% increase in the price of

purchased gilts can escalate the total cost per piglet by 2–4%, a factor particularly critical for farms with high culling rates.Net present value models [19] suggest that in-house breeding becomes economically preferable under conditions of stable sow reproductive performance (ideally, at least three parities) and controlled feed costs. While feed represents the main cost component in raising one's own replacement gilts [6, 9, 10, 24, 29], the strategy of internal rearing offers a crucial benefit: the ability to perform selective culling. This practice allows producers to avoid retaining productively inferior animals, thereby lowering the long-term cost of replacement and enhancing the genetic homogeneity and biosecurity of the breeding herd.

External sourcing of replacement gilts offers swine operations immediate access to cutting-edge genetics while concurrently reducing the logistical demands of maintaining a dedicated gilt development unit [1, 2, 5, 24]. However, the true economic burden of purchasing animals substantially exceeds the initial procurement price. This cost encompasses essential expenses for rigorous quarantine periods, diagnostic screening, necessary infrastructure adjustments, and, most critically, the substantial biosecurity risks associated with introducing diseases such as Porcine Reproductive and Respiratory Syndrome (PRRS), Mycoplasma hyopneumoniae, or Aujeszky's disease [8]. Evidence from industry analysis [2, 16] indicates that even minor breaches in biosecurity protocols during external acquisition can easily undermine the economic advantages of superior genetics, leading to elevated culling rates and compromised herd fertility. Internal Rearing (Own Production) Conversely, implementing an internal gilt production program provides the primary economic advantage of mitigating variable input costs and achieving greater independence from fluctuations in the commercial breeding material market [28, 42]. According to calculations by [16, 17], farms that manage in-house reproduction typically observe a 12–18% reduction in overall herd replacement expenditures. An added benefit is the capture of long-term genetic progress: controlled internal selection, even when applied moderately, can enhance the herd's productive indicators by 1–2% annually, contributing positively to the net present value over an extended period. In contrast, producers who are completely dependent on external purchasing relinquish control over the rate of genetic improvement and remain subject to the volatility inherent in the breeding stock market [8, 31, 57].

Under Ukrainian production conditions [3, 5, 35, 56], the epizootic background – particularly the risks associated with African swine fever (ASF) – is a determining factor in planning reproductive strategies. In regions where biosecurity requirements are especially stringent, maintaining an internal breeding program often demonstrates higher economic resilience, since it reduces expenditures and losses connected with the possible introduction of pathogens through purchased stock. Nevertheless, this advantage is realized only when farms possess an adequate production infrastructure [35, 45, 54, 56]. A complete cycle of gilt development requires dedicated facilities, specialized feeding schemes and well-trained staff; in the absence of such conditions, the overall cost of raising replacement animals may exceed the price of purchasing them.

Overall, the reviewed literature indicates that the economic justification for rearing one’s own replacement gilts is achieved when several key conditions are met: controlled feed and housing expenditures, the capacity to obtain at least three productive parity cycles from each sow, the presence of facilities that allow for isolated gilt rearing, and heightened regional risks related to biosecurity. While the acquisition of replacement animals can be advantageous in the short term or during rapid genetic improvement, this strategy requires careful consideration of the accompanying biosecurity measures and potential risks, which may substantially affect the real cost-effectiveness of production [3, 5, 35, 36, 45, 54].

At the same time proper development of replacement gilts is critical for ensuring their long-term reproductive performance and

improving piglet survival rates [20, 21, 41, 47]. Management and selection processes must begin at birth: indicators such as birth weight, litter characteristics, lactation conditions and weaning environment play a decisive role in early selection strategies and serve as predictors of the future productivity and efficiency of breeding animals [19, 22, 29, 36, 42, 52].

Research on weaning age has predominantly focused on economic aspects and on assessing piglet performance throughout the growth period up to slaughter [12, 18, 46, 49]. Although these studies were not directly aimed at gilt development, a number of their conclusions are highly relevant to understanding replacement gilt physiology. Evidence indicates that early weaning increases intestinal permeability [39] and compromises the piglet's ability to mount an adequate immune response to stress [12]. Importantly, the adverse consequences of early weaning have been shown to persist for prolonged periods – for example, mast cell hyperplasia observed in early-weaned piglets [44] continued into adulthood. These findings highlight the long-lasting influence of early-life gut health on the future robustness and productivity of gilts.

A body of research also confirms that both the age at weaning and subsequent post-weaning growth trajectories have a substantial impact on reproductive outcomes and the long-term economic value of replacement females. Weaning before 24 days of age is associated with higher mortality and shorter herd life, whereas weaning at 24 days or later ensures more consistent growth, greater weight gain, and improved immune competence – advantages that ultimately translate into better piglet survival [19]. Later weaning enhances gilt longevity and improves performance not only in the first but also in subsequent farrowings [41, 42].

An additional dimension of gilt management concerns the economic justification of different weaning strategies. Weaning period within the recommended range (24–28 days) yields measurable productivity gains: each extra day of later weaning increases annual sow output by approximately 0.185 piglets across four parities [29]. Thus, prolonging weaning age by only three days may result in more than half a piglet gained per sow per year, which has a marked positive effect on overall economic returns. Although early weaning at 15–19 days may appear cost-effective due to lower immediate expenses for care and feed, later weaning provides substantially greater long-term benefits. These include decreased replacement rates, lower culling levels, and enhanced productivity throughout the sow's reproductive lifespan.

Economic analyses reinforce this conclusion. Careful monitoring of gilt health in the post-weaning period can reduce cost per piglet by 4.9%, primarily through improved survival and reduced involuntary culling [2, 11, 17]. The additional expenditure associated with keeping gilts longer after late weaning was negligible relative to the financial gains achieved, making later weaning economically advantageous. Conversely, early weaning-particularly in piglets with birth weights below 1 kg is linked to higher mortality, lower weaning weights, and poorer lifetime performance, ultimately increasing economic losses through more frequent culling and repeated herd replacement requirements [36, 42].

Physiological differences between sexes further emphasize the need for adjusted management strategies. Enteric nervous system of females exhibits a stronger neuronally mediated secretory response and heightened cholinergic activation in response to weaning stress compared to males [40]. This suggests that gilts experience more pronounced adverse effects from early weaning, underscoring the importance of applying later weaning practices in herds producing replacement females.

Weaning age also plays a critical role in survival outcomes. Multiple studies have confirmed a substantial association between later weaning and increased numbers of pigs reaching market weight [18, 37]. Increasing weaning age from 19 to 28 days reduced piglet losses by 0.63% per day, meaning that a three-day extension could decrease mortality and culling by nearly 2%. Besides contributing to improved gut development,

later weaning serves as an effective strategy for enhancing gilt survival and overall herd longevity [37].

Comprehensive assessment of pre- and post-weaning determinants in a cohort of 6,249 replacement gilts entering commercial production systems, examining how these variables shaped lifetime productivity. Within this dataset, weaning age varied between 15 and 27 days. The analysis demonstrated that each additional day of weaning delay was associated with a gain of 0.185 piglets per sow per year across four parities. Consequently, extending weaning age by just three days translated into an increase of more than half a piglet per sow annually. Moreover, later weaning positively influenced retention rates from herd entry through the second farrowing [29].

When managing gilt development, the economic implications of modifying weaning age must also be taken into account. Given the demonstrable benefits for gilt health and reproductive success, breeding herds are advised to avoid weaning replacement females before 24 days of age.

Genetic background is a decisive factor in determining optimal weaning strategies [52]. Landrace gilts typically show strong adaptability to later weaning, exhibiting consistent growth, high survival rates, and sustained longevity within the herd [4, 20]. In contrast, Large White gilts particularly fast-growing genetic lines require closer regulation of post-weaning growth to prevent excessive body weight at first service, a condition that can predispose animals to limb disorders and structural weaknesses.

For both genetic types, it is essential to implement tailored nutritional programs and controlled growth management after weaning. This includes the precise adjustment of dietary amino acid profiles and overall energy density to support optimal physiological maturation and extend productive lifespan [13, 23, 25, 27, 34, 55].

Scientific evidence consistently demonstrates that the optimal weaning age for replacement gilts should be no less than 24 days, as this threshold ensures a balanced combination of improved survival, controlled growth trajectories, and overall economic efficiency. Management strategies, however, must be tailored to breed-specific genetic characteristics. Landrace-derived lines generally perform well under standard later-weaning protocols supplemented with regulated feeding, whereas Large White gilts particularly those belonging to high-growth genetic lines require more intensive dietary adjustments and continuous monitoring of body weight to prevent excessive growth and associated structural or limb problems. Adoption of such genotype-oriented management practices enhances herd productivity, reduces economic losses and contributes to higher profitability of commercial pig enterprises [14, 29, 31].

Taken together, contemporary research clearly indicates that gilt-rearing strategies must integrate biological, genetic and economic considerations. Nevertheless, although numerous studies address physiological development, growth patterns and reproductive traits, the economic viability of rearing replacement gilts specifically within Large White and Landrace populations remains insufficiently explored. This research gap is significant, as these two breeds constitute the foundation of most commercial herds, and their productive longevity and survival directly influence the profitability of pig production systems.

The aim of this study was to analyze and compare the economic efficiency of raising replacement gilts of the Large White and Landrace breeds, considering the influence of weaning age and the distinct genetic characteristics of each breed. In addition, the research sought to evaluate the performance and profitability of fattening surplus and culled young pigs under the production conditions of a single industrial pig farm.

MATERIALS AND METHODS

The research was carried out to evaluate how the length of the suckling period and sow breed influence productivity and the economic efficiency of a complete piglet-rearing cycle under the production conditions of the breeding farm LLC «NVP «Globynskyi Pig

Compleks» (Poltava region). The analysis considered profitability and cost-effectiveness at each technological stage. The study involved Landrace and Large White sows, which were assigned according to a factorial design into groups with two lactation durations: 21 and 28 days. For every sow, annual performance was recorded, including the number of farrowings, the number of live-born piglets, the number weaned, their average live weight, and total litter weight at weaning. These indicators formed the basis for modelling subsequent herd movements in rearing, breeding, and fattening units.

Four experimental groups, each consisting of 60 sows, were formed for the study. Coloured identification tags matching group allocation were used to distinguish the animals. Piglets from groups two and four were relocated to the rearing unit at 21 days of age, marking the end of their suckling phase. One week later, piglets from groups one and three were transferred under the same conditions after completing a 28-day lactation period. Throughout the rearing phase, all groups were maintained under uniform housing and feeding conditions.

Post-weaning data included the annual number of piglets per sow that progressed to the rearing facility, along with their live weight, feed expenses, maintenance costs, and their distribution into two production pathways: replacement breeding stock or non-replacement animals intended for fattening. At the conclusion of the rearing stage, when the animals reached an average age of 78 days, 40 gilts from each group were chosen for continued development and evaluation for breeding purposes. The selection process relied on individual body weight measurements and visual assessment in accordance with PIC® guidelines and the analogue-group approach [43].

Selected gilts were placed in the gilt-rearing facility in groups of 10–11 animals per pen, with partially slatted concrete flooring and identical management and ad libitum feeding using specialized dry rations. For the gilt-rearing stage, data were collected on the number of animals entering and exiting the testing period, average live weight, and key traits determining breeding suitability. The cost of rearing and evaluating gilts was also calculated, along with the market value of breeding females sold per sow on an annual basis.

The surplus young stock comprising all remaining piglets, including boars and gilts that did not meet the preliminary selection criteria for breeding was group-weighed and subsequently transferred to the fattening unit. There, the animals were placed in pens of 50 head each, on fully slatted flooring, with a stocking density of 0.71 m² per pig. All experimental groups were housed under uniform conditions, and feeding was provided through a multiphase liquid feeding system using specialized fattening diets. Throughout the fattening period, records were kept on the number of animals removed, their live weight at removal, and the date of removal. Feed intake was automatically monitored using an Austrian-made VEDA feeding station. At the end of the fattening phase, all pigs were group-weighed, which allowed calculation of the number of marketable animals, their final live weight, total fattening costs, and the market value of products obtained from each experimental group.

At 168–170 days of age, the gilts intended for breeding were subjected to a bonitation procedure that assessed essential reproductive and conformation traits, such as body weight, leg soundness, and the number of functional teats, in accordance with PIC® criteria [43]. Individuals that met the selection requirements were incorporated into the breeding herd, whereas those failing to qualify were culled and marketed for slaughter. The resulting dataset served as the basis for developing a comprehensive economic model to evaluate production efficiency across all technological pathways. The economic assessment accounted for annual sow maintenance costs under varying lactation lengths, expenditures associated with rearing and growing young stock, and income generated from sales of piglets, replacement animals, and fattened pigs. For each sow, net profit, profitability, gross output, and the effect of shortening the suckling period on the cost of progeny were determined. This

statistical approach made it possible to assess the economic effectiveness of each production stage and to calculate the integrated financial result per sow per year. Such a framework enabled a comprehensive assessment of both the biological and economic consequences of shortening the lactation period and allowed evaluation of breed-specific responses among the main maternal lines.

The data obtained were subjected to biometric processing using variational statistical methods to test the reliability of differences between groups, employing Microsoft Excel 2016 software [32, 33]. Statistical significance thresholds were set at $^{*}(p < 0.05)$, $^{**}(p < 0.01)$, and $^{***}(p < 0.001)$.

RESULTS AND DISCUSSIONS

Selection of replacement gilts commenced immediately after birth. At the earliest stage, piglets were evaluated based on individual body weight and the presence of any visible developmental abnormalities. Throughout the lactation period, all piglets remained with their dams until weaning, after which they were moved to the rearing unit. During this phase, animals underwent an additional evaluation that included assessment of growth rate and exterior traits. Upon completion of the rearing stage, the young stock was allocated into production groups. Surplus animals including all boars and any gilts that failed to meet the target selection criteria were transferred to the fattening facility for finishing and subsequent sale to the meat processing plant.

Piglets that met the predefined requirements of the PIC breed standard were placed in the gilt-development facility, where they continued to be assessed under a controlled feeding regimen. At 168–170 days of age, the replacement gilts underwent a comprehensive evaluation, which included verification of live weight compliance with breed norms, measurement of backfat thickness, assessment of limb soundness and structural correctness, and evaluation of teat number and functionality. Based on the outcomes of this assessment, non-conforming animals were culled and sent for slaughter, while gilts that met the selection standards were retained either for breeding stock sales or for replenishment of the farm's own sow herd.

The comparative analysis of sow productivity for both breeds demonstrated a clear relationship between annual reproductive performance and the duration of the lactation period (Table 1).

Table 1. Annual efficiency of obtaining and raising piglets from one sow during the suckling period

Indicator	Pig breed			
	Landrace		Large White	
Group of animals	I	II	III	IV
Lactation duration, days	28	21	28	21
Number of weaned piglets per sow per year, head	32.2±1.01	34.3±0.67	33.4±0.56	35.3±0.43$^{cc\ ff}$
Live weight of weaned piglets per sow per year, kg	237.8±6.41$^{aaa\ eee}$	188.8±2.79	240.2±3.48$^{eee\ fff}$	189.0±1.45
Operating cost of maintaining one sow per year, EUR	6,150.54	5,762.40	6,206.27	5,778.76
Operating cost of rearing piglets from one sow per year, EUR	657.43	595.80	664.31	597.66
Value of output received (excluding VAT), EUR	935.57	844.77	941.59	842.71
Annual profit from rearing piglets per sow, EUR	278.14	248.97	277.28	245.05
Profitability of piglet production and rearing during the lactation period, %	42.31	41.79	41.74	41.00

Note: ^{aaa} 1–2; ^{bbb} 1–3; ^{ccc} 1–4; ^{ddd} –2– 3; ^{eee} 2–4; ^{fff} 3-4
Source: own calculations.

An evaluation of the annual productivity of sows under different suckling durations reveals pronounced differences in both absolute and relative performance indicators, underscoring the complex advantages and limitations associated with early weaning. Shortening the lactation period from 28 to 21 days resulted in a measurable increase in the annual number of weaned piglets per sow. In Landrace sows, this increase amounted to 2.10 piglets (+6.5%), while in Large White sows it averaged 1.82 piglets (+5.5%). Such gains positively influence herd turnover by enabling the production of a greater number of litters within a year.

However, this benefit was offset by a reduction in the average live weight of piglets at weaning. In Landrace sows, the total annual live-weight output decreased by approximately 49.26 kg (–20.6%), and in Large White sows by 51.25 kg (–21.3%). This decline represents the primary drawback of early weaning, as lower weaning weights directly affect subsequent production value.

From an economic standpoint, the shortened suckling period reduced the annual operational cost of maintaining a sow by 19,407.8–427.50 EUR (–6.3% to –6.9%). Combined with a decrease in the cost of rearing piglets by 61.62–66.65 EUR, this generated substantial savings within the production cycle. Nevertheless, the diminished total output mass resulted in a lower market value of the annual piglet yield: in Landrace sows by 90.80 EUR (–9.7%) and in Large White sows by 98.87 EUR (–10.5%). This loss is only partially offset by the increased number of weaned piglets.

Annual profit from piglet rearing under reduced lactation declined moderately by 29.17 EUR in Landrace sows (–10.5%) and 32.22 EUR in Large White sows (–11.6%). Despite this, profitability ratios remained consistently high, with only a slight decrease of 0.52–0.74%.

Overall, early weaning enhances reproductive turnover and reduces production costs but simultaneously lowers weaning weights and partially diminishes the market value of the piglet output.

Following an assessment of the annual efficiency of piglet production and rearing during lactation, the subsequent finishing phase becomes crucial because it determines the final number and quality of young pigs available for breeding or for fattening as surplus stock. A seamless transition between these stages makes it possible to evaluate how alterations in suckling duration influence annual growth performance and economic outcomes. As indicated in Table 2, reducing the suckling period from 28 to 21 days increased the number of piglets that successfully completed the growing phase: by 0.96 head (+3.0%) in Landrace sows and by 1.76 head (+5.5%) in Large White sows.

Table. 2. Annual efficiency of rearing piglets from one sow

Indicator	Pig breed			
	Landrace		Large White	
Animal group	I	II	III	IV
Duration of suckling period, days	28	21	28	21
Annual number of piglets from one sow removed from rearing, heads	31.68	32.65	32.36	34.12
Annual cost of piglets when placed for rearing, EUR	744.68	746.20	749.53	744.49
Annual cost of rearing piglets from one sow, EUR	774.55	889.39	772.12	919.03
Cost of all piglets when removed from rearing, EUR	1,519.22	1,635.59	1,521.65	1,663.52
Market value of all piglets received from the sow in the year after completion of rearing, EUR	3,092.01	2,963.10	3,008.16	3,054.34
Profit from receiving and rearing all piglets in the year, EUR	1,572.79	1,327.51	1,486.51	1,390.82
Profitability of receiving and rearing one-year litter from one sow, EUR	2.07	1.62	1.95	1.67

Source: own calculations.

This reflects both the higher number of piglets produced during lactation and their satisfactory survival during rearing. Importantly, the annual value of piglets at the onset of the growing stage remained nearly identical to that of the control groups, suggesting that the initial economic value of the animals was largely unaffected by suckling duration.

The production expenses associated with the rearing phase increased in groups where the lactation period had been shortened. In Landrace sows, the rise amounted to 114.84 EUR (+14.8%), whereas in Large White animals the increase reached 146.91 EUR (+19.0%). At the same time, the aggregated value of all piglets at the point of removal from the growing stage increased proportionally to the larger number of animals: by 102.23 EUR (+6.8%) in Landrace and by 145.79 EUR (+9.7%) in Large White pigs. However, the subsequent market valuation of this young stock differed between breeds: in Landrace animals it declined by 128.91 EUR (–4.2%), while in Large Whites it demonstrated a moderate rise of 46.18 EUR (+1.5%).

The annual profit derived from producing and raising piglets showed contrasting tendencies. In the Landrace group, profitability dropped by 245.27 EUR (–15.6%), attributable to both higher operating expenses and a reduction in market price. Among Large White animals, the decline was less pronounced, amounting to 95.69 EUR (–6.4%). Profitability ratios also decreased when the suckling period was shortened, falling by 22.36% in Landrace and by 14.08% in Large White groups. Despite this downturn, both breeds maintained high profitability levels (81.2% and 83.6%, respectively), confirming the economic viability of the production system.

Overall, the findings from the growing stage demonstrate that earlier weaning reliably increases the output of young animals eligible for subsequent production routes. Nevertheless, this benefit is offset by higher per-unit rearing costs, underscoring the importance of determining an optimal balance between piglet productivity and the resources needed for their development. This cost-productivity relationship represents a key factor in improving technological strategies on breeding farms.

Once piglets complete the rearing stage, the herd transitions to the subsequent, critically important phase of the breeding-farm cycle-replacement gilt development. This stage forms the foundation of the breeding program, as its final product high-quality breeding gilts determines the genetic advancement of the herd. Allocation of young animals is based on a comprehensive selection protocol that incorporates growth performance, development, body conformation, exterior traits, and genetic criteria defined by the breeding organization. All gilts that complete rearing are evaluated and divided into two distinct categories. The first includes those that meet breeding standards and remain on the farm for continued development until first mating; these animals constitute the commercial core of breeding operations. The second group consists of boars and gilts that do not qualify for breeding. This stock is transferred to the fattening unit, where it contributes to additional economic returns through finishing and sale to meat enterprises. Such a herd structure underscores the necessity of an optimal balance between breeding and commercial production, as farm sustainability relies on the efficiency of both sectors.

Analysis of the indicators presented in Table 3 demonstrates that shortening the suckling period increased the number of piglets eligible for subsequent performance testing.

The annual effectiveness of replacement gilt rearing was influenced by breed characteristics, lactation duration, and the number of piglets entering and completing the testing process.

In Landrace sows, shortening the suckling period from 28 days (Group I) to 21 days (Group II) resulted in a minor increase in the number of animals entering performance testing by 0.39 head (+3.0%) and those completing it–by 0.35 head (+2.9%).

Table 3. Annual efficiency of rearing replacement pigs

Indicator	Pig breed			
	Landrace		Large White	
Animal group	I	II	III	IV
Duration of suckling period, days	28	21	28	21
Annual number of piglets from one sow transferred for testing, heads	12.67	13.06	12.94	13.65
Annual number of gilts withdrawn from testing heads, pigs	12.33	12.68	12.63	13.30
Number of gilts from one sow transferred for breeding, head	7.03	6.72	8.21	9.05
Share of gilts transferred for breeding, %	57.00	53.00	65.00	68.00
Cost of breeding gilts obtained from one sow per year, EUR	2,206.15	2,109.91	2,577.65	2,840.38
Cost of raising all replacement gilts obtained from one sow per year, EUR	896.91	855.60	1,029.32	1,141.07
Income from raising replacement gilts obtained from one sow per year, EUR	1,309.25	1,254.31	1,548.33	1,699.30
Profitability of raising replacement gilts obtained from one sow per year, %	145.97	146.60	150.42	148.92

Source: own calculations.

Nevertheless, the proportion of gilts allocated to the breeding category declined by 7.55% (from 57% to 53%), which correspondingly reduced the actual number of breeding-quality animals by 4.61% (from 7.03 to 6.72 head). This reduction had a direct economic impact: the value of breeding animals decreased by 4.4%, and revenue fell by 4.2%, even though production costs declined by 4.6%. Despite these changes, profitability remained exceptionally high (146.60% vs. 145.97%), showing only marginal differences between lactation-length groups.

In contrast, the Large White breed exhibited the opposite pattern. Reducing the suckling period to 21 days (Group IV) compared with 28 days (Group III) produced a 5.04% increase in the number of animals completing testing. The proportion of gilts selected for breeding rose from 65% to 68%, and the number of breeding-quality animals increased by 10.2% (from 8.21 to 9.05 head). This improvement translated into a substantial rise in the value of breeding stock–by 262.72 EUR (+10.2%) and an increase in revenue by 150.97 EUR (+9.8%), although production costs also grew by 10.9% (reaching 1,141.06 EUR). Profitability in both groups was similarly high (150.42% and 148.92%), confirming the economic soundness of both rearing strategies.

A comparison of groups maintained under the same lactation regime demonstrates a consistent advantage of Large White pigs over their Landrace counterparts across all key economic indicators. Under the 28-day suckling period, Large White animals (Group III) displayed an 8% higher proportion of gilts selected for breeding (65% vs. 57% in Group I), resulting in 1.18 additional breeding-quality animals. Consequently, the value of breeding animals increased by 16.8% and revenue by 18.3%, despite rearing costs being 14.8% higher. Profitability was also superior in the Large White group by 4.45% (150.42% vs. 145.97%).

Under the shortened 21-day suckling period (Group IV compared with Group II), the advantage of Large White pigs became even more pronounced. The difference in the proportion of animals selected for breeding reached 15% (68% vs. 53%), yielding 2.33 more breeding-quality gilts (+34.6%). This resulted in a 730.46 EUR (+34.6%) higher valuation of breeding animals and a 444.99 EUR (+35.5%) increase in revenue. Although production costs were also higher by 285.46 EUR (+33.4%), the profitability of Large White pigs still exceeded that of Landrace animals by 2.32% (148.92% vs. 146.60%).

Thus, the decisive factor shaping the overall economic efficiency of the system is the number of gilts that successfully complete

performance testing and proceed to breeding use. Across all evaluated scenarios, Large White gilts demonstrated a consistently higher proportion of animals meeting the breeding criteria, which ensured substantially greater income and maintained profitability at a stable and exceptionally high level (approximately 150%), even under conditions of higher production costs. Additionally, the inherent genetic advantages of the Large White breed generated a notable economic benefit compared with Landrace pigs, irrespective of differences in the duration of the suckling period.

An examination of the number of replacement gilts culled from the breeding nucleus and the resulting economic outcomes of their sale revealed that altering the length of the suckling period directly influences the absolute financial return from meat sales (Table 4). At the same time, the profitability of this component remained stable and was not affected by either the lactation duration or the animals' genotype. Consequently, reducing the suckling period from 28 to 21 days affects not only the number of high-quality replacement females suitable for breeding, but also the economic performance of auxiliary production segments specifically, the fattening of surplus replacement stock and the sale of culled gilts to meat-processing enterprises. Given that breeding production constitutes the core economic function of a breeding farm, the findings demonstrate that revenue generated from surplus and culled animals represents a substantial and economically meaningful component of the annual financial outcome, which is sensitive to technological adjustments.

For Landrace pigs, shortening the suckling period from 28 to 21 days led to a 12.45% increase in the number of culled gilts (from 5.30 to 5.96 head), accompanied by a rise in the culling rate from 43.00% to 47.00%

Table 4. Annual meat production efficiency of culled replacement gilts from one-year-old offspring of one sow

Indicator	Pig breed			
	Landrace		Large White	
Animal group	I	II	III	IV
Duration of suckling period, days	28	21	28	21
Number of gilts culled after evaluation and sold to a meat processing plant, heads	5.30	5.96	4.42	4.26
Share of gilts culled after testing,%	43.00	47.00	35.00	32.00
Average weight of one culled gilt sold for failure, kg	118.2	117.9	116.1	116.8
Weight of culled gilts sold to a meat processing plant, kg	626.49	702.54	513.19	497.20
Cost of culled gilts sold to a meat processing plant, EUR	676.61	758.74	554.25	536.97
Market value of culled gilts sold to a meat processing plant, EUR	905.91	1,015.87	742.08	718.95
Profit from culled gilts sold to a meat processing plant, EUR	229.30	257.13	187.83	181.97

Source: own calculations.

Because the average live weight of animals at the time of sale remained stable (approximately 118 kg), the increase in the number of culled gilts directly translated into a proportional rise in the total volume of sold meat products. Consequently, the annual profit grew by 12.14% (from 229.29 EUR to 257.12 EUR).

In contrast to the Landrace breed, Large White animals exhibited a different response to the shortened suckling period. Under the 21-day regime, the number of culled gilts decreased by 3.62% (from 4.42 to 4.26 head), and the culling rate declined from 35.00% to 32.00% compared with the conventional 28-day lactation. This reduction resulted in a proportional decrease in annual profit from the sale of culled gilts by 3.12% (from 187.82 EUR to 181.97 EUR). Such dynamics point to greater breeding stability in the Large White breed, which yields fewer culled animals and therefore reduces income from meat sales

under intensified production conditions. Notably, the profitability of selling culled replacement gilts remained unchanged at 33.89% regardless of breed or lactation duration, indicating the structural resilience of this production segment.

Thus, shortening the suckling period from 28 to 21 days exerts a differentiated economic influence on the fattening of culled replacement gilts, determined largely by breed characteristics. For Landrace pigs, reduced lactation length increases both the culling rate and associated profit, whereas in Large White animals it lowers the number of culls and accordingly diminishes the financial return. At the same time, the stability of profitability suggests that quantitative parameters rather than technological adjustments or changes in production cost dictate the overall economic outcome.

Reducing the suckling period from 28 to 21 days also affected the annual economic indicators associated with the fattening of surplus replacement stock in both breeds (Table 5). However, the nature and direction of this influence varied substantially between the two genotypes.

Table 5. Annual economic efficiency of fattening over-repair young pigs obtained from one sow

Indicator	Pig breed			
	Landrace		Large White	
Animal group	I	II	III	IV
Duration of suckling period, days	28	21	28	21
Annual number of over-repair pigs from one sow removed from fattening, head	18.49	19.02	18.94	19.95
Average weight of over-repair pigs removed from fattening, kg	127.3	126.2	125.1	124.8
Weight of all over-repair pigs from one sow fattened per year, kg	2,353.70	2,399.98	2,369.90	2,490.25
Cost of all over-repair pigs from one sow fattened per year, EUR	2,127.74	2,169.59	2,142.39	2,251.19
Realization value of all over-repair pigs from one sow removed from fattening per year, EUR	3,403.45	3,470.38	3,426.87	3,600.90
Annual income from the sale of over-repair fattening livestock from one sow, EUR	1,275.71	1,300.79	1,284.48	1,349.72

Source: own calculations.

In Landrace sows, shortening the suckling period resulted in a modest increase in the number of surplus replacement pigs sent to fattening, amounting to +0.58 head per sow annually, which corresponds to a 3.0% rise. This change contributed to an increase in the annual total live weight of pigs marketed by 46.29 kg (2.0%), accompanied by a proportional growth in production costs of 41.84 EUR and an increase in sales revenue of 66.92 EUR (also 2.0%). As a result, income from animal sales rose by 25.08 EUR, demonstrating a moderate but positive economic response to production intensification in this breed.

For Large White pigs, the effect of early weaning was more pronounced. The number of surplus pigs removed from fattening increased by 1.06 head per sow per year (5.5%). Consequently, the annual volume of marketable live weight grew by 120.4 kg (5.1%), which led to an increase in production costs by approximately 108.79 EUR and the sales value of marketed animals by 174.03 EUR (5.1%). Annual income rose by 65.23 EUR (5.1%), a growth rate surpassing that observed in the Landrace breed, indicating a higher sensitivity of Large White pigs to changes in the technological regime.

In summary, reducing the suckling period from 28 to 21 days yielded a positive economic effect in both breeds, although the magnitude of this effect varied. For Landrace animals, the increase was moderate (approximately 2% according to key financial indicators), whereas in Large White pigs it was more substantial, consistently exceeding 5%. These findings indicate that the Large White breed more effectively realizes its production potential under earlier weaning conditions.

A shortened lactation period also increased the total annual number of pigs delivered to the meat-processing plant in both breeds; however, the scale and direction of change differed by genotype (Table 6).

Table. 6. Economic efficiency of fattening replacement gilts and over-replacement young pigs

Indicator	Pig breed			
	Landrace		Large White	
Animal group	I	II	III	IV
Lactation duration, days	28	21	28	21
Number of over-repair and culled pigs removed from fattening, head	23.79	24.98	23.36	24.21
Weight of all fattened and culled pigs from one sow per year, kg	2,353.70	2,399.98	2,369.90	2,490.25
Cost of livestock sold to a meat processing plant, EUR	2,804.36	2,928.33	2,696.64	2,788.16
Realization value of all pigs sold to a meat processing plant from one sow per year, EUR	4,309.36	4,486.25	4,168.95	4,319.85
Profit from pigs sold to a meat processing plant, EUR	1,505.00	1,557.92	1,472.31	1,531.69
Profitability of livestock meat processing plants,%	53.67	53.20	54.60	54.94

Source: own calculations.

Among Landrace animals, the reduction in the suckling period resulted in an increase of approximately 1.19 head per year (+5.0%) in the number of pigs marketed for meat, whereas in the Large White breed this increase amounted to about 0.85 head (+3.6%). The higher number of animals automatically led to an increase in the annual volume of live weight sold by 104.4–122.3 kg (3.6–4.1%) which subsequently caused proportional changes in production costs and sales value. As a result, the sales revenue from Landrace pigs rose by 176.88 EUR (4.1%), while in Large White pigs the increase was 150.90 EUR (3.6%). Although these values are considerably lower than those associated with the production of breeding stock, they still constitute an economically meaningful component of annual profit, particularly under intensified production systems.

The breeds also differed in their profitability response to the shorter lactation period. Under the 21-day suckling regime, Landrace pigs generated an additional 52.9 EUR of annual profit (+3.5% compared with the standard suckling period), whereas Large White pigs showed a greater increase 59.36 EUR (+4.0%). This growth, although moderate, was stable, underscoring the role of fattening surplus and culled animals as a supplemental yet economically important source of income capable of offsetting fluctuations in the primary breeding segment. Profitability of animals delivered to the meat-processing plant remained consistently high at 53.2–54.9%, with only minor variation between groups (up to 1.3%). These data indicate that the technological efficiency of meat production is largely independent of lactation duration or genotype; instead, the economic effect is determined primarily by quantitative changes in the number of surplus and culled animals.

Overall, the findings demonstrate that, while breeding remains the central priority and the main target of intensification, the segment of fattening surplus and culled stock plays a critical stabilizing role, contributing as much as 25–30% of the total annual profit generated from one sow's offspring. Shortening the suckling period and thus increasing the number of animals entering the fattening pipeline enhances the contribution of this supplementary segment, making it an integral component of the economic framework of modern pig production.

A systematic assessment of economic indicators for rearing replacement gilts and fattening surplus animals, presented in Table 7, confirms that shorter lactation significantly alters the annual production structure of a breeding farm.

Table 7. Annual economic efficiency of raising replacement pigs and fattening over-replacement young pigs obtained from one sow

Indicator	Pig breed			
	Landrace		Large White	
Animal group	I	II	III	IV
Lactation duration, days	28	21	28	21
Annual number of grown piglets from one sow, head	31.68	32.65	32.36	34.12
Of which: – placed for breeding, head	12.67	13.06	12.94	13.65
– transferred for fattening, head	19.01	19.59	19.41	20.47
Total cost of growing and fattening pigs from one sow, EUR	3,701.27	3,783.93	3,725.95	3,929.23
Realization value of grown and fattened pigs from one sow, EUR	6,515.51	6,596.15	6,746.60	7,160.23
Profit from fattening and breeding sales of pigs from one sow, EUR	2,814.25	2,812.23	3,020.64	3,230.99
Profitability of fattening and breeding sales of pigs from one sow,%	76.03	74.32	81.07	82.23

Source: own calculations.

Because replacement gilts constitute the primary and most valuable breeding output, their quantity and quality are critical for the reproductive cycle and long-term genetic improvement. At the same time, surplus animals transferred to fattening and later sold for meat represent an additional, economically meaningful segment that significantly strengthens the overall profitability of the enterprise.

The comparative assessment of feeding costs revealed that, although the experimental pigs consumed feed with a marginally higher price per unit, the total expenditure per kilogram of live weight was lower than in the control group. Specifically, the average feed cost from weaning to slaughter was reduced by approximately 5–6% in the experimental cohort. This economic advantage stemmed from more efficient nutrient utilization and faster growth rates, leading to a lower feed cost per kilogram of weight gain. The inclusion of milk replacer in the diet contributed to improved feed conversion efficiency, thereby enhancing overall production profitability.

In summary, introducing pig milk replacer during the rearing phase promoted more intensive growth, reduced feed intake per unit of gain, and lowered the cost per kilogram of both weight gain and final live mass. These findings underscore the economic benefit and practical applicability of incorporating milk replacer feeding into modern pig production systems. As profitability remains the key goal of commercial pork production, Table 3 outlines a comparative economic analysis for low-birth-weight piglets in the control group (standard diet) and the experimental group (supplemented with milk replacer during rearing). Shortening the suckling period from 28 to 21 days led to an increase in the annual number of piglets raised in both breeds: +0.97 head in Landrace sows (+3.0%) and +1.76 head in Large White pigs (+5.5%). This growth, although moderate, was consistent and directly associated with a faster restoration of the sow's reproductive cycle. Notably, the proportion of replacement gilts within this cohort also increased in groups with shortened lactation by 0.39 head (+2.9%) in the Landrace breed and by 0.71 head (+5.5%) in the Large White breed indicating a higher rate of formation of the primary breeding output, which is essential for maintaining genetic advancement.

At the same time, the number of surplus gilts transferred to fattening also rose: by 1.19 head (+5.0%) in Landrace animals and by 0.85 head (+3.6%) in Large White pigs. Although this category functions as a secondary segment relative to breeding production, its expansion reflects a clear economic strengthening of the herd due to additional volumes of meat products. Economic indicators further confirm the value of both

production components. The total sales revenue per sow increased under shortened lactation by approximately 80.64 EUR (+1.2%) in Landrace pigs and by 413.62 EUR (+6.1%) in Large White pigs due to both a greater number of replacement gilts and a larger volume of surplus animals destined for fattening. Simultaneously, the cost of raising and fattening the annual pig crop also rose slightly (by 2.2–5.5%), although the growth rate of expenses remained lower than that of income, thus securing an overall improvement in profitability.

Annual profit from combined breeding and fattening activities showed different patterns in the two breeds. In Landrace sows, it remained almost unchanged (–0.1%), while in Large White animals it increased substantially by 210.34 EUR (+7.0%), highlighting the superior economic responsiveness of the Large White breed under intensified reproductive management.

Profitability analysis of integrated production reveals a partial advantage of the groups kept under the 21-day suckling period. In Landrace pigs, profitability declined slightly (by –1.71%, from 76.03% to 74.32%), whereas in Large White pigs it increased by 1.16% (from 81.07% to 82.23%). High and stable profitability indicators across both breeds under both lactation durations confirm their strong suitability for intensive production systems and their considerable economic potential in combined breeding and meat-production operations.

The findings clearly demonstrate that replacement gilts continue to represent the primary and most valuable output of a breeding farm. However, the additional segment the sale of surplus young stock substantially enhances the overall economic stability of production. Reducing the suckling period stimulates growth in both the core and supplementary production sectors, with the Large White breed showing a more pronounced economic response, indicating its strong adaptability to intensified reproductive regimes. Overall, combining breeding with the fattening of surplus stock creates a balanced and economically efficient production model for breeding enterprises.

In summary, shortening the suckling period is an economically justified and multifacetedly effective management decision. It simultaneously reduces sow maintenance costs, increases the number of piglets produced and reared through the final technological stages, raises the proportion of replacement gilts, generates additional income from surplus stock, and ensures stable profitability across all production stages. The most substantial positive effects are observed in the Large White breed, although Landrace sows also demonstrate a steady improvement in efficiency. Therefore, reducing the suckling period represents a valuable tool for optimizing the economics of breeding pig farms and enhancing their overall competitiveness.

The results obtained in our study regarding the influence of suckling duration and breed on the economic efficiency of rearing replacement gilts and fattening surplus young pigs generally correspond well with patterns described in the scientific literature, while simultaneously revealing several specific features that may highlight new technological considerations.

First, the positive effect of shortened lactation on increasing the number of piglets (both replacement and surplus) aligns with findings previously reported by other authors. For example, reducing lactation by approximately 23–32% decreases weaning weight but does not significantly affect the number of weaned piglets [48, 49]. Similar tendencies were observed in our experiment: earlier weaning increased the total number of piglets produced per sow annually, although the average live weight of piglets at weaning was somewhat lower. This confirms the well-known trade-off in pig production shortening lactation enhances herd turnover even when individual weaning weights decline.

Second, published research on the economic performance of replacement gilts supports our conclusion that the proportion of animals redirected into breeding is one of the key determinants of farm profitability. Gilts of differing breeding value classes exhibit substantial variation in performance traits and financial efficiency [28]. Although our study

did not employ BLUP-based classification, the observed increase in the proportion of animals qualified for breeding use likewise had a measurable positive impact on profitability, even when a part of the stock was subsequently designated for fattening.

At the same time, some discrepancies with earlier findings were also noted. Studies reported comparatively low profitability of raising replacement gilts (approximately 10%) under certain feeding systems [14, 53]. In contrast, profitability in our study reached substantially higher levels up to 82% in Large White gilts which may be attributed to a more optimized balance between breeding and fattening groups, as well as more efficient feeding and housing technologies applied in our research conditions.

It should also be emphasized that the literature rarely considers the combined economic effect of using replacement stock simultaneously in breeding and fattening roles. However, in our study, the ratio between gilts allocated to breeding and those redirected for fattening proved to be a critical driver of overall economic efficiency. Thus, our findings expand existing scientific knowledge and offer practical justification for farms aiming to optimize the selection and use of replacement gilts through an integrated approach that includes both breeding and commercial objectives.

The findings of this study support previously reported patterns, especially those related to the effects of lactation length and the share of animals selected for breeding. At the same time, the research adds a new applied perspective by demonstrating that fine-tuning the allocation of replacement gilts between the breeding herd and fattening groups can enhance overall economic performance. This observation creates avenues for future investigations and encourages the adoption of production strategies that align genetic potential with the economic objectives of contemporary pig-producing operations.

CONCLUSIONS

Reducing the lactation period from 28 to 21 days improves sow reproductive performance, yielding a greater number of replacement and surplus gilts and, as a result, boosting the farm's annual revenue. The increase in income exceeds the additional production expenses, leading to an overall rise in profitability. This effect is especially pronounced in Large White sows, where profit levels grew by approximately 7%.

The profitability of integrated operations (breeding and fattening) remains consistently high, and in groups with reduced lactation in the Large White breed, it even rises further, demonstrating the economic rationale for intensifying the reproductive cycle.

Combining breeding activities with the marketing of surplus breeding stock strengthens the financial resilience of the enterprise, while reducing the suckling period serves as an effective strategy for boosting the competitiveness of a breeding farm.

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EXCHANGE TRADING FOR AGRICULTURAL PRODUCTS IN BULGARIA IN THE CONTEXT OF SUSTAINABLE AGRICULTURAL DEVELOPMENT

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Abstract

The stock market, as an organized market and part of the modern agrarian economy, provides mechanisms for a more efficient allocation of resources in agriculture through market pricing and risk management. On a global scale, food demand is one of the main factors determining the structure and functioning of the stock market for agricultural products. The volumes and dynamics of prices on organized markets are influenced by demographic changes, a growing population, increasing incomes and changing eating habits. This study aims to analyze the correspondence between the structure of agricultural production in Bulgaria and the development of stock trading, assessing the role of the organized market as a tool for achieving economic sustainability and managing price risk in the sector. Questions are raised regarding the sustainable development of agriculture, environmental sustainability, social justice and regulation. The study is based on an analysis of scientific literature, statistical data and market trends. The results show that global food demand not only increases the volume of the stock market, but also changes its structure, strengthening its role in international markets.

Key words: *commodity exchange, agricultural products, sustainable agriculture, price indices, food security.*

INTRODUCTION

The development of the agricultural market in Bulgaria over the past two decades has been a dynamic process of transformation of the sector from a traditional to a modern, market-oriented and partially integrated agricultural market in international supply chains. This transition laid the foundations for the creation of organized markets and exchange systems in the country. Integration with European and world markets has been achieved. According to the Ministry of Agriculture and Food of Bulgaria (2023) [36], structural changes improve competitiveness and create effective exchange mechanisms despite existing challenges. In the context of globalization and European integration, the Bulgarian agricultural sector is reorienting towards exchange trading, electronic platforms and sustainable models of production and consumption. Exchange trading plays a key role in pricing, liquidity and risk management, providing standardized mechanisms and transparency, but also poses new challenges to sustainability, including environmental and social aspects. The implementation of electronic exchange platforms and the modernization of infrastructure can improve market efficiency and sustainable development of the sector (Jones, Smith, & Martinez, 2021; Ministry of Agriculture, 2024) [32, 37]. The purpose of this study is to analyze the correspondence between the structure of agricultural production in Bulgaria and the development of exchange trading, assessing the role of the organized market as a tool for achieving economic sustainability and managing price risk in the sector.

Table 1. Structure of Commodity Exchange Trading by Product Group in Bulgaria (% of Volume)

Group	Share
Fruits and Vegetables	35–40%
Basic Foods (flour, sugar, cooking oil, etc.)	30–35%
Grain and Raw Materials	20–25%
Animal Products	10–15%

Source: SCCCE (State Commission on Commodity Exchanges and Effluents) [11].

The analysis examines the status, structure and trends of exchange trading in agricultural products in Bulgaria, based on data from the

Sofia Commodity Exchange (SCE) and market reports for the period 2022–2026. Exchange trading in agricultural products in Bulgaria is carried out mainly through organized commodity exchanges and electronic trading platforms. The data in Table 1 show that exchange trading in Bulgaria is concentrated in a narrow group of commodities, which limits the diversification and depth of the market. Trade is characterized by relatively low liquidity and dominance of spot transactions. Unlike developed markets in the EU, the use of futures and derivative instruments still remains limited. This limits the ability of farmers to hedge price risks. At the same time, the efficiency of the commodity market as a tool for sustainable development of agriculture is reduced.

The most actively traded products are cereals and oilseeds, including wheat, corn and sunflower. In the exchange trade in Bulgaria, wheat dominates and accounts for nearly half of the total volume of traded goods. Corn and sunflower also have significant shares, while the remaining products are traded in limited quantities. This reflects the strong specialization of Bulgarian agriculture in grain production.

MATERIALS AND METHODS

The research methodology is based on a combined approach, including descriptive, comparative and analytical methods. Descriptive analysis is used to track the dynamics and structure of exchange trade in agricultural products in Bulgaria for the period 2020–2026, through indicators such as trade volume, transaction value, relative shares by commodity groups and price levels. Comparative analysis is applied to compare the Bulgarian exchange market and developed markets in the EU in order to identify differences in liquidity, trading instruments and the degree of institutional development. The analytical approach includes a study of the dependencies between the structure of agricultural production and the structure of exchange trade, as well as an assessment of the influence of external factors such as global demand, geopolitical events and climatic conditions on market dynamics. The chosen methodology aims to show the influence of the exchange as an organized market on the sustainable development of agriculture in the context of increased globalization, integration and changing market mechanisms.

For the purposes of the analysis, secondary data from official statistical sources were used - National Statistical Institute, Ministry of Agriculture and Food, Sofia Stock Exchange, as well as international databases (Eurostat, FAO, OECD, World Bank).

RESULTS AND DISCUSSIONS

The role of stock exchange trading for the sustainable development of the agricultural sector in Bulgaria

The concept of sustainable agricultural development aims to maintain agricultural systems over a long period of time by balancing the economic, social and environmental aspects of production and consumption. Stock markets play a key role in the allocation of resources, pricing and stability of agricultural products in the context of globalization, integration and regulation of economies (FAO, 2018) [20].

Trading takes place on specialized organized markets (financial, commodity exchanges and e-commerce platforms), where standardized contracts for a certain quantity and quality of agricultural goods are bought and sold through brokers (Georgieva, 2021) [25].

The stock exchange as a structure is an organized market where transactions are concluded through various standardized contracts for agricultural goods, including trading in futures, options and other derivatives, ensuring transparency, liquidity and risk control. Futures exchange-traded mechanisms serve as a tool for hedging against price fluctuations, which is particularly important for farmers facing climate and market risks (Lou, 2024; Cortazar, Ortega & Pérez, 2025; Richardson & Farris, 1973) [33, 6, 44]. This allows producers and traders of agricultural products to forecast prices and manage the risk of price fluctuations – an essential element of

sustainable agriculture (Demir, Martell & Skou, 2025) [9].

Modern agricultural commodity exchange markets have an impact on price transparency and the efficient functioning of the agricultural sector through good risk management and the establishment of sustainable production and consumption patterns. Agricultural commodity exchange trading is an organized market through which producers, traders, industrial users and investors buy and sell agricultural raw materials and goods. It is an important part of the agrarian economy, as it provides mechanisms for market-based price formation, liquidity, price risk management and access to international markets (Ivanov, 2019; Gardner, 2012) [31, 24].

Futures and derivatives markets in an international context play a significant role in the sustainable development of agriculture (Demir, Martell & Skou, 2025; Cortazar, Ortega & Pérez, 2025; Glauber, 2013) [9, 6, 26].

In Bulgaria, the agricultural exchange market has been developing in recent years and is not as well developed as in countries with traditional commodity exchanges, where institutional mechanisms exist that support trade and offer platforms for market-making, standardization and risk management (AFMORG, n.d.; Hadjieva, 2004) [1, 28]. The Bulgarian Stock Exchange (BSE) and other specialized markets play a key role (Agro TV, 2024) [3]. Bulgarian participants often face challenges such as low liquidity, weak interest from institutional investors and limited infrastructure for standard contracts.

In Bulgaria, exchange trading, by reducing intermediate margins through direct access to producers and creating risk management mechanisms, helps to increase the transparency and competitiveness of market prices. This is of particular importance in conditions of unstable climatic factors (Lubenov, 2015; Bachev et al., 2022; Dai, Dai & Zhou, 2023; Manogna & Kulkarni, 2025) [34, 4, 8, 35].

Specialized commodity exchanges for agricultural products play a strategic role for the sustainable development of agriculture. They contribute to improving farmers' incomes through better and more transparent prices; increase the competitiveness of the national agricultural sector; and create a link between local producers and international markets, which strengthens economic sustainability (Bachev et al., 2022; Lubenov, 2015) [4, 34].

Table 2. Structure of Agricultural Production in Bulgaria, 2022–2025

Subsector	**2022**		**2023**		**2024**	
	Value (BGN mn)	**Share**	**Value (BGN mn)**	**Share**	**Value (BGN mn)**	**Share**
Crop Production	9,700	75.5 %	7,124	67.5 %	6,447.6	66.7 %
Livestock	2,290	17.9 %	2,535	24.0 %	2,414.0	24.9 %
Agricultural Services	590	4.6 %	590	5.6 %	547.8	5.7 %
Secondary Activities	270	2.1 %	305	2.9 %	298.1	3.1 %
Total	**12,850**	**100 %**	**10,554**	**100 %**	**9,707.5**	**100 %**

Source: NSI and Ministry of Agriculture and Food, 2022–2024 [56, 37].

Data from the National Statistical Institute and the Ministry of Agriculture and Food for the period 2022–2025 reveal a strong dominance of crop production in the structure of the sector, with its share varying between 66% and 75% (Table 2). Although livestock breeding shows a smooth growth trend after 2022, reaching around 25%, the sector remains closely specialized in the production of raw materials. This trend is also confirmed by the stable, albeit minimal share of agricultural services and secondary activities (5–8%), which emphasizes the focus on extensive production over processing and added value (Ivanov & Dimitrov, 2021) [30].

The high concentration of cereals and oilseed crops in the crop subsector creates a direct prerequisite for the development of exchange

trading. Since these crops are the main objects of standardized contracts, the structure of domestic production is naturally adapted to the mechanisms of commodity exchanges. This also explains the historical peak of production in 2022 of 6.6 billion euros, driven by the dynamics of international prices (Trading Economics, 2025) [48]. In conclusion, Bulgarian agriculture continues to occupy a more significant place in the national economy (1.8% of GDP) compared to the EU average (1.2%). However, the excessive dependence on crop production and the slow pace of diversification towards livestock and services define the sector as high-risk to climate and market fluctuations, which necessitates a more effective use of stock exchange instruments for hedging risk.

Analysis of the dynamics of commodity exchange trading (2020–2026)

Exchange trading in Bulgaria, concentrated mainly in the Sofia Commodity Exchange (SCE), functions as an organized market for energy resources and agricultural products. In the agricultural sector, activity is concentrated in the Grain sub-circle, where wheat, corn and sunflower occupy a strategic place as indicators of food security and a raw material base for the industry. Data for the period 2024–2025 reveal a specific market model: relatively low transaction intensity (on average 10–15 significant contracts per month), but with a high unit volume of transactions (Sofia Commodity Exchange, 2024) [46]. In 2025, there was also increased interest in forward transactions in sunflower, provoked by the desire to hedge climate risk (Sofia Commodity Exchange, 2025) [47].

Although Bulgaria is a leading producer and exporter of grain with record volumes of over 6.5 million tons of wheat, there is a serious disproportion between physical turnover and exchange sales (Trading Economics, 2025) [48]. Only 5–8% of the total output passes directly through exchange mechanisms, while the remaining 92–95% is realized through over-the-counter transactions. Despite this limited share, the exchange plays a critical role as a price guide. The quantitative analysis of the ratio between exchange trading and total production for the period 2020–2025 proves that although the majority of exports occur outside the SSE, the pricing of almost 100% of these quantities is based on current exchange quotes (Sofia Stock Exchange, 2025) [47]. In conclusion, the analysis confirms the presence of a direct relationship between the country's production specialization and exchange activity. The concentration of trade in cereals and oilseeds (60–70% of the exchange volume) corresponds exactly to the dominant share of crop production in the national agrarian structure (Ivanov & Dimitrov, 2021) [30]. Although the organized market still covers a small part of the physical volume, its importance for transparency and market price formation is decisive for the international competitiveness of Bulgarian agriculture.

Table 3. Trading Volumes on Commodity Exchanges in Bulgaria (2020–2025)

Year	Total Turnover (million BGN)	Volume (thousand tons)*	Share: Food Products	Share: Grain and Raw Materials	Other Goods
2020	550	900	65%	25%	10%
2021	650	1050	67%	23%	10%
2022	730	1200	70%	22%	8%
2023	600–650	1100	68%	24%	8%
2024	750–850	1150	66%	26%	8%
2025	700–800	1100	65%	27%	8%

Source: SCCCE (State Commission on Commodity Exchanges and Effluents) for the period 2020–2025 [11].

During the period 2020–2022, there was an intensive growth in the turnover of the Bulgarian stock exchanges – from BGN 550 million to over BGN 730 million, which represents an increase of about 32–35%. After this peak, the market entered a stabilization phase in the range of BGN 600–850 million,

which demonstrates the adaptability of the sector to global economic shocks.

The dynamics of trade are defined by three key stages:

• Recovery and logistical changes after the COVID-19 pandemic

• High volatility caused by the conflict in Ukraine in the period 2022 – 2024. During this period, wheat prices on the Sofia Commodity Exchange (SCE) reached record levels of over 700 BGN/ton, followed by a correction to 350-420 BGN/ton as supply chains were restored (Ministry of Agriculture and Food, 2024) [37].

• Moderate increase and institutional development. In early 2026, a new increase in quotations was observed, due to climatic factors and increased production costs. The "sell" offers for bread wheat vary around 430-450 BGN/ton, and for corn, deals are concluded at levels around 230-235 EUR/ton for delivery to port (DKSBT, 2026) [11].

The functioning of the local market is directly dependent on the international situation and climatic conditions. Several stable correlations are observed:

• Regional and global linkage: Bulgarian stock exchange prices closely follow the trends of European markets and in particular the quotes of Euronext (MATIF) in Paris (Euronext, 2024) [13]. The analysis confirms a stable "discount" of around 10–15% for Bulgarian wheat, which reflects the logistical costs of transport from the Black Sea region to the main European destinations.

• Climate and liquidity: The frequent droughts in 2024 have a direct impact on the liquidity of the stock exchange. In the event of a poor harvest, the number of transactions decreases as producers hold onto goods in anticipation of higher prices. The price of sunflower reached levels of 1,000–1,140 BGN/ton due to reduced yields (Center for Agricultural Economic Research, 2025) [7].

• Currency integration: By 2026, there is a trend towards quoting exchange contracts directly in euros, due to strategic preparations for Bulgaria's accession to the Eurozone, aimed at reducing currency risk in transactions with international traders.

• Structure of imports and exports: Bulgaria maintains a high export potential, with wheat exports exceeding 6 million tons in 2024 and 2025 (Ministry of Agriculture and Food, 2024) [37]. However, in the first half of 2025, an unusually negative trade balance was recorded in the agricultural sector due to massive imports of rapeseed and processed products.

Bulgarian commodity exchanges are moving from a period of volatile growth to a phase of stabilization and structural maturity. Statistical data confirm that the highest market activity is observed seasonally in the period July–September (National Statistical Institute, 2025) [56].

Although a significant part of physical trade is carried out through direct contracts, exchange trading performs an essential function as a price indicator and transparency mechanism. In the long term, integration with European markets and the upcoming currency integration are prerequisites for higher sustainability of the agricultural sector in Bulgaria.

Comparative analysis of commodity exchange trading - Bulgaria and the European Union

The connection between the local and European markets is becoming increasingly one-way. The lack of developed financial instruments in the country forces major market players to seek hedging solutions on international markets (OECD, 2024) [41]. By 2026, a sustainable trend is observed: Bulgarian producers are showing increased interest in European exchanges for risk management, which paradoxically "drain" liquidity from local exchange structures (Euronext, 2025) [14].

The main parameters illustrating the lagging behind of the local market in terms of its structure and instruments are systematized in Table 4.

The analysis of commodity exchange trading reveals significant structural differences between the Bulgarian market and that in the European Union (EC) (European Commission, 2024). While the EU is dominated by highly integrated and highly liquid derivatives platforms such as Euronext,

the Bulgarian market remains predominantly spot, focused on real physical delivery, and highly fragmented (Euronext, 2025) [14].

Table 4. Comparative Characteristics of Agricultural Commodity Exchange Trading – EU vs. Bulgaria

Indicator	European Union (EU)	Bulgaria
Annual Turnover (Exchanges)	Hundreds of billions of €	0.7–0.8 billion BGN
Value of Agricultural Production	500+ billion €	6–7 billion €
Major Exchanges	Euronext, ICE Futures Europe	SCE (Sofia Commodity Exchange), BACE (Bulgarian Agricultural Commodity Exchange) platforms
Type of Trading	Spot and developed futures markets	Predominantly spot transactions
Liquidity	High	Low
Participants	Institutional investors, funds, global agribusiness	Limited number of local producers and traders
Financial Instruments	Futures, options, index derivatives	Highly limited / non-existent
Digitalization	High level of electronic trading	Partial / in development
Role in Pricing	Global benchmark	Local price signals

Source: SCCCE (State Commission on Commodity Exchanges and Effluents); OECD; European Commission; Euronext Market Reports [11, 33, 34, 35, 11, 12, 13, 14, 10]

On a European scale, exchange trading is a major pillar of global pricing and risk management (OECD, 2024) [41]. Pricing there is fully transparent, and exchange quotes serve as a binding benchmark for concluding commercial contracts. In contrast to this model, exchange trading in Bulgaria is characterized by limited liquidity and a small number of participants (DKSBT, 2025) [11]. Although the local exchange is used as a price indicator, the actual transfer of ownership often occurs through direct over-the-counter agreements in order to avoid fees and strict regulatory requirements.

The empirical analysis of quotations for the period 2022–2025 shows that the dynamics of the Bulgarian market are directly linked to geopolitical shocks and climate anomalies, refracted through local specificities (European Commission, 2025) [19]. Trade in agricultural products (wheat, corn and sunflower) remains highly concentrated in spot transactions, which reflects the raw material structure of agricultural production in our country (DKSBT, 2024) [11].

The relationship between the local and European markets is becoming increasingly one-way. The lack of developed financial instruments in the country forces major market players to seek hedging solutions on international markets (OECD, 2024) [41]. By 2026, a sustainable trend is observed: Bulgarian producers are showing increased interest in European exchanges for risk management, which paradoxically "draining" liquidity from local exchange structures (Euronext, 2025) [14].

In conclusion, Bulgaria still perceives commodity exchanges primarily as platforms for physical trading and transparent public procurement, while in the EU they function as complex financial mechanisms (European Commission, 2025) [19]. Without the introduction of derivative instruments and incentives to increase exchange liquidity, the country will remain in the role of a "price taker", heavily dependent on international quotes, but without effective domestic instruments to protect against market volatility.

Digitalization and Sustainable Development of Agricultural Commodity Exchange Trading in Bulgaria

In Bulgaria, the regulatory framework for exchange trading is in line with European standards and is under the control of the Financial Supervision Commission (FSC) and the Ministry of Agriculture (BgFermer, 2016; Lubenov, 2015) [5, 34]. The rules for participant registration, standardization of contracts, and transaction reporting aim to increase trust and minimize the risks of speculation.

Despite the presence of specialized platforms (such as Agri.BG, FarmingBuy.com, and Agriniser), exchange trading in our country remains at an early stage compared to Western European markets.

The main challenges include:

Low liquidity: Especially in futures and derivative contracts, which limits small producers (Bachev et al., 2022) [4].

Limited scope: Private exchanges still lag behind the main commodity exchanges in terms of volume (Hadjieva, 2004) [28].

Information deficit: Low awareness of farmers and insufficient traded quantities.

The transfer of good practices from international digital markets is essential for the rapid transformation of the sector (Lou, 2024) [33]. Modernization is no longer limited to physical infrastructure, but is closely linked to digital solutions that integrate traditional practices with innovative tools (European Commission, 2023; OECD, 2021) [18, 39].

The implementation of electronic platforms provides:

Price transparency: Displaying values in real time, which reduces the risk of manipulation and facilitates planning (Cortazar, Ortega & Pérez, 2025; Bachev et al., 2022) [6, 4].

Direct access: Reducing intermediaries and connecting small farmers to global markets (FAO, 2022) [23].

Financial management: Using futures and options to hedge against market fluctuations (Dai, Dai & Zhou, 2023; Manogna & Kulkarni, 2025; Venegas et al., 2024) [8, 35, 51].

Smart logistics: Through warehouse management software, GPS optimization and QR codes for traceability (FAO, 2022; European Commission, 2023) [23, 16].

Sustainable agriculture combines economic efficiency, social justice and environmental responsibility (UNCTAD, 2021) [49]. It is a key factor for the development of organic production and the reduction of chemical fertilizers. Exchange mechanisms integrating sustainability criteria stimulate "green" trade through product certification (USDA, 2022; World Bank, 2022) [50, 53].

The main aspects of sustainability include:

Environmental: Resource conservation and adaptation to climate change (Dimitrov & Bozhilova Sakova, 2025; FAO, 2020) [10, 22].

Economic: Stable incomes for producers through price risk management (Demir, Martell & Skou, 2025) [9].

Social: Support for small and family farms and rural development (European Commission, 2023) [16].

Market development in Bulgaria requires a combination of economic liberalization and state support. Bulgaria's Strategic Plan for the Common Agricultural Policy (CAP) emphasizes modernization and competitiveness (Dimitrov & Bozhilova Sakova, 2025) [10]. The integration of European environmental measures directly affects price levels and market infrastructure (European Commission, 2020) [15].

In conclusion, digitalization and sustainable exchange mechanisms are strategic tools that make the Bulgarian agricultural sector more transparent, adaptable and internationally competitive (OECD, 2019; Zhang & Tang, 2024) [38, 55].

Challenges and prospects for agricultural commodity exchange trading in the context of sustainable agricultural development

Exchange trading in agricultural products is a key mechanism for the efficient functioning of the market, price stabilization and risk management. In the context of sustainable development, it has the potential to support environmentally and socially responsible practices, ensuring economic stability and food security (Gardner, 2012; Petkov & Todorova, 2020) [24, 42].

Despite the existence of exchange mechanisms in Bulgaria and around the world, there are significant barriers to their effectiveness:

Regulatory framework and transparency: Modernization of legislation is needed to align exchange instruments with the principles of sustainable development and ESG standards (European Commission, 2023; Petrov & Ivanova, 2022) [16, 18, 43].

Lack of liquidity and critical mass: Limited participation and the lack of a developed derivatives market hinder efficient exchange

operations (Ivanov, 2019; Hadjieva, 2004) [31, 28].

Price volatility and speculation: Sharp fluctuations caused by climate anomalies or geopolitical shocks threaten farmers' profitability and discourage investment in sustainable technologies (FAO, 2021; Smith, 2020; Irwin & Sanders, 2011) [21, 45, 29].

Limited access for smallholder farmers: Due to low financial literacy and lack of capital, smallholder producers often remain isolated from exchange mechanisms (World Bank, 2020; Lubenov, 2015) [52, 34].

Sustainable agricultural development and exchange markets complement each other in several key areas:

Economic stability: Through forward contracts (e.g. on the Sofia Commodity Exchange), farmers mitigate the risks of volatility, which is a fundamental pillar of economic sustainability within the Green Deal.

Environmental responsibility: Exchange information allows the prioritization of sustainable, high-yielding crops with less impact on soil and water (Dimitrov & Bozhilova Sakova, 2025) [10].

Social justice: Transparency and standardization mechanisms allow small farmers to be equal market participants (Bachev et al., 2022) [4].

The future of the sector is linked to innovations that connect policy measures with economic realities:

Digitalization and technology: The integration of blockchain and IoT (Internet of Things) ensures product traceability and increases trust (World Bank, 2022; Lou, 2024) [53, 33].

Financial innovation: The creation of "green derivatives" stimulates direct investment in environmental practices (Jones et al., 2021) [32].

Institutional support: Expanding support through RDPs and promoting public-private partnerships to adapt to new models of production and trade (UNCTAD, 2021) [49].

The combination of modern exchange mechanisms and the principles of sustainability can ensure a competitive and transparent market that strengthens food security and supports the long-term development of the agricultural sector in Bulgaria and globally.

CONCLUSIONS

The analysis of the exchange trade in agricultural products in Bulgaria in the context of sustainable agrarian development allows the formulation of the following main conclusions:

1. There is a direct relationship between the production structure of Bulgarian agriculture and the exchange turnover. The dominance of crop production (over 65% of agricultural production) predetermines the focus of commodity exchanges on grain and oilseed crops. However, the concentration solely on raw materials (wheat, corn, sunflower) limits the potential of the exchange to support sectors with higher added value.
2. The Bulgarian exchange market performs a critical function as a price reference, although only a small part of the physical volume of production passes through it (5–8%). The main deficit remains the low liquidity and the absence of developed futures and derivative instruments. This turns local participants into "price takers", highly dependent on quotes on international platforms such as Euronext.
3. The sustainable development of the sector is directly linked to the financial stability of farmers. The lack of internal mechanisms for hedging price risk (due to the nascent stage of derivative trading) forces large producers to seek protection on international markets, which further "drains" liquidity from national exchange structures.
4. Digital transformation and the transition to euro listing (in the context of integration into the Eurozone by 2026) are key factors for increasing transparency and reducing transaction costs. The modernization of the exchange infrastructure and the introduction of "green" trading standards are necessary conditions for achieving environmental and economic sustainability.

In conclusion, in order for exchange trading to become an effective tool for sustainable agricultural development in Bulgaria, a targeted policy is needed to:

• Stimulate liquidity by attracting institutional investors;
• Develop risk management tools accessible to small and medium-sized farmers;
• Accelerated digitalization of trade processes to achieve full integration with the single European market.

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AGRICULTURAL INCOME CONVERGENCE IN THE EUROPEAN UNION AFTER EASTERN ENLARGEMENT: EVIDENCE FROM SIGMA, BETA AND CLUB CONVERGENCE TESTS

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Abstract

This paper examines agricultural income convergence across the 27 EU member states over 2001 to 2025, focusing on post-Eastern enlargement dynamics. Using Eurostat's Indicator A, the index of real income of factors in agriculture per annual work unit (AWU, 2015 = 100), the study applies four complementary approaches: sigma-convergence analysis, absolute beta-convergence regressions with a new member state interaction term, the Phillips and Sul (2007) log-t club convergence test, and distributional dynamics through kernel density estimation and Markov transition matrices. The results reveal a statistically significant declining trend in cross-sectional income dispersion over the full period (slope = -0.009, p = 0.005), consistent with sigma-convergence, though the pattern is U-shaped, with rapid convergence during 2001 to 2015 giving way to renewed divergence after 2020. Beta-convergence estimates confirm a significant negative relationship between initial income and subsequent growth (β = -0.038, $p < 0.001$, $R^2 = 0.70$), with new member states converging faster than EU-15 incumbents. The Phillips and Sul log-t test rejects full-panel convergence (t = -2.35), identifying three clubs: a high-income group of nine countries that converges internally, a middle group of thirteen countries with internal convergence, and a low-income group of five countries that fails to converge. Policy implications point toward differentiated CAP instruments that account for club-specific convergence dynamics rather than a uniform approach.

Key words**:** *agricultural income, convergence, beta-convergence, sigma-convergence, club convergence*

INTRODUCTION

When Bulgaria and Romania joined the European Union in 2007, agricultural income per worker in Romania stood at roughly one-tenth of the level recorded in the Netherlands. Two decades of integration, structural funds, and Common Agricultural Policy transfers later, the question of whether this gap has narrowed remains open, and the answer carries considerable weight for the design of post-2027 agricultural policy. The convergence debate is not merely academic; it shapes the allocation of tens of billions of euros in CAP direct payments and rural development funds, and it determines whether the promise of economic cohesion embedded in the Treaty of Rome extends meaningfully to the agricultural sector.

Convergence in agricultural incomes across the EU sits at the intersection of two well-established research traditions. The first, rooted in the neoclassical growth model of Solow [27] and formalized by Barro and Sala-i-Martin [4], predicts that economies with lower initial capital intensity will grow faster due to diminishing marginal returns, eventually converging to a common steady state. The second tradition focuses on the distributional consequences of EU integration, examining whether accession to the single market and the CAP accelerate catch-up or, conversely, entrench structural disparities through mechanisms such as unequal payment allocations and heterogeneous institutional capacity. Both traditions generate testable predictions, yet their application to agricultural income, as distinct from aggregate GDP or total factor productivity, remains surprisingly sparse.

Several gaps in the existing literature motivate the present study. Most convergence analyses in agriculture focus on productivity measures, particularly total factor productivity or labour productivity, rather than on the income metric most directly relevant to farm household

welfare and CAP targeting. Wimmer and Finger [33], for instance, documented substantial productivity dispersion and persistence across more than 100,000 European farms but did not examine income convergence per se. Similarly, while Baer-Nawrocka et al. [1] and Florianczyk et al. [11] studied labour productivity convergence using FADN data, their indicator captures only one dimension of the income generation process. The Eurostat Indicator A, which measures real income of factors in agriculture per annual work unit, offers a more comprehensive picture because it incorporates the joint effects of output prices, input costs, subsidies, and structural change on farm-level remuneration.

A further limitation of existing studies is temporal coverage. The period since 2020 has introduced a sequence of asymmetric shocks whose effects on convergence trajectories have not been systematically assessed. The COVID-19 pandemic disrupted supply chains and altered consumption patterns. The Russia-Ukraine conflict then triggered an unprecedented spike in energy and fertilizer costs, while the 2023 CAP reform introduced new conditionality requirements that reshaped the policy landscape. Eurostat data show that EU agricultural income per worker rose 13 per cent year-on-year in 2022 before falling 6.6 per cent in 2023, with particularly sharp declines in Romania and Hungary, precisely the new member states that had been converging most rapidly. Whether these shocks represent a temporary interruption or a structural reversal of convergence requires updated empirical investigation. The convergence question in European agriculture has been examined from multiple complementary angles in recent literature. The neoclassical foundations articulated by Mankiw, Romer and Weil [16] and refined through the inferential perspectives of Galor [13] and Quah [24] continue to shape empirical work, although the agricultural sector adds layers of complexity related to land constraints, policy support, and sectoral specificities. At the EU level, Calegari et al. [5] showed that regional convergence in agricultural productivity depends on the joint effects of agricultural and regional policies, while Radicic et al. [25] documented persistent total factor productivity gaps between New and Old Europe at the industry level. The club convergence framework has been productively applied to greenhouse gas emissions in agriculture by Gkagkavouzis et al. [14] and to energy productivity by Balezentis et al. [2], confirming that EU agriculture rarely exhibits a single convergence path.

A second strand of literature focuses on farm income measurement and the farm-nonfarm gap. Finger and Benni [10] introduced new perspectives on farm income measurement that informed subsequent EU studies, while Marino et al. [17] and Marino et al. [18] documented the conditional and distributional dimensions of the farm-nonfarm income gap across the Union. Mittenzwei [20] reached similar conclusions for Norway, and Nowak and Zakrzewska [21] assessed competitiveness across EU member states from 2012 to 2021. Wasilewski et al. [32] examined agricultural land price dynamics across the EU and confirmed convergence patterns driven by CAP transfers and foreign investment. The Common Agricultural Policy itself has attracted substantial scrutiny as a determinant of income trajectories. Barral and Detang-Dessendre [3] reviewed the 2023-2027 CAP reform from multidisciplinary perspectives, while Ciliberti et al. [6] and Ciliberti et al. [7] documented disparities in direct payment allocations across farming systems in Portugal and Italy respectively. Frascarelli et al. [12] examined the coherence between redistributive and environmental goals in CAP design, while Ferraro and Cataldo [9] proposed alternative payment calculation mechanisms to accelerate external convergence. Viegas et al. [30] documented inequality in CAP allocations in Portugal, with implications for the broader EU equity debate. The post-2020 polycrisis has introduced new dimensions to the convergence debate. Mikula and Czarnecki [19] analyzed food security across EU-27 countries during the COVID-19 pandemic and found asymmetric impacts on lower-income member states, while Swinnen and McDermott [29] provided early evidence on

global food security disruptions. Volkov et al. [28] assessed the resilience of future European farmer profiles using Lithuanian data, finding that intensive and corporate profiles, common in many NMS, exhibit lower resilience to external shocks. These findings collectively suggest that the convergence achieved before 2020 may be vulnerable to structural shocks affecting input costs, energy prices, and trade flows.

The present study addresses these gaps in several ways. We construct a balanced panel of 27 EU member states covering 2001 to 2025, a period that spans the pre-accession baseline, the Eastern enlargements, both the 2014-2020 and 2023-2027 CAP programming periods, and the polycrisis episode. This dataset is analysed through four complementary convergence tests: sigma-convergence analysis of cross-sectional dispersion, absolute beta-convergence regressions with a new member state interaction term, the Phillips and Sul [22] log-t club convergence test, and distributional dynamics through kernel density estimation and Markov transition probability matrices. Beyond the methodological breadth, the paper makes two additional contributions that have received little attention in prior work. We explicitly address the base-year indexing artifact inherent in Indicator A, which produces zero dispersion in the reference year 2015, and show that this feature does not invalidate the convergence findings once appropriately handled. We also draw policy implications for post-2027 CAP design by linking club convergence membership to structural and institutional characteristics.

The remainder of the paper proceeds through a review of the theoretical and empirical convergence literature, a description of data and methodology, a presentation of results across all four tests, a discussion of findings and their policy relevance, and concluding remarks.

MATERIALS AND METHODS

Data collection

The analysis draws on Eurostat's Economic Accounts for Agriculture (EAA), specifically the dataset estat_aact_eaa06, which reports Indicator A: the index of the real income of factors in agriculture per annual work unit. This indicator is deflated by the implicit price index of GDP at market prices and indexed to a base year of 2015 = 100. The panel covers all 27 current EU member states observed annually from 2001 to 2025, yielding 669 country-year observations. The 13 new member states (NMS-13) that joined through the 2004, 2007, and 2013 enlargements are Bulgaria, Croatia, Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, and Slovenia. The remaining 14 countries constitute the EU-15 group.

A methodological note is warranted regarding the base year. Because all countries are indexed to 100 in 2015 by construction, the cross-sectional standard deviation of the income index equals zero in that year. This is an artifact of the indexing procedure, not evidence of actual income equality. All sigma-convergence analyses reported below exclude the 2015 observation to avoid spurious results, and the base-year artifact is clearly marked in all figures.

Sigma-convergence

Sigma-convergence is assessed by tracking the the variation in log-income across the panel of N = 27 member states throughout the observation period. For each year t, we calculate both the standard deviation of the natural logarithm of Indicator A and its associated coefficient of variation, with y_{it} representing the income index value observed for country i at time t. We compute the standard deviation of $\ln(y_{it})$,, where y_{it} denotes Indicator A for country i in year t, along with the coefficient of variation CV(t). A declining trend in dispersion indicates sigma-convergence. We estimate a linear trend regression and test whether the slope is negative at conventional significance levels. Sub-period regressions are estimated for the convergence phase (2001-2015) and the divergence phase (2015-2025) to characterize the U-shaped pattern. The total variance is decomposed into between-group (NMS-13 vs. EU-15) and within-group components to identify the source of dispersion changes.

Absolute beta-convergence

Absolute beta-convergence tests whether countries with lower initial agricultural income grow faster, consistent with the neoclassical prediction of unconditional catch-up [4].

The baseline specification regresses the annualized growth rate on initial log-income:

$$(1/T) \cdot ln(y_iT / y_{i0}) = \alpha + \beta \cdot ln(y_{i0}) + \varepsilon_i \quad (1)$$

where: y_{i0} is the 2001 value of Indicator A, y_iT is the 2025 value, and T denotes the temporal length of the observation window. Absolute convergence is established when the estimated coefficient β is negative and statistically significant.

The implied speed of convergence is calculated as

$$\lambda = -ln(1 + \beta \cdot T) / T \quad (2)$$

and the half-life of convergence as

$$\tau = ln(2) / \lambda \quad (3)$$

To test whether new member states converge at a different rate, we augment the model with an NMS dummy and its interaction with initial income:

$$(1/T) \cdot ln(y_iT / y_{i0}) = \alpha + \beta \cdot ln(y_{i0}) + \gamma \cdot NMS_i + \delta \cdot (NMS_i \times ln(y_{i0})) + \varepsilon_i \quad (4)$$

Standard errors are heteroskedasticity-robust (HC1). The Ramsey RESET test checks for functional form misspecification, and Cook's distance identifies influential observations.

Club convergence

T To examine whether EU agricultural incomes follow multiple convergence paths rather than a single steady state, we apply the framework of Phillips and Sul [22]. The transition parameter

$$h_{it} = ln(y_{it}) / [(1/N) \Sigma_{i=1}^{N} ln(y_{it})] \quad (5)$$

captures the position of each country relative to the contemporaneous cross-country mean of log-income. Complete convergence implies that h_{it} approaches unity for every country, meaning all economies align around a shared trajectory. The accompanying measure of cross-country dispersion, denoted H(t), should then decline toward zero over time.

The log-t test regresses

$$log\left(\frac{H^1}{H}_t\right) - 2 \cdot log(log(t)) = a + b \cdot log(t) + u_t, t = [rT], \ldots, T \quad (6)$$

with r = 0.3 as trimming threshold. Full-panel convergence is rejected when the slope t-statistic drops below -1.65, signalling distinct convergence clubs. The delineation follows the iterative approach of Phillips and Sul [23]: countries are ranked by their terminal transition parameter, a core group is assembled from those at the top, and remaining economies are appended one at a time if inclusion keeps the club-level t-statistic above zero. Neighbouring clubs are then tested jointly for possible consolidation.

Distributional dynamics

The evolution of the entire income distribution is examined using kernel density estimation and Markov transition probability matrices. Gaussian kernel densities of relative income (country income divided by the EU mean) are estimated at five key dates: 2001, 2007, 2013, 2019, and 2025. Bandwidth is selected using Silverman's rule of thumb. A shift from bimodal to unimodal density signals convergence, while re-emergence of bimodality indicates divergence.

The Markov transition matrix is estimated over five-year windows using quintile-based states. The 5x5 transition probability matrix $P = [p_{kj}]$ characterizes the probability of moving from income quintile k to quintile j over a five-year period. The ergodic (steady-state) distribution reveals the long-run implications of observed dynamics.

The Shorrocks [26] mobility index

$$M = \frac{(Q - tr(P))}{(Q-1)} \quad (7)$$

summarizes overall mobility, where Q = 5 is the number of states and tr(P) is the trace of the transition matrix.

RESULTS AND DISCUSSIONS

Descriptive statistics

Table 1 presents summary statistics for Indicator A by country group and sub-period. Over the full sample, the mean income index is 104.5 with a standard deviation of 33.2, reflecting considerable cross-country heterogeneity. The NMS-13 group starts from a substantially lower base (mean of 66.2 during 2001-2007) and exhibits a steeper trajectory, reaching 128.1 during 2020-2025. The EU-15 group shows a more stable pattern, with mean income rising from 101.4 to 134.2 across the same periods.

Table 1. Descriptive statistics of Indicator A by country group and sub-period

Group	Period	N	Mean	SD	Min	Max
EU-15	2001-07	98	101.4	27.3	63.5	238.6
	2008-13	84	102.0	26.7	66.0	220.6
	2014-19	84	108.5	16.6	86.5	159.1
	2020-25	84	134.2	32.8	89.1	278.9
NMS-13	2001-07	79	66.2	30.1	29.6	149.8
	2008-13	78	89.4	20.3	46.0	143.1
	2014-19	78	107.6	17.0	62.7	148.0
	2020-25	78	128.1	36.1	57.4	224.2

Source: Authors' calculations based on Eurostat EAA (estat_aact_eaa06) [34].

The gap between the two groups narrowed from 35 index points in the first sub-period to approximately 6 points by the last, though the standard deviation within the NMS-13 group remains higher (36.1 vs. 32.8), indicating greater internal heterogeneity among the newer members.

Figure 4b, page 7, illustrates the mean trajectories of the two groups. The NMS-13 mean climbed from approximately 55 in 2001 to values exceeding 120 by 2022, while the EU-15 mean fluctuated around 100-110 until 2020 before rising sharply. The income gap contracted markedly between 2007 and 2019, consistent with a catch-up process that accelerated during the first years after accession.

Sigma-convergence

Figure 1 displays the evolution of cross-sectional dispersion over 2001-2025. Two distinct phases emerge in the trajectory of cross-country dispersion. Between 2001 and 2014, the standard deviation of log-income contracted markedly, moving from 0.50 down to 0.16, which corresponds to a reduction of approximately 70 percent. The coefficient of variation tracked this same downward path, falling from 0.46 to 0.18 over the equivalent interval. From 2016 onward, however, the direction shifted: by 2025, dispersion had climbed back to 0.30 in standard-deviation terms and to 0.31, levels comparable to 2006-2007. The linear trend regression over the full period confirms a statistically significant negative slope of -0.009 ($p = 0.005$), consistent with sigma-convergence when viewed from beginning to end. Sub-period regressions reveal the underlying dynamics more precisely: the convergence phase from 2001 to 2015 shows a steep negative slope of -0.030 ($p < 0.001$), while the divergence phase from 2015 to 2025 shows an equally significant positive slope of 0.025 ($p < 0.001$). The post-2020 subperiod alone yields a slope of 0.017 ($p = 0.003$), indicating that the reversal accelerated during the polycrisis.

The variance decomposition in Table 2 reveals an important structural shift. In 2001, the between-group component (NMS-13 vs. EU-15) accounted for 51.6 per cent of total income variance, reflecting the large gap between old and new member states. By 2013, between-group variance had collapsed to just 1.7 per cent, meaning that virtually all remaining dispersion was within groups. By 2025, however, the between-group share had risen back to 12.0 per cent.

Table 2. Variance decomposition of log-income: between-group vs. within-group

Year	Total var.	Between	Betw. %	Within %
2001	0.254	0.131	51.6	48.4
2007	0.093	0.030	32.5	67.5
2013	0.031	0.001	1.7	98.3
2019	0.023	0.000	0.2	99.8
2025	0.088	0.011	12.0	88.0

Source: Authors' calculations. Between-group: NMS-13 vs. EU-15

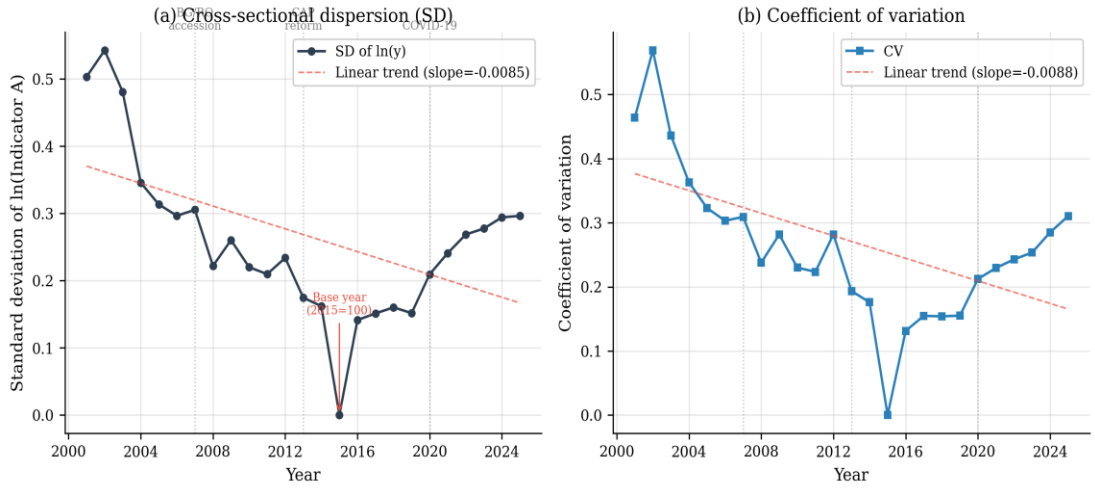

Fig. 1. Sigma-convergence in EU agricultural income, 2001-2025. (a) Standard deviation of log-income; (b) Coefficient of variation. Vertical lines mark structural breaks. The 2015 dip is a base-year artifact.
Source: Authors' own elaboration using Econometry360 (Python-based econometric platform)

This resurgence, though still far below its 2001 level, indicates that the polycrisis reintroduced a systematic NMS-EU-15 divide, even if the gap is now smaller than two decades ago.

Beta-convergence

Table 3 reports the cross-sectional beta-convergence estimates. Over the full period 2001-2025, the coefficient on initial log-income is -0.038 ($p < 0.001$), with an R-squared of 0.698, indicating that nearly 70 per cent of the cross-country variation in growth rates is explained by initial income levels alone. The implied speed of convergence is 10.3 per cent per annum, substantially faster than the canonical 2 per cent benchmark from the aggregate growth convergence literature [4]. The half-life is 6.7 years, suggesting that, on average, half the initial income gap was closed within less than seven years. This rapid pace reflects the combined effect of EU integration, CAP transfers, and the low base from which many NMS started.

Sub-period estimates reveal time-varying convergence dynamics. The 2007-2013 period shows the fastest convergence ($b = -0.143$, $p < 0.001$), coinciding with the first years of full CAP eligibility for Bulgaria and Romania and the ramp-up of structural funds. During the polycrisis period 2020-2025, the beta coefficient drops to -0.014 and becomes statistically insignificant ($p = 0.774$), indicating that the catch-up process has effectively stalled in recent years.

The NMS interaction model enriches the picture considerably (R-squared = 0.856). The interaction term between NMS status and initial income is strongly negative ($d = -0.054$, $p < 0.001$), confirming that new member states converge faster than EU-15 countries conditional on their starting point. The NMS dummy itself is positive and significant ($g = 0.229$, $p < 0.001$), indicating a systematically higher growth rate for new member states that cannot be attributed solely to their lower initial income. This suggests that accession-related factors, including CAP direct payments, structural fund transfers, and institutional reform, provided an additional growth impetus beyond what the neoclassical catch-up mechanism alone would predict.

Table 3. Beta-convergence estimates: cross-sectional OLS with HC1 standard errors

	Full	07-13	07-19	20-25	NMS int.
b (initial)	-0.038***	-0.143***	-0.090***	-0.014	-0.007
SE	(0.007)	(0.017)	(0.009)	(0.048)	(0.011)
g (NMS)					0.229***
d (NMS*init)					-0.054***
R-sq	0.698	0.705	0.828	0.004	0.856
N	25	27	27	27	25
Half-life	6.7 yr	2.1 yr	-	48.4 yr	-

Source: Authors' calculations.
*** p < 0.01, ** p < 0.05, * p < 0.10

Figure 2 illustrates the absolute beta-convergence in agricultural income, EU-27, 2001-2025.

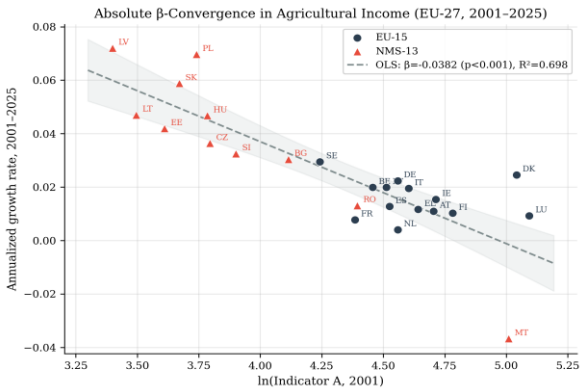

Fig. 2. Absolute beta-convergence in agricultural income, EU-27, 2001-2025. Circles = EU-15, triangles = NMS-13. Dashed line = OLS fit with 95% confidence band.
Source: Authors' own elaboration using Econometry360 (Python-based econometric platform)

Club convergence

The Phillips and Sul [22] log-t test for the full panel yields a slope coefficient of -1.00 with a t-statistic of -2.35, which falls below the critical value of -1.65. The null hypothesis of full-panel convergence is therefore rejected. This result indicates that agricultural incomes across the EU-27 do not move toward a single common steady state. Instead, the evidence is consistent with the expectation that structural differences in farm size, production specialization, institutional quality, and CAP payment arrangements give rise to multiple equilibrium paths.

Three convergence clubs are identified (Table 4).

The High club comprises nine countries: Denmark, Poland, Luxembourg, Latvia, Germany, Ireland, Slovakia, Italy, and Finland. This group has a positive log-t coefficient (t = 1.34), confirming internal convergence, and includes both EU-15 members and three NMS (Poland, Latvia, Slovakia), suggesting that the NMS-EU-15 divide is not deterministic. The Middle club contains thirteen countries, including several NMS alongside EU-15 members such as Portugal, Austria, and Spain. This group also converges internally (t = -0.79).

The Low club, consisting of the Netherlands, Lithuania, Estonia, France, and Malta, fails to converge internally (t = -1.86).

The presence of the Netherlands and France in the low club is noteworthy: these traditionally high-income agricultural economies have experienced stagnating or declining real income per AWU relative to the EU average in recent years.

Club merging tests indicate that the High and Middle clubs could be merged (t = -0.64), but the Middle and Low clubs cannot (t = -2.49). This suggests a two-club structure may be more parsimonious: a large convergence club of 22 countries and a divergent group of five countries whose agricultural income trajectories are decoupling from the EU mainstream.

Table 4. Convergence clubs identified by the Phillips and Sul (2007) algorithm

Club	Members	N	Log-t	Conv.?
High	DK, PL, LU, LV, DE, IE, SK, IT, FI	9	1.342	Yes
Middle	PT, AT, SE, BE, EL, HU, BG, ES, HR, CY, RO, SI, CZ	13	-0.792	Yes
Low	NL, LT, EE, FR, MT	5	-1.856	No

Source: Authors' calculations.
Convergence at t-stat >= -1.65. r = 0.3.

Figure 3 presents the convergence club transition paths, 2001-2025.

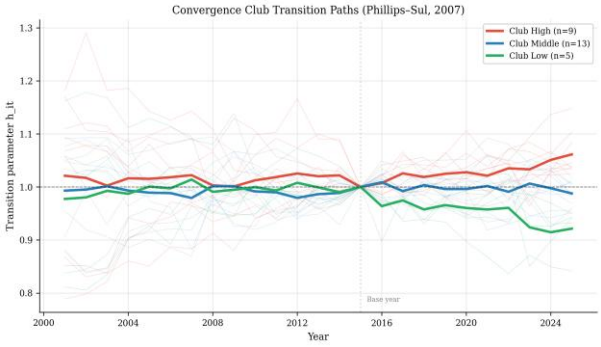

Fig. 3. Convergence club transition paths, 2001-2025. Bold lines = club means. Thin lines = individual countries. h_it = 1 indicates alignment with the panel average.
Source: Authors' own elaboration using Econometry360 (Python-based econometric platform)

Distributional dynamics

Figure 4a presents kernel density estimates of relative income at five key dates. In 2001, the distribution was distinctly bimodal, with a lower peak around 0.5-0.7 (corresponding to NMS) and a broader upper mode around 1.0-1.3 (EU-15).

By 2013, the distribution had become sharply unimodal and tightly concentrated around unity, consistent with the sigma-convergence

evidence. By 2025, the distribution had flattened noticeably and shifted rightward, with a wider spread suggesting renewed dispersion, though without the clear bimodality of 2001.

The Markov transition matrix (Table 5) reveals the persistence structure underlying these distributional changes.

The highest persistence is observed in the top quintile (Q5), where 51.9 per cent of country-year observations remain in Q5 after five years. The lowest quintile (Q1) also shows moderate persistence at 37.7 per cent, though upward mobility from Q1 is non-trivial: 29.2 per cent of Q1 observations move to Q2 within five years. The Shorrocks mobility index of 0.856 indicates substantial overall mobility, consistent with the active catch-up dynamics observed in the beta-convergence analysis.

The ergodic distribution is approximately uniform across quintiles (ranging from 0.181 to 0.225), suggesting that in the long run, the observed transition dynamics would produce a relatively egalitarian steady-state distribution.

Table 5. Markov transition probability matrix (five-year transitions, quintile states)

From/To	Q1	Q2	Q3	Q4	Q5
Q1 (Low)	0.377	0.292	0.142	0.132	0.057
Q2	0.333	0.144	0.211	0.178	0.133
Q3	0.178	0.244	0.278	0.167	0.133
Q4	0.156	0.111	0.233	0.256	0.244
Q5 (High)	0.077	0.125	0.096	0.183	0.519

Ergodic: [0.225, 0.186, 0.186, 0.181, 0.222]. Shorrocks index: 0.856

Source: Authors' calculations. Excluding 2015 base year.

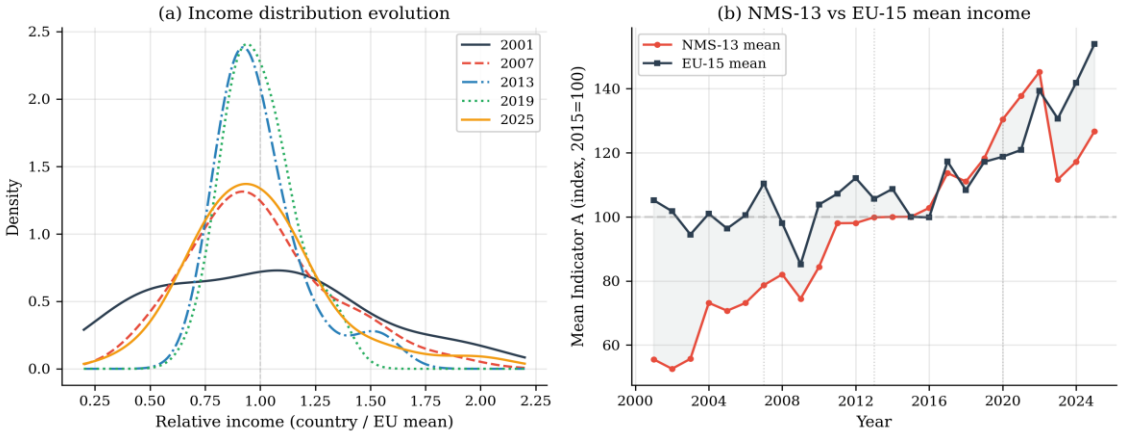

Fig. 4. (a) Kernel density estimates of relative income at five key dates; (b) Mean Indicator A for NMS-13 vs. EU-15, 2001-2025.

Source: Authors' own elaboration using Econometry360 (Python-based econometric platform)

Robustness and diagnostics

The full-period beta-convergence model passes all standard diagnostic tests. The Ramsey RESET test does not reject the null of correct functional form ($F = 0.50$, $p = 0.614$). Residuals are approximately normal according to both the Jarque-Bera test ($p = 0.342$) and the Shapiro-Wilk test ($p = 0.334$). The Breusch-Pagan test finds no evidence of heteroskedasticity ($p = 0.155$).

Three countries are identified as influential observations based on Cook's distance: Denmark ($D = 0.377$), Malta ($D = 0.580$), and Poland ($D = 0.176$). Excluding these observations leaves the convergence finding intact ($b = -0.035$, $p < 0.001$, R-squared = 0.817), confirming that the result is not driven by outliers.

General discussion

The convergence speed of 10.3 per cent per annum documented in this study is substantially faster than the 2 per cent benchmark commonly reported in the cross-country GDP convergence literature [4]. Several factors help explain this difference. Agricultural income is more directly affected by policy transfers than aggregate GDP; CAP direct payments, which were phased in gradually for new member states, provided a direct boost to farm income that has no parallel in general fiscal transfers. Structural transformation also played a role: the rapid

decline in agricultural employment in NMS countries mechanically raised income per remaining worker, even when total sectoral income grew modestly.

The stalling of convergence during 2020-2025 deserves careful interpretation. The polycrisis affected NMS and EU-15 agriculture differently. Energy and fertilizer price spikes hit NMS disproportionately because their farming systems tend to be more input-intensive per unit of output and less hedged against commodity price volatility [31]. At the same time, several EU-15 countries, notably Denmark and Belgium, experienced sharp income increases in 2022-2025 driven by favourable terms of trade in livestock and dairy sectors.

The club convergence results challenge the assumption, implicit in much CAP design, that a single convergence trajectory describes the EU agricultural sector. The presence of three distinct clubs, with the Netherlands and France in the divergent low club, suggests that income dynamics are shaped by country-specific factors that cannot be addressed through uniform area-based payments. This finding echoes the broader observation by Colombo et al. [8] that convergence can occur toward a less favourable equilibrium.

Poland's membership in the high club is perhaps the most striking result. With an initial income index below 50 in 2001 and a 2025 value exceeding 200, Poland's agricultural income growth trajectory represents the most successful catch-up story in the EU agricultural sector. This success likely reflects the combination of large-scale structural fund absorption, rapid farm consolidation, and a competitive agri-food export sector. Romania, by contrast, remains in the middle club with a more modest trajectory, consistent with the slower pace of land consolidation and institutional reform documented in the literature [15].

CONCLUSIONS

The analysis of agricultural income convergence across the 27 EU member states over a quarter of a century reveals a process that is neither linear nor guaranteed. Between 2001 and approximately 2015, the cross-sectional dispersion of real agricultural income per annual work unit declined by nearly 70 per cent, driven largely by the rapid catch-up of new member states following their accession to the single market and gradual integration into the Common Agricultural Policy payment system. This convergence was not merely statistical: the variance decomposition shows that the between-group component, which captured over half of total income variation in 2001, had essentially vanished by 2013. For a brief period, the NMS-EU-15 divide in agricultural income appeared to be closing in a meaningful, structural sense.

The reversal that followed 2020 complicates this narrative considerably. The polycrisis, encompassing the COVID-19 pandemic, the energy and input cost shock triggered by the Russia-Ukraine conflict, and the transition to new CAP conditionality requirements, reopened income gaps that had taken fifteen years to close. The between-group variance share rose from near zero to 12 per cent by 2025, and the beta-convergence coefficient for the 2020-2025 subperiod is statistically indistinguishable from zero. These findings carry a sobering implication: convergence gains in agriculture are not self-sustaining and can be quickly eroded when asymmetric shocks interact with structural vulnerabilities in input dependency, farm size, and institutional capacity.

The rejection of full-panel convergence by the Phillips and Sul log-t test, and the identification of three distinct convergence clubs, adds an important layer of complexity. The fact that Poland, Latvia, and Slovakia belong to the high-income club alongside Denmark and Germany suggests that EU accession can, under certain conditions, propel new member states into the top tier of agricultural income performance. At the same time, the presence of the Netherlands and France in the divergent low club challenges conventional assumptions about which countries lead and which lag in European agriculture. These two economies, traditionally considered agricultural powerhouses, have seen their relative income

positions decline as the EU average was pulled upward by fast-growing NMS and Nordic livestock sectors. The policy implication is that convergence is not a one-directional process from East to West; relative positions shift, and countries that do not adapt their agricultural structures risk falling behind even from privileged starting points.

For the design of the post-2027 CAP, these results suggest that the external convergence mechanism, while effective in narrowing per-hectare payment gaps across member states, addresses only one dimension of a multidimensional problem. Area-based direct payments cannot substitute for investments in farm consolidation, technology adoption, risk management instruments, and human capital development, all of which shape the structural capacity of agricultural sectors to generate and sustain income growth. The club convergence evidence argues against uniform policy prescriptions and in favour of differentiated approaches that recognize the distinct trajectories and needs of different country groupings. Countries in the middle club, including Romania, would benefit most from targeted Pillar II instruments that accelerate structural transformation, while countries in the low club may require a fundamental rethinking of how agricultural competitiveness is maintained in the face of shifting comparative advantages.

Several limitations qualify these findings and point toward directions for further investigation. The reliance on a single aggregate indicator, Eurostat's Indicator A, masks the considerable heterogeneity that exists within countries across farm types, economic sizes, and regions. Complementary analyses using FADN microdata at the farm level or Eurostat regional accounts at the NUTS-2 level would provide a more granular picture of where convergence is occurring and where it is not. The absence of conditioning variables, such as CAP payment intensities, farm structural indicators, and measures of institutional quality, limits the present analysis to absolute convergence and prevents identification of the specific mechanisms driving club membership. Future research should also explore whether the convergence clubs identified here are stable over time or whether membership shifts in response to policy reforms and structural change. The application of conditional convergence models, including system GMM estimation with appropriate control variables, would strengthen the causal interpretation of the results. Agricultural income convergence in the European Union is real, empirically robust, and policy-relevant, but it is also fragile, uneven, and conditional on a stable macroeconomic environment that the past five years have not provided. The trajectory from here depends less on whether poorer countries can grow faster, the beta-convergence evidence confirms they can, and more on whether the institutional and policy frameworks are in place to sustain that growth through periods of turbulence.

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SUSTAINABILITY AND ADDED VALUE OF THE COMMUNITY-LED LOCAL DEVELOPMENT APPROACH IN THE NORTHWESTERN REGION OF BULGARIA

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Abstract

The article aims to assess the long-term impact of the implementation of CLLD strategies by LAG Lom and LAG "Western Balkan" - Berkovitsa, Godech, and Dragoman, considering them as a representative model of the application of the approach in the Northwestern region. The two territories share similar demographic and structural challenges but apply different organizational and governance practices. This provides a basis for a comparative analysis focused on the factors influencing absorption capacity, project effectiveness, and the achieved socio-economic outcomes. The analysis covers the 2014-2020 programming period, which offers sufficient empirical evidence and allows for an assessment of both project implementation and the level of sustainability achieved. The comparison between the two LAGs highlights their specific approaches, institutional capacity and partnerships. Particular emphasis is placed on the added value of CLLD, ranging from economic and social effects to the strengthening of local governance. The study also formulates recommendations for improving the implementation of the approach in the 2021-2027 period, with a focus on integration, adaptability, and the sustainable building upon accumulated experience.

Key words**:** *Community-Led Local Development (CLLD), Local Action Groups, sustainability, added value, North-West region*

INTRODUCTION

Persistent regional inequalities and structural territorial imbalances remain a major challenge for European Union policies aimed at economic, social and territorial cohesion, particularly in peripheral rural areas. These territories are typically characterized by limited economic capacity, unfavourable demographic dynamics, shrinking labour markets and restricted access to public services and investment resources.

In this context, achieving sustainable and inclusive rural development requires integrated and territorially oriented governance models capable of addressing complex socio-economic constraints. The Community Led Local Development (CLLD) approach has therefore became an important instrument for improving the effectiveness of public interventions in rural areas.

The study focuses on the implementation of the CLLD approach in North-West region Bulgaria - a region characterized by structural weaknesses, depopulation and peripheral economic position. The objective is to evaluate the added value of the approach in addressing socio economic challenges in rural territories, with particular emphasis on the role of Local Action Groups (LAGs) as intermediaries in local governance and development processes.

MATERIALS AND METHODS

The research is based on a comparative analysis of the implementation of the CLLD approach in two Local Action Groups - LAG Lom and LAG "Western Balkan" - Berkovitsa, Godech and Dragoman. The selection of the case studies is determined by their territorial specificity, similar socio-economic conditions and active participation in the implementation of CLLD during the programming period 2014-2020.

The analysis relies on secondary data obtained from official sources, including strategic documents of the Local Action Groups, annual reports, policy documents of the

Common Agricultural Policy, as well as publications from scientific research and analytical reports related to regional development and the implementation of the CLLD approach were also reviewed. The main indicators used for the evaluation include the scope and structure of supported projects, the allocation of financial resources by priorities, the participation of local stakeholders, as well as indicators measuring the socio-economic impact on the territories of the two Local Action Groups.

The data processing methods include comparative analysis, analysis of statistical data, and qualitative content analysis of strategic documents. The aim of the study is to examine the long-term impact of Community-Led Local Development (CLLD) as an instrument of the Common Agricultural Policy (CAP) for promoting sustainable and inclusive development in rural areas, as well as to formulate conclusions and recommendations relevant to the current programming period 2021-2027.

RESULTS AND DISCUSSIONS

Features in the development of the Northwestern region and the application of the CLLD approach. The Northwestern region of Bulgaria is characterized by persistent socio-economic disparities, including low economic activity, high unemployment, unfavourable demographic trends and accelerated depopulation. The territorial scope of the region is presented in Figure 1. Compared to other Bulgarian regions, the region continues to rank among the lowest according to key indicators of economic and social development at both national and European levels, placing it among the least developed regions in the European Union. A study conducted by Nikolova et al. (Nikolova, M., Slaveva, K., Pavlov, P., & Lazarova, E., 4/2024) [10] emphasizes that the economic and demographic indicators in North-West region Bulgaria remain significantly lower than those observed in other regions of the country, highlighting the need for targeted and flexible policies aimed at sustainable development and the mobilization of local resources.

The Northwestern region is one of the six planning regions in Bulgaria (NUTS 2 level), covering 17.18% of the country's territory and 11.4% of its population. It includes the western part of the Danube Plain between the Balkan Mountains and the Danube River and the territories of the districts of Vidin, Montana, Vratsa, Pleven, Lovech with the 51 municipalities located in them. It is among the least socio-economically developed regions not only in Bulgaria but also in the European Union, characterized by an extremely unfavorable demographic structure, despite possessing a rich diversity of natural resources.

Fig. 1. Territorial Coverage within the North-West Region
Source: https://2020.eufunds.bg/ [3].

The region is distinguished by the lowest level of gross domestic product (GDP) in the country and, together with the North Central region, contributes the smallest share to the national economy (Nikolova, M., Doichinova, Yu., Stoyanova, Z., Slaveva, K. et al., 2024) [8]. According to statistical data from the National Statistical Institute (NSI) [12], presented in the Census Handbook published in 2023, the population of the region based on the latest census (2021) amounts to approximately 691 thousand inhabitants, representing 10.6% of the total population of Bulgaria. These values are the lowest among all planning regions in the country. The territory of the region is sparsely populated and in certain areas severely depopulated, with several relatively small urban centers. The demographic structure and trends observed in recent years are strongly negative. Increased outward migration beyond the boundaries of the region, together with declining birth rates, are the

main factors contributing to negative natural population growth. The region's contribution to the national economy remains relatively low. Trends in key economic indicators show that more than half of the country's population (51.2%) is concentrated in the Southwestern and South Central regions, while the Northwestern region has the smallest population, with 691 thousand inhabitants, representing 10.6% of the country's population (Figure 2).

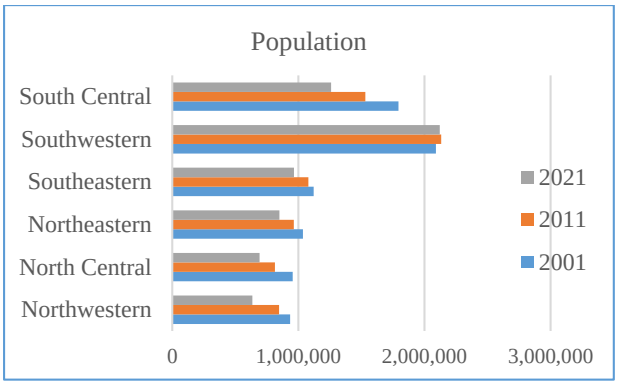

Fig. 2. Population by census years and regions, 2021
Source: NSI [12].

The Northwestern region of Bulgaria underwent administrative expansion in 2007, including areas such as Lovech and Pleven (within the NUTS 2 region), in order to address significant demographic challenges.

Severe depopulation, population aging, and high emigration necessitate the pooling of resources to promote economic development, reduce vulnerability, and improve the absorption of European funds (Table 1).

In all six statistical regions of Bulgaria, the population has decreased compared to the previous census. The largest relative decline is observed in the North Central (-18.7%) and North-West region (-18.5%) regions, while the smallest decrease is recorded in the Southwestern region (-5.1%).

Studies conducted by Bulgarian researchers over the years indicate that poverty and social exclusion in North-West region Bulgaria have a persistent character and have a direct impact on the limited level of economic activity and migration processes, particularly among the young and economically active population. (Mikova, 2/2022), (Atanasov, D., Beluhova-Uzunova, R., & Hristov, K., 2021) [7, 1].

These trends are further reinforced by pronounced regional disparities in access to employment, public services, and investment resources, which deepen territorial imbalances within the country and hinder the achievement of sustainable and balanced spatial development.

Table 1. Population by census years, North-West statistical region

STATISTICAL REGION	POPULATION - NUMBER			INCREMENT, %	
	2001	2011	2021	2001-2011	2012-2021
GENERAL ABOUT THE COUNTRY	7,928,901	7,364,570	6,519,789	-7.1	-11.5
NORTH-WEST REGION	1,037,304	847,138	690,685	-18.3	**-18.5**
VIDIN	130,074	101,018	75,408	-22.3	-25.4
VRATSA	243,036	186,848	152,813	-23.1	-18.2
LOVECH	169,951	141,422	116,394	-16.8	-17.7
MONTANA	182,258	148,098	119,950	-18.7	-19.0
PLEVEN	311,985	269,752	226,120	-13.5	-16.2

Source: https://www.nsi.bg [12].

Despite the presence of significant natural and territorial potential, the region continues to rank among the least developed within the European Union. This situation necessitates the search for effective solutions and appropriate instruments for the sustainable development of territories, particularly in less developed regions. These challenges require the application of integrated and innovative development approaches, which are to a large extent implemented through Local Action Groups aimed at mobilizing local resources and activating community participation (Nikolova, M., Slaveva, K., Pavlov, P., 2025) [9].

As an instrument for territorial development, the Community-Led Local Development (CLLD) approach generates substantial added value for local communities and contributes to better coordination and integration of public policies at the territorial level. This governance model also strengthens social capital and encourages local communities to actively seek new opportunities

for economic and social sustainability (Guidance on community-led local development in European structural and investment funds, 2014) [4].

Despite these positive effects, the implementation of the approach continues to face a number of challenges, primarily related to administrative complexity and the institutional framework, which limit the readiness of public authorities to fully exploit its potential. Although in some countries the application of the approach has been discontinued during the 2021-2027 programming period, practice shows its expansion in other countries, with the accumulated experience generally being assessed as positive. In this context, the CLLD approach, embedded within the framework of the Common Agricultural Policy (CAP) and supported by the European Structural and Investment Funds, has established itself as a key instrument for promoting sustainable development and generating added value. It achieves this by encouraging active involvement of local communities in planning, decision-making, and project implementation processes within their territories, as highlighted in the analysis by (Kah, S., Martinos, H., & Budzich-Tabor, U., 2023) [6]. Empirical evidence underscores that the intermediary and coordination functions performed by Local Action Groups (LAGs) are pivotal for enhancing the competitiveness, adaptive capacity, and long-term resilience of rural territories, particularly in peripheral and socioeconomically lagging regions such as North West region Bulgaria (Shishkova, 2021) [16]. The CLLD approach has a demonstrated impact on the development of local communities through the application of its specific characteristics, notably the "bottom-up" methodology. Through its partnership-based governance model, the approach facilitates the integration of sectoral policies and the implementation of territorially oriented development strategies. Given the particularities and negative trends in the socio-economic development of the Northwestern planning region, this study is based on an examination of the effects of implementing local CLLD strategies in two Local Action Groups (LAGs): LAG Lom and LAG "Western Balkan". The selection of these groups is motivated by their territorial specificity, comparable socio-economic characteristics, and active engagement in applying the CLLD approach during the previous programming period (2014-2020). The objective of the study is not only to identify the distinctive features of the two groups but also to assess the effectiveness, sustainability, and added value of the interventions in terms of local economic development, social inclusion, and the strengthening of institutional capacity. Furthermore, the analysis aims to identify existing constraints and key factors influencing the outcomes of the approach, with a view to formulating recommendations for its improvement in the next programming period.

Comparative analysis of the application of the CLLD approach by LAG - Lom and LAG 'Western Balkan' - Berkovitsa, Godech, and Dragoman. The territory of LAG Lom encompasses nine settlements, as shown in Figure 3, and is characterized by pronounced socio-economic contrasts, the presence of industrial traditions, but limited entrepreneurial activity and high unemployment. The primary economic activities are associated with agriculture, the food processing industry, and metalworking.

Fig. 3. Territory of LAG Lom.
Source: Official website of the municipality of Lom [13].

Table 2 presents the main priorities and programs of the CLLD strategies of LAG Lom and LAG "Western Balkan" for the 2014-2020 programming period, outlining the distinct models of territorial planning and the financing instruments for project interventions.

The CLLD strategy of **LAG Lom** for the 2014-2020 period prioritizes six key areas: social inclusion, environmental sustainability, competitiveness, employment, infrastructure, and

culture. The association implements integrated projects across measures from four operational programs, engaging municipal administrations, schools, cultural centers, NGOs, local entrepreneurs, and farmers. This multidimensional approach, supported by combined financing from the four operational programs, facilitates the delivery of complex, complementary interventions across social, economic, and educational domains.

Table 2. Main priorities in local strategies and scope of programs in implemented projects for the period 2014-2020

CLLD STRATEGY OF LAG LOM	CLLD STRATEGY OF LAG "WESTERN BALKAN"
• Promoting social inclusion and reducing poverty; • Preserving and protecting the environment and promoting resource efficiency, including activities for risk prevention and management, as well as the utilization of cultural heritage potential; • Fostering innovation by encouraging its practical application; • Promoting sustainable and quality employment and supporting labor mobility; • Enhancing the competitiveness of local economies and opportunities for local business development, including through diversification, alternative activities, and sustainable aquaculture production; • Improving the quality of education and increasing the qualification level of the population.	• Creating sustainable employment and utilizing local growth potential in order to improve the quality of life and income levels of the local population; • Enhancing the competitiveness of the local economy and creating opportunities for the development of local businesses; • Preserving and protecting the environment and promoting resource efficiency, including the utilization of the potential of cultural heritage.
PROGRAMS	
• Rural Development Program (RDP) • Operational Program Human Resources Development (OPHRD) • Operational Program Science and Education for Smart Growth (OPSESG) • Operational Program Competitiveness and Innovation (OPCI)	• Rural Development Program (RDP)

Source: Author's work based on data from https://miglom.org/miglom/strategy.php, https://mig-bg.org

LAG "Western Balkan" - encompassing the municipalities of Berkovitsa, Godech, and Dragoman (Figure 4) - covers mountainous and semi-mountainous territories with diverse natural potential. While the region has been less affected by industrialization, it maintains strong traditions in agriculture, tourism, and local crafts, providing a foundation for territorially tailored development strategies.

Fig. 4. Territory of LAG "Western Balkan"
Source: Official website of LAG Western Balkans https://www.mig-bg.org/about-us/ [14].

The CLLD strategy of LAG "Western Balkan" demonstrates a more concentrated and territorially focused model, emphasizing economic diversification, tourism and local products, access to services, and digital connectivity. Its priorities are primarily aimed at fostering sustainable employment, enhancing the competitiveness of the local economy, promoting local entrepreneurship, and preserving natural resources and cultural heritage. Implementation of activities is predominantly within the framework of the Rural Development Program, which ensures consistency and specialization of interventions but limits opportunities for cross-sectoral integration compared to the more diversified model of LAG Lom. The territorial scope of LAG "Western Balkan" necessitates coordinated governance and a
high level of partnership among the three municipalities and local stakeholders, which represents both an advantage (broader territorial coverage and resources) and a challenge (more complex administrative coordination).
Comparative analysis of the data indicates that while LAG Lom adopts a multi-program, integrated approach aimed at simultaneously addressing social, economic, and educational dimensions, LAG "Western Balkan" relies on a more narrowly specialized strategy tailored to the local economic and natural potential. These differences reflect the adaptation of the CLLD/LEADER approach to the specific needs

and resources of each territory and underscore the flexibility of the instrument as a mechanism for sustainable local development. During the previous programming period (2014-2020), both LAGs succeeded in implementing their strategies, albeit with varying degrees of fund absorption and diversity in project proposals (Table 3).

Table 3. General characteristics of the results from the implementation of local strategies

	LAG Lom	LAG "Western Balkan"
Total budget of the strategy	3,819,088.73 €	1,908,522 €
Implemented projects	52 contracts	45 contracts
Main directions for investments	Agriculture, social services, culture, education, infrastructure, and support for small businesses.	Tourism infrastructure, support for start-up farms, and promotion of short supply chains
Conclusions	High interest reported from local NGOs and schools in measures for social inclusion and education.	A high level of cross-sector partnership and good exchange of experience between the three municipalities.

Source: Annual reports of LAG Lom and LAG "Western Balkan" [13, 14].

Data from Table 3 reveal clear differences in the scale and thematic focus of the strategies implemented by **LAG Lom and LAG "Western Balkan",** reflecting the specific needs and potential of their respective territories. LAG Lom operates with a larger financial allocation (3,819,088.73 €) and a higher number of concluded contracts (52), with investments directed toward a broad spectrum of interventions, including agriculture, social services, education, culture, infrastructure, and support for small enterprises. This diversified project portfolio is complemented by strong engagement from local NGOs and educational institutions in measures aimed at social inclusion and human capital development.

In contrast, LAG "Western Balkan" pursues a more concentrated approach, with a budget of 1,908,522 € and 45 contracts, focusing primarily on tourism infrastructure, the development of start-up farms, and the promotion of short supply chains. At the same time, the region demonstrates a high degree of cross-sectoral partnership and effective coordination among the three municipalities, enhancing institutional capacity and the sustainability of implementation.

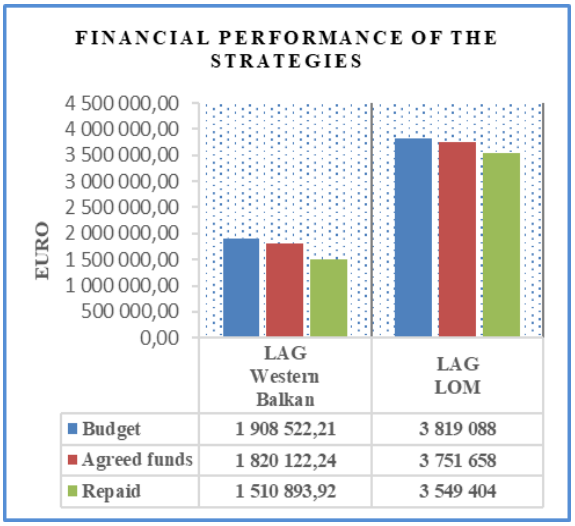

Fig. 5. Financial performance of CLLD
Source: author's calculations based on accounting data from ISUN [5].

In summary, the results indicate that both LAGs implement strategies adapted to their local context, with differences in priorities and resources shaping distinct models of territorial impact.

Figure 5 presents a comparative analysis of the degree of contracting and actual disbursement of funds under the CLLD strategies of the two local action groups.

LAG Lom is characterized by a larger financial allocation and a higher intensity of project activity, measured by the greater number of concluded contracts. The substantial budget allows the implementation of a diversified and integrated approach, covering a wide range of sectors, including agriculture, social services, education, culture, infrastructure, and support for small enterprises. This reflects a commitment to achieving comprehensive impacts on the socio-economic environment and addressing economic, social, and infrastructural deficits simultaneously. As a result, LAG Lom demonstrates a higher degree of cross-sectoral integration and a broader scope of supported beneficiaries.

In contrast, LAG "Western Balkan" operates with more limited financial resources and fewer projects but follows a clearly focused and specialized strategy. Investments are primarily concentrated on the development of tourism infrastructure, support for start-up farms, and the promotion of short supply chains, reflecting an orientation toward leveraging local natural and

entrepreneurial resources and stimulating small-scale business development. This model implies more targeted economic impacts and sectoral specialization aligned with the territorial potential.

In summary, LAG Lom follows a model of broad-based, integrated development, whereas LAG "Western Balkan" emphasizes thematic concentration and sectoral specialization. Both approaches illustrate the adaptability of the CLLD approach to local conditions, with the differences highlighting the importance of territorially tailored planning for achieving sustainable outcomes.

The total budget for the strategy implementation period and its allocation across the various measures and interventions within the CLLD strategies of the two LAGs are presented in Tables 4 and 5, providing a basis for a detailed analysis of the funding structure and priority investment areas.

Table 4. Scope of measures and budget for the implementation of LOM CLLD

Measure code	*Name of the measure*	*Euro*	*%*
Measures financed under the Rural Development Program 2014-2020 (EAFRD)		3,732,700	**47.35**
4.1	Investments in agricultural farms	250,545	7.59
4.2	Investments in the processing and marketing of agricultural products	0	0
6.4.1	Investments in non-agricultural activities	828,560	20.66
7.2	Investments in the creation, improvement, or expansion of small-scale infrastructure	679,396	17.79
7.5	Support for publicly accessible recreational and tourist infrastructure	49,999	1.31
Measures outside the scope of Regulation (EC) 1305/2013 but aligned with its objectives (financed by EAFRD)			
6	Investments in the study, development, and promotion of the cultural, historical, and natural heritage, as well as local traditions, within the territory of LAG Lom	99,998	2.62
Measures financed by OP SESG (ESF)		**420,297**	**11.01**
M7	Access to quality education through integration of children and students from marginalized communities, including Roma, into the formal education system	420,297	11.01
Measures financed by OP HRD (ESF)		**502,195**	**12.84**
M8	Access to employment for economically inactive and unemployed individuals	67,164	1.19
M9	Promotion and support of youth employment	0	0
M10	Integration of marginalized communities, including Roma, migrants, etc.	44,916	1.17
M11	Active inclusion of those most distant from the labor market, with support for families with children	0	0
Measures financed by OP IC (ERDF)		**999,984**	**26.18**
M13	Enhancing the growth capacity of SMEs within the territory of LAG Lom	999,984	26.18
GRANT TOTAL		**3,819,088**	**100**

Source: Author's synthesis based on data from the CLLD strategies of Local Action Groups https://miglom.org/miglom/strategy.php

The analysis of budget allocation indicates that the highest relative share of funds under the Rural Development Program is allocated to Measure 6.4.1, "Investments in support of non-agricultural activities," reflecting a focus on economic diversification and the promotion of entrepreneurship beyond traditional agriculture. A substantial portion of resources is also directed to Measure 7.2 (small-scale infrastructure), highlighting the need to improve basic technical and social infrastructure within the territory. The significant share of funds under the Operational Program Competitiveness and Innovation (26.18%) demonstrates an orientation toward supporting small and medium-sized enterprises and enhancing their competitiveness, thereby broadening the economic scope of interventions beyond the agricultural sector. The achieved results for the funded measures under the implementation of the CLLD strategy of LAG Lom, expressed in monetary terms, are presented in the following figure (Figure 6). Based on the distribution of the value of project proposals submitted to LAG Lom, a clearly high level of interest and significant project activity among local beneficiaries can be observed. The total financial volume of requested funds exceeds the available budget under the strategy, indicating that demand for financing substantially surpasses the resources available within the program.

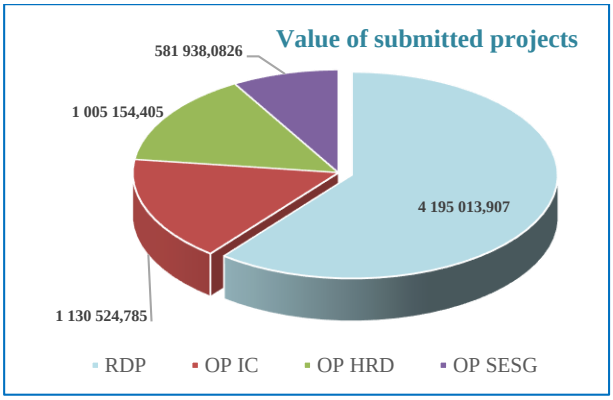

Fig. 6. Value in euros of the proposals submitted to LAG LOM
Source: official data from ISUN [5].

The largest share of submitted proposals by value is concentrated under the Rural Development Program (RDP), accounting for more than half of the total requested amount, followed by measures under the Operational Program Competitiveness and Innovation (OPCI) and the Operational Program Human Resources Development (OPHRD), while projects under the Operational Program Science and Education for Smart Growth (OPSESG) represent a smaller but still significant share. This distribution reflects a predominant focus on investments in agriculture, entrepreneurship, employment, and social inclusion, aligning with the identified local needs and priorities for economic diversification and quality-of-life improvement. At the same time, the fact that the total value of submitted project proposals significantly exceeds the available financial resources highlights the presence of unrealized investment potential and limited capacity to meet all identified needs. This can be interpreted both as an indicator of strong confidence in the CLLD approach and as evidence of the need to expand financial coverage and introduce more flexible funding mechanisms in future programming periods. In this context, LAG Lom has established itself as an active intermediary for mobilizing local initiatives, while simultaneously underscoring the necessity to increase resource availability to fully exploit the existing territorial potential.

In contrast to LAG Lom, all project proposals submitted to **LAG "Western Balkan"** are financed entirely under the **Rural Development Program** (measures pursuant to Article 96, item 2 of the Law on Support for Agricultural Producers), with a total value of €4,770,214.15, according to data from the **Management and Monitoring Information System of EU Funds in Bulgaria (MIS)**. This corresponds to full coverage of the applicable measures under the program and reflects a clearly defined sectoral concentration of interventions within the development of rural areas.

The fact that both submitted and implemented project proposals fall entirely within the RDP confirms the strategy's strong reliance on the instruments of the European Agricultural Fund for Rural Development and the absence of a multi-fund approach. While this single-fund structure provides focus and administrative clarity in implementation, it simultaneously limits opportunities to integrate a broader range of measures and resources that could support more complex and diversified territorial development.

The allocation of the budget across individual measures for the CLLD strategy of **LAG "Western Balkan"** is presented in Table 5.

The budget structure of LAG "Western Balkan" reveals a pronounced concentration within the Rural Development Program (98.73% of the total budget), indicating a single-fund financing model. The largest relative share is allocated to Measure 6.4 (44.38%), aimed at supporting non-agricultural activities, which confirms the strategic orientation toward economic diversification and the development of tourism and alternative economic activities. A substantial portion of resources is also directed to Measure 7.2 (26.22%), related to improving local infrastructure conditions, indirectly supporting tourism development. The analysis of the structure of supported projects indicates a predominance of interventions focused on supporting small and medium-sized enterprises, developing agricultural activities, and improving local infrastructure.

In LAG Lom, a relatively higher share of projects aimed at the modernization of agricultural holdings and job creation can be observed, reflecting the economic profile of the territory and the need to address high unemployment levels.

Table 5. Scope of measures and budget for the implementation of LAG Western Balkan

Measure code	***Name of the measure***	***Euro***	***%***
Measures financed under the Rural Development Program 2014-2020 (EAFRD)		1,884,302	98.73
4.1	Investments in agricultural farms	384,084	20.12
4.2	Investments in the processing and marketing of agricultural products	0	0
8.6	Investments in forestry technologies and in the processing, mobilization, and trade of forest products	37,963	1.99
6.4	Investments in non-agricultural activities	846,958	44.38
7.2	Investments in the creation, improvement, or expansion of small-scale infrastructure	500,459	26.22
7.5	Support for public use in recreational infrastructure, tourist information, and small-scale tourist infrastructure	114,836	6.02
Measures outside the scope of Regulation (EC) 1305/2013 but aligned with its objectives (financed by EAFRD)			
7.6	Preservation and integration into the local cultural, historical, and natural heritage	24,219	1.27
GRAND TOTAL		1,908,522	**100**

Source: Author's synthesis based on data from the CLLD strategies of Local Action Groups https://mig-bg.org [17].

In LAG "Western Balkan," a larger proportion of projects is related to tourism development, the preservation of natural and cultural heritage, and the promotion of alternative economic activities, which corresponds to the existing natural potential and the geographical location of the region.

Despite the positive results achieved, several limitations in the implementation of the approach can also be identified, including delays caused by administrative burdens, changes in the regulatory framework, insufficient capacity of local administrations, and restrictions during the COVID-19 pandemic in 2020–2021.

In both LAGs, administrative complexity and lengthy procedures for project approval and implementation emerge as major deterrents to the participation of potential beneficiaries.

Delays in contracting and disbursement of funds reduce the effectiveness of interventions and weaken the motivation of local economic actors to engage actively in the programs.

These findings confirm the conclusions of several scholars, particularly the analyses of (Kah, S., Martinos, H., & Budzich-Tabor, U., 2023) [6], as well as (Pollermann, K., Raue, P., & Schnaut, G., 34/2014) (Nikolova, M., Doichinova, Yu., Stoyanova, Z., Slaveva, K. et al., 2024), (Doichinova, 2013) [15, 10, 2].

Their research emphasizes that institutional complexity and administrative burden represent some of the main challenges to the sustainable and effective implementation of the CLLD approach, as they constrain the autonomy, flexibility, and innovation capacity of Local Action Groups.

In the long term, the sustainability and added value of the CLLD approach in the Northwestern region depend on:

-The simplification of administrative procedures

-The strengthening of the expert and institutional capacity of Local Action Groups

-Closer integration with regional and sectoral policies

-He expansion of financial resources in line with the actual investment interest of local stakeholders.

Addressing these factors is essential for enhancing the effectiveness of the approach and for unlocking the full territorial potential of rural communities in the region.

As a result of the conducted empirical study and in line with the objective of providing a comparative assessment of the achieved results, the degree of resource absorption, and the territorial impact, specific similarities and differences in the implementation of the strategies of **LAG Lom** and **LAG "Western Balkan"** have been identified.

The comparative analysis highlights both common characteristics related to the activation of local partnerships and the mobilization of community resources, as well as differences in terms of financial scale, sectoral orientation of interventions, and the organizational model of governance, which are summarized in Table 6.

Table 6. Comparative characteristics in the implementation of CLLD strategies of the two LAGs

Similarities	**Differences**
Both LAGs apply integrated strategies, combining economic, social, and infrastructure measures.	**LAG Lom** - multifund strategy, 4 EU Operational Programmes **LAG "Western Balkan"** single-fund strategy - 1 EU Operational Program
Focus on support for micro and small enterprises and social inclusion.	**LAG Lom** - industrial and social projects; focus on vulnerable groups and ethnic minorities **LAG "Western Balkan"** - tourism, entrepreneurship, cultural heritage
Limited administrative and expert capacity, especially in the early stages of implementation.	**LAG Lom** - active engagement of the municipal administration. **LAG "Western Balkan"**- diverse partnerships with more private entities
Lack of interest in the measure 'Investments in processing/marketing of agricultural products'	The geographical and economic characteristics determine a different model - industrial for **Lom** and eco-tourism in the **Western Balkans**

Source: Authors' development.

The comparative analysis of the implementation of the strategies of **LAG Lom** and **LAG "Western Balkan"** reveals the presence of significant similarities in the conceptual approach to local development, as well as clearly differentiated implementation models shaped by the specific territorial contexts. Both Local Action Groups implement integrated strategies combining economic, social, and infrastructural interventions, with a particular focus on supporting micro- and small enterprises and promoting social inclusion. A common feature of both LAGs is the limited administrative and expert capacity, especially during the initial stages of implementing the approach, as well as the relatively weak interest in investments related to the processing and marketing of agricultural products, which restricts the potential for developing local production chains with higher added value.

Alongside these similarities, notable differences emerge in terms of scale, sources of financing, and sectoral orientation of the interventions. LAG Lom applies a multi-fund strategy financed through several operational programs, creating opportunities for the implementation of a broader spectrum of industrial, social, and educational projects and fostering stronger engagement of the municipal administration. In this context, a Bulgarian author emphasizes that "the implementation and management of multi-fund strategies provide opportunities for greater comprehensiveness, for the development of small and medium-sized enterprises, and for the realization of a larger number of investment initiatives related to the development of local potential, employment generation, and the promotion of local identity" (Nikolova, 2016) [11] which confirms the positive effects observed in the implementation of the strategy.

In contrast, LAG "Western Balkan" operates within a single-fund model primarily concentrated on measures under the Rural Development Program, with priorities focused on tourism, entrepreneurship, and the preservation of cultural heritage, relying more actively on private sector participation and cross-sectoral partnerships. These differences shape two distinct profiles of territorial development-a more industrially oriented model in Lom and a predominantly eco-tourism-oriented model in the Western Balkan area-demonstrating the adaptability of the CLLD approach to local needs and territorial potential.

The results obtained from the study are consistent with the conclusions of both international and Bulgarian authors (Kah, S., Martinos, H., & Budzich-Tabor, U., 2023) [6], who emphasize the importance of the CLLD approach as an instrument for mobilizing local potential, while also highlighting the need for institutional strengthening and the simplification of administrative procedures. Similarly, the observed role of Local Action Groups as intermediaries between different levels of governance confirms the findings of (Doichinova, 2013) [2] and (Shishkova, 2021) [16] regarding the importance of the coordination function in enhancing the resilience of lagging regions.

CONCLUSIONS

In conclusion, the results of the analysis confirm the importance of the partnership-based governance model for activating local communities and mobilizing local potential. In both LAGs, a high level of participation by

representatives of the public sector, non-governmental organizations, and local businesses can be observed in the processes of planning and decision-making, which corresponds to the "bottom-up" principle characteristic of the CLLD approach. This participation contributes to a more accurate identification of local needs and to the formulation of interventions tailored to the specific characteristics of the respective territories.

Despite these positive aspects, the impact on long-term economic indicators remains limited. The jobs created and the supported enterprises contribute to the temporary mitigation of negative trends but do not lead to significant structural changes in local economies. This confirms the need for stronger integration of CLLD strategies with other sectoral and regional policies, as well as for clearer prioritization aimed at diversifying the economic base and enhancing the competitiveness of local territories. From the perspective of social impact, the results indicate positive trends in terms of the activation of local communities and the strengthening of social capital. Through the implementation of the CLLD approach, conditions are created for increasing trust among stakeholders, expanding partnership networks, and encouraging civic participation. These effects are particularly important for peripheral and demographically vulnerable territories such as North-West region Bulgaria, where social cohesion represents a key factor for sustainable development.

In summary, the results of the comparative analysis demonstrate that the implementation of the CLLD approach in the North-West region region creates real opportunities for mobilizing local communities and implementing integrated interventions tailored to territorial specificities. At the same time, the effectiveness of the approach remains highly dependent on institutional capacity, the administrative framework, and the degree of integration with other public policies. These findings highlight the need to further improve governance mechanisms and to utilize the CLLD approach more strategically as an instrument for sustainable and inclusive rural development. Therefore, CLLD should not be viewed merely as a compensatory policy tool but rather as a strategic mechanism for territorial governance, whose impact is cumulative and strongly dependent on the quality of the institutional environment.

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CONSUMER DEMAND FOR AGROECOLOGICAL PRODUCTS: PERCEPTUAL, MOTIVATIONAL AND ECONOMICAL DETERMINANTS

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Abstract

This study investigates consumer demand for agroecological products by examining perceptual, motivational, and economic determinants influencing consumption behaviour. The research is based on a quantitative survey conducted on 92 respondents, using descriptive statistical analysis and Chi-square testing. The findings reveal a high level of consumer interest in agroecological products, with 78.9% considering them very important and 72.8% perceiving them as healthier than conventional alternatives. Additionally, 86.8% of respondents reported a willingness to pay a premium price. However, the level of knowledge about agroecology add the adoption of agroecological practices remain low (7.6%). The study results show significant correlations between knowledge and adoption of agroecological practices, as well as between perceived health benefits and willingness to pay. At the same time, major barriers such as lack of information and uncertainty limit the transition to sustainable practices. The study highlights the existence of an attitude-behaviour gap and emphasizes the need for integrated policy interventions to support the development of agroecological markets.

***Key words*:** *agroecological products, consumer behavior, environmental perception, food sustainability, green consumerism, sustainable agriculture*

INTRODUCTION

In the current context of the transition towards sustainable economies, agri-food systems are undergoing an accelerated transformation process, driven by multiple pressures, such as climate change, natural resource degradation and the increasing demand for healthy and safe food. In this context, agroecology is considered an authentic emerging model that can integrate agricultural production with the ecological, economic and social aspects, which contributes to the development of sustainable food systems. (HLPE, 2019; FAO, 2021) [7, 5]. In many Eastern European nations, including Romania, there is a significant lack of recognition of agroecological practices as unique factors contributing to improving production quality, as well as a poor understanding of how to differentiate and combine agroecological practices with organic farming methods (Moudrý et al., 2018; Wezel et al., 2023) [9, 19].

This context makes it analytically important to distinguish between different categories of actors, producers, hobby gardeners, and end consumers, who engage with agroecological products and practices from fundamentally different positions within the agri-food system. Restructuring the supply-demand relationship on the agri-food market is

necessary in the tranzition to agroecological production. Consumers thus become central actors in this transitional process, as their preferences and consumption behaviours influence both the production structure and the marketing strategies of producers. In fact, the demand for agroecological products can be interpreted as the result of the interaction between perceived utility (health and environmental benefits) and associated costs (higher prices and reduced accessibility) (European Commission, 2020; OECD, 2021). [3, 12]. Recent literature highlights that agroecological products are perceived as value-added goods, as they are considered to include fewer chemical residues, have a reduced impact on the environment and make a greater contribution to food security (Sultan et al., 2023) [16].

These characteristics cannot be directly assessed by consumers, who need information, detailed labels and trust in certification systems (Nguyen et al., 2023) [10].

From a theoretical point of view, consumer behaviour can be explained by several models, such as the following:

-The Theory of Planned Behaviour (TPB), which suggests that attitudes, social norms and perceived behavioural control influence consumption intentions (Ajzen, 2020) [1].

-Value-Belief-Norm (VBN), which highlights the role of personal values and ecological beliefs in shaping sustainable behaviour (Stern, 2020) [15].

Several recent studies indicate that the integration of these two models provides a deeper understanding of consumer decisions in the context of agroecological products (Sogari et al., 2022) [14].

Health perceptions are also considered to be the main determinant of demand for agroecological products, followed by environmental and animal welfare concerns, which influence consumers' choices and the possibility of paying them. (Testa et al., 2021; Verain et al., 2021) [17, 18].

These perceptions and consumers' level of information and trust influence the willingness to pay a premium price (Rana & Paul, 2020) [13].

However, the literature highlights a persistent discrepancy between favorable attitudes and actual consumer behaviors. This phenomenon, known as the "attitude–behavior gap", is explained by the existence of structural and cognitive barriers, such as lack of information, uncertainty about real benefits and low accessibility of products (Joshi & Rahman, 2020; Nguyen et al., 2022) [8, 11]. Recent studies emphasize that this gap represents one of the main challenges in developing sustainable markets (White et al., 2020). In addition, recent research highlights the essential role of access to information and education in facilitating the adoption of sustainable behaviors. Lack of knowledge and practical experience is identified as a major obstacle in the transition to agroecology, both at the level of consumers and producers (FAO, 2022) [6]. In this context, educational interventions and public policies aimed at raising awareness are considered essential for the development of this sector (European Environmental Agency, 2023) [4]. Thus, the present study aims to contribute to the existing literature by analyzing consumer demand for agroecological products using an integrated approach that combines perceptual, motivational and economic dimensions, as well as by identifying the barriers that limit their adoption (Nguyen et al., 2022; White et al., 2020) [11, 20]. The present study focuses specifically on the demand side of this system, analysing the perceptions, motivations, and economic behaviour of end consumers regarding agroecological products. This analysis is part of a broader multi-stakeholder research initiative conducted within the AllEcoSys project, which also examined agroecological practice awareness and implementation among active growers (hobby gardeners and farmers) in Romanian tomato systems (Ciceoi et al., 2026) [2]. While those companion studies address the supply and production side of agroecological transition, the present study contributes the consumer perspective, examining how demand-side actors perceive, value, and respond to agroecological products, a dimension that is analytically distinct but

equally essential for understanding the conditions for market development.

Conceptual model

The study proposes the integration of socio-economic, cognitive and behavioural determinants of demand for agroecological products, based on the extension of the Theory of Planned Behavior and the Value-Belief-Norm Theory model. It assumes that socio-demographic variables indirectly influence consumption behavior through the level of knowledge and perceptions, while barriers act as inhibitory factors on actual behavior. The model proposes a sequential relationship: socio-demographic characteristics influence the level of knowledge, knowledge shapes perceptions (health, environment), perceptions influence willingness to pay (WTP), willingness to pay influences actual behavior, and barriers negatively moderate the relationship between intention and behaviour.

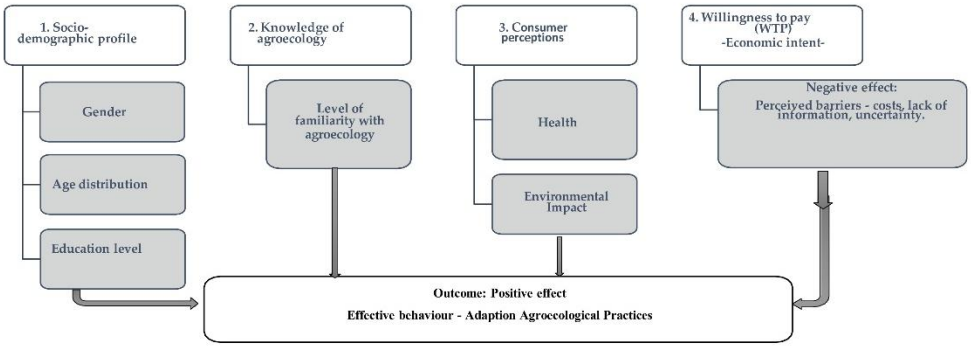

Fig.1. Conceptual model of consumer demand for agroecological products.
Source: Authors' concept.

The model reflects the established structure of sustainable consumer behaviour, in which knowledge functions as an essential cognitive factor in the formation of attitudes, perceptions (especially those related to health) represent key motivational variables, willingness to pay reflects behavioral intention, and actual behavior is influenced by external constraints. This approach is supported by recent literature, which highlights the relationship between intentions and behaviours is mediated by contextual factors and structural barriers. The model is based on the following research hypotheses:

H1: Age and education level have a significant positive effect on the degree of familiarity with agroecology.

H2: The degree of familiarity with agroecological techniques and perceptions of health benefits positively influence the possibility of paying a premium price for agroecological products.

H3: Uncertainty, high costs, lack of information as perceived barriers have a negative effect on the adoption of agroecological practices.

H4: There is a significant discrepancy between favorable attitudes towards agroecological products and actual consumer behaviors.

The proposed conceptual model provides an integrated framework for analyzing consumer behavior in the context of agroecology, highlighting the interdependence between knowledge, perceptions, and behaviors as well as the role of barriers in limiting the adoption of sustainable practices.

MATERIALS AND METHODS

Research design: The present study adopts a quantitative, cross-sectional approach, aiming to investigate the determinants of demand for agroecological products from the perspective of consumers. The research is descriptive and explanatory in nature, aiming both to characterize consumer behaviour and to identify relationships between socio-demographic, perceptual and behavioural variables. The methodological design is based on the use of a standardized questionnaire, which allows the collection of primary data

and their analysis in order to test the research hypotheses.

Sample and data collection procedure: The present study draws on data collected through a structured questionnaire developed and administered within the AllEcoSys project framework. The full dataset, comprising 289 completed responses collected in Romania in 2025, is publicly available at Zenodo (https://doi.org/10.5281/zenodo.19161803).

Of the 289 respondents, 92 identified exclusively as end consumers without agricultural activity and constitute the analytical sample of the present study. The remaining respondents, who reported active cultivation (hobby gardeners and farmers), are the subject of companion analyses within the same research programme. The selection of participants was carried out through a non-probability convenience sampling method, justified by the accessibility and availability of the respondents.

Research tool: The instrument used was a structured questionnaire, consisting of closed and semi-closed items, organized into several thematic sections: socio-demographic characteristics (gender, age, level of education), level of familiarity with agroecology, perceptions of health benefits and environmental impact, consumption behaviour, willingness to pay, knowledge and application of agroecological techniques, perceived barriers, and informational needs. The variables were measured using nominal and ordinal scales, and Likert-type scales were used to assess perceptions.

Data analysis method: Data analysis was carried out in two main stages. In the first stage, descriptive statistical analysis was used, by calculating absolute and relative frequencies, to highlight the distribution of responses and to characterize the sample. In the second stage, to test the research hypotheses and identify relationships between variables, the Chi-square (χ^2) test was applied, appropriate for the analysis of categorical variables. The statistical significance threshold was set at $p < 0.05$. To assess the intensity of associations, the Cramer's V coefficient was used. The analysis was oriented towards identifying relationships between socio-demographic variables and the level of familiarity, consumer perceptions and willingness to pay, and the level of knowledge and application of agroecological practices.

Operationalization of variables: In the analysis we included the followig variables:

- Socio-demographic characteristics (level of education, gender, age), the degree of familiarity with agroecology structured as i*ndependent variables;*
- The use of agroecological practices, willingness to pay, consumption behaviors, structured as d*ependent variables;*

Mediating variables: perceptions of health and environmental impact;

Explanatory variables: perceived barriers and the level of knowledge of agroecological techniques.

This structure allows the investigation of associations and mechanisms that influence consumer behavior.

RESULTS AND DISCUSSIONS

Descriptive profile of the sample. The analytical sample comprised 92 end consumers. The sample was predominantly female (64.1%), with the largest age group being 41–60 years (51.1%). Educational attainment was high, with 93.5% of respondents holding university or postgraduate degrees. All participants identified themselves as non-agricultural, confirming the demand-side focus of the present analysis.

Descriptive analysis of results and verification of research hypotheses: The results of the descriptive analysis highlight a high level of interest among respondents in agroecological products. Thus, 78.9% of the participants consider these products very important, and 72.8% perceive them as significantly healthier than conventional products. These results indicate a clear orientation of consumers towards sustainable products, in line with recent literature on health-oriented food preferences and environmental protection. In terms of economic behaviour, 86.8% of respondents declared that they are willing to pay a higher price for agroecological products, most of

them accepting an additional cost of up to 10%. This result confirms that the perceived product value is an essential determinant of the purchase decision. However, the level of familiarity with agroecology is relatively low, with only 5.4% of respondents declaring a high level of knowledge. At the same time, the effective adoption of agroecological practices is limited, with only 7.6% of respondents applying such techniques. This discrepancy highlights the existence of factors that inhibit the transformation of intentions into concrete behaviors. To verify the formulated hypotheses, the Chi-square (χ^2) test was used to identify the relationships between the analysed variables.
The results are summarized in Table 1.

Table 1. Hypothesis testing (Chi-square)

Hypothesis	Relationship tested	X^2	df	p-value	Cramer's -V	Results
H1	The age, the education - Agroecology familiarity	8.21	3	0.016	0.30	Supported
H2	Health perception - Willingness to pay	12.33	2	0.002	0.37	Supported
H3	Perceived barriers-Adoption behaviour	10.45	2	0.005	0.34	Supported
H4	Atitude-Behaivour	-	-	-	-	Supported (descriptive)

Source: Authors' results.
Note: H1 – significant ($p < 0.05$), H2 – highly significant ($p < 0.01$), H3 – significant ($p < 0.01$), H4 – validated through the attitude-behavior gap (not tested using Chi-square, but validated through descriptive comparison of attitudes and behavior). Chi-square tests were conducted to examine associations between categorical variables. Cramer's V was used to assess the strength of associations. Values of 0.1, 0.3, and 0.5 indicate small, medium, and strong effects, respectively. H4 was assessed descriptively

The results of the Chi-square test highlight the existence of statistically significant relationships between the analyzed variables, confirming the formulated research hypotheses. For hypothesis H1, a significant association is observed between socio-demographic variables (age and education level) and the degree of familiarity with agroecology ($p < 0.05$), suggesting that education level and age contribute to increasing the level of knowledge of the respondents. Regarding hypothesis H2, the analysis indicates a significant relationship between the degree of familiarity, perceptions of health benefits, and the willingness to pay a premium price for agroecological products ($p < 0.01$). This result highlights the important role of health-related perceptions in underpinning consumers' economic behavior. For hypothesis H3, the results show that perceived barriers have a significant negative effect on the adoption of agroecological practices ($p < 0.01$). Lack of information and the uncertainty of the results, represent major obstacles to the implementation of sustainable behaviors, limiting the transition from intention to action. In addition, the analysis highlights the existence of statistically significant associations between the variables analyzed, including between health perceptions and willingness to pay ($p < 0.01$), as well as between socio-demographic variables and level of familiarity ($p < 0.05$). The intensity of these relationships, assessed by the Cramer's V coefficient, indicates moderate associations, suggesting relevant but not dominant effects. The comparative analysis between attitudes and behaviors confirms hypothesis H4, highlighting a significant discrepancy between the high level of positive attitudes (over 70% of respondents) and the low level of concrete behaviors (below 20% of respondents). This result confirms the existence of an "attitude–behavior gap", a phenomenon frequently documented in the literature on sustainable consumption. Overall, the results support the interdependence between socio-demographic, cognitive and behavioral factors, highlighting the essential role of perceptions and barriers in determining demand for agroecological products. The results obtained show that the relationships identified between socio-demographic variables, knowledge level, consumer perceptions and actual behaviours are consistent with the established theoretical

frameworks in the relevant literature. Thus, the significant influence of health perceptions on willingness to pay confirms the determining role of attitudinal factors in shaping behavioral intentions, as described in the Theory of Planned Behaviour (Ajzen, 2020) [1]. Also, the relationship between the level of knowledge and the formation of perceptions support the hypotheses formulated within the Value-Belief-Norm Theory (Stern, 2020) [15] according to which individual values and beliefs influence sustainable behaviors through cognitive and normative mechanisms. The empirical results validate the sequential structure proposed in the conceptual model, confirming the following relationships:

H1: Socio-demographic characteristics influence the level of knowledge;

H2: Knowledge and Perceptions influence Willingness to Pay (WTP);

H3: Barriers negatively influence Behavior (negative effect);

H4: Attitudes and Behavior differ substantially (gap).

This sequence suggests the existence of an underlying mechanism in which cognitive variables mediate the relationship between individual characteristics and actual behavior, while barriers act as negative moderating factors.

Discussions: The results of the study confirm that perceptions of health and the environment are the main determinants of demand for agroecological products. At the same time, low levels of knowledge and information barriers limit their adoption. The discrepancy between attitudes and behaviors highlights that consumer interest is not sufficient to generate real changes in behavior. This situation can be explained by the lack of accessible information, the absence of practical experience, and the uncertainty regarding the effectiveness of agroecological methods. The results are consistent with the Theory of Planned Behavior and Value-Belief-Norm Theory, which highlight the role of attitudes, perceptions and contextual factors in determining behavior. The results also validate the proposed conceptual model, confirming the interdependence between knowledge, perceptions and behaviors, as well as the role of barriers in limiting the adoption of sustainable practices. In this context, empirical findings highlight the need for integrated interventions at the public policy level, aimed at both reducing existing constraints and stimulating sustainable behaviours. Therefore, the main directions of intervention aim to reduce informational and economic barriers, increasing the level of knowledge and stimulating demand for agroecological products, implicitly contributing to reducing the gap between attitudes and behaviors.

Specifically, the proposed measures (Figure 2) include the development of economic instruments, such as subsidies, grants and tax incentives, aimed at reducing financial barriers and supporting the transition to agroecological practices. In parallel, the implementation of environmental regulations and standards, including product certification and reducing the use of chemical inputs, contributes to increasing transparency and consumer confidence in the market.

Also, differentiated policies, adapted to the different types of farmers and the specificities of the rural and urban environment, can increase the efficiency of interventions and ensure a fair distribution of benefits.

Market development, through the promotion of local products, clear labelling and the stimulation of sustainable consumption, plays an essential role in transforming potential demand into actual consumer behavior. The integration of these measures into a coherent public policy framework, together with investments in education, innovation and knowledge transfer, can lead to a significant increase in the adoption of agroecological practices. Thus, the relationship identified in the conceptual model – according to which knowledge and perceptions influence behavior, and barriers limit it – is also confirmed at the level of public policy intervention, where the combination of education, economic incentives, regulations and market development becomes essential. In conclusion, the promotion of agroecology does not depend exclusively on the existence of a favorable demand, but on the capacity of

the institutional system to transform this demand into effective behaviors, through integrated policies that reduce barriers and strengthen information and economic incentive mechanisms.

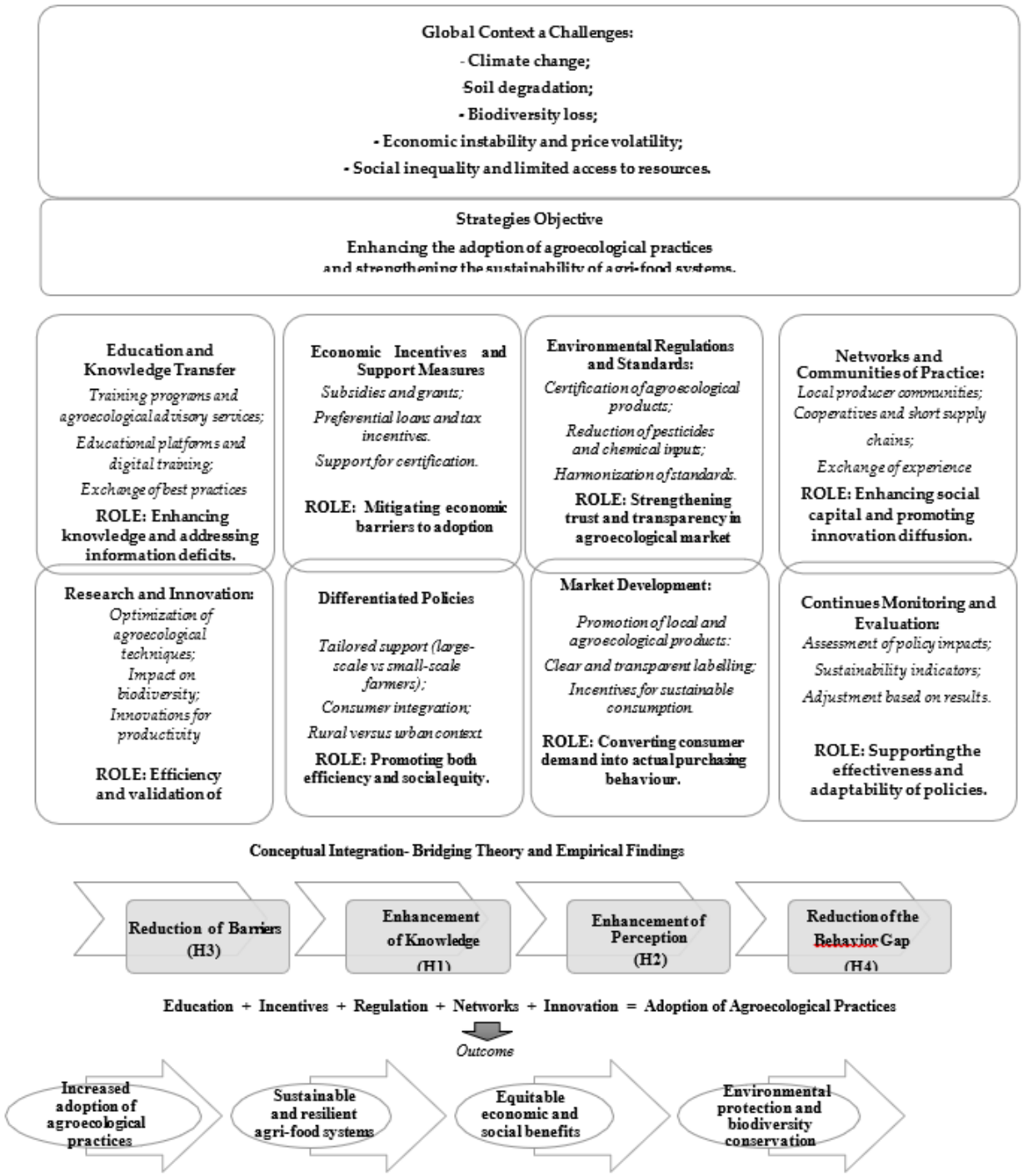

Fig. 2. Policy recommendations for supporting Agroecology
Source: Authors' conception.

Study Limitations: The study presents a series of limitations that must be considered when interpreting the results. First, the use of non-probabilistic sampling method causes the research results to reflect rather the trends of the analyzed sample and limit the possibility of generalizing the conclusions to entire population.

Second, small sample size may influence the robustness of the statistical analyses and the power of the applied tests. In addition, the data collected are based on self-reporting,

which may introduce perception errors or social biases, especially in the context of assessing sustainable behaviors. Also, the cross-sectional nature of the research does not allow for the establishment of firm causal relationships between variables, but only the identification of statistical associations. In this context, future research could use larger samples and probabilistic sampling methods, as well as advanced econometric models or longitudinal analyses, to deepen causal relationships and validate the results obtained.

CONCLUSIONS

This study analyzed through a coherent conceptual model consumer demand for agroecological products from the perspective of perceptual, motivational and economic factors.The results show the existence of important development opportunities of the agroecological products market, supported by positive perceptions and a high willingness to pay. Consumers demonstrate strong interest in agroecological products, which are perceived as healthier and safer compared to conventional alternatives. The willingness to pay a premium price is significant and is mainly determined by the perceived health benefits, confirming the role of perceptual factors in shaping economic behavior. However, the results highlight a low level of knowledge of agroecology and its specific techniques, which limits the adoption of sustainable behaviors. At the same time, information barriers and uncertainty regarding the effectiveness of agroecological practices represent the main obstacles to their implementation. A central finding of the study is the identification of a significant gap between favorable attitudes and actual consumer behaviors, confirming the existence of the "attitude–behavior gap." This discrepancy highlights that positive intentions do not automatically translate into actual behaviors, as they are influenced by contextual factors and external constraints. The statistical results confirm the existence of significant associations between socio-demographic variables and the level of familiarity ($p < 0.05$), as well as between health perceptions and willingness to pay ($p < 0.01$). The intensity of these relationships is moderate, suggesting relevant but not dominant effects. Barriers also significantly influence adoption behavior ($p < 0.01$), confirming their role as major limiting factors. Overall, the results validate the proposed conceptual model and highlight that the transition to agroecology is not limited by the lack of demand, but by cognitive, informational and institutional factors. Therefore, the development of agroecological systems requires an integrated approach, combining educational, economic and public policy interventions.

The results of this study converge with complementary analyses conducted within the same research program. While farmers, hobby gardeners and active growers show relatively high rates of using agroecological practice, their willingness to pay a premium for agroecologically produced food tends to increase with proximity to production and direct knowledge of its costs (Ciceoi et al., 2026) [2]. The present study demonstrates that end consumers, who are furthest from production, exhibit strong positive attitudes and high stated willingness to pay, yet remain limited by informational barriers and low familiarity with agroecology as a distinct concept. Taken together, these parallel findings converge on a single policy implication: agroecological market development requires simultaneous investment on both sides, building consumer knowledge and economic confidence while reducing structural and financial barriers for producers. Neither demand-side nor supply-side interventions alone are sufficient.

In this sense, transforming consumer interest into sustainable behaviors depends on reducing informational barriers, increasing access to knowledge and creating a favorable institutional framework capable of stimulating both the supply and demand for agroecological products.

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FROM WASTE TO VALUE: ADDRESSING FOOD LOSS IN THE REPUBLIC OF MOLDOVA

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Abstract

The study aims to analyse food loss and food waste in the Republic of Moldova, with reference to both their impact on food security and sustainable development. Information was collected through the analysis of statistical and documentary sources from FAO, Eurostat, the Ministry of Agriculture of the Republic of Moldova, the World Bank, UNDP, as well as scientific literature. Data availability in the period between 2019 and 2025 was a concern for the analysis. The primary indicators were food waste volume, food waste per capita, economic losses, and distribution of food loss across the supply chain. Some of the research methods used included comparative analysis, statistical analysis, and document analysis. The results showed that in the Republic of Moldova the waste of food constitutes a problem of economic, social, and environmental dimensions. Every year around 180,000 tons of food goes to waste, more than 70 kilograms per person. Food waste has its greatest effect on food security and household budgets. The food waste problem is caused by inefficiency of the food supply chain, with about 40% of the waste coming from households. The remainder occurs during the period of production, processing, storage, and distribution. In Moldova, total economic value of wasted food is greater than 19 billion MDL each year. In addition, only a limited proportion of surplus food is redistributed to vulnerable population groups. High levels of food waste are mainly associated with inefficient consumption patterns, the limited institutional coordination between local authorities and national food waste management policies. Therefore, reducing food waste requires a multipronged approach based on public awareness campaigns, improved storage and transport infrastructure, stronger food prevention and redistribution measures, and enhanced collaboration between public authorities and private stakeholders.

***Key words*:** *food waste, food loss, Republic of Moldova's sustainable development, food security*

INTRODUCTION

As reported by the United Nations [30], the global population reached approximately 8.1 billion in 2024 and is projected to grow further, placing escalating strain on food systems at the global level. Such demographic trends will eventually demand the availability of safe and abundant food, a dilemma further compounded by the declining natural resources, climate change adversely impacting crop yield, and increasing threats to food safety [22]. To overcome these challenges, sustainable strategies must be defined to secure food and satisfy public needs while preventing excessive waste [31], [25]. Not only can such strategies ensure that food production is equitable and profitable, but they also must reduce food loss and waste at all stages of the supply chain [16], [27]. Losses and wastes related to food throughout the agri-food chain should be treated as a serious threat to food security not only during processing and distribution but also in households [16, 18]. Recent studies have shown that in developed countries, higher levels of food loss and waste are generated at household level than during agro-industrial stages [16], [19], [27]. In the Republic of Moldova, food waste is also a critical issue, not only because it decreases access to food, but also because it leads to environmental degradation due to the emission of greenhouse gases (causing around 6% of total emissions), the inefficient use of natural resources, and serious economic losses [19], [27]. A new law addressing the reduction of food loss and waste was introduced in 2022, bringing national policies in line with the recommended framework of the FAO [15]. Food loss and food waste occur at every stage of the supply chain, which can lead to the poor management of resources, unsustainable consumption behaviour or unreasonable purchases [6]. Agri-food waste originates from agricultural processes and food

processing activities along with loss of vegetable residues: fruits and vegetables of poorer quality, peels or other plant compounds and waste caused from processing plants [1], [2]. Unmanaged agricultural residues, as well as food industry residues that produce waste products, break down and emit potent greenhouse gases like methane (CH_4) and nitrous oxide (N_2O), which is significantly more damaging to average global temperatures than carbon dioxide (CO_2) [17].

Furthermore, poor handling of such wastes results in the loss of valuable components that may be recovered via composting or anaerobic digestion [1], [3]. In recent years, the reduction of FLW has become a major concern in European countries, a direction also progressively followed by the Republic of Moldova. The European Green Deal and the Circular Economy Action Plan promote the reduction of biodegradable waste disposal in landfills and encourage composting and recycling practices. Obedience of these rules opens opportunities to funding European Union project programmes like LIFE, Horizon Europe and the Eastern Partnership for funding modern waste management projects [5], [9, 10], [11].

Principal Causes of Food Waste

Food waste results from a complex combination of interrelated factors acting simultaneously across different stages of the food supply chain. These factors include consumer behaviour, inefficiencies in storage and transport infrastructure, agricultural and climatic constraints, retail practices, and the limited development of redistribution mechanisms. A systematic understanding of these causes is essential for designing effective intervention measures aimed at reducing food loss and waste.

At household level, food waste is predominantly determined by three distinct behavioural patterns: deficient purchase planning (over-buying, especially under promotional influence), excessive food preparation, particularly during social events and traditional holidays, and the frequent misinterpretation of expiry labels, where the "best before" date is often confused with the "use by" date, leading to the disposal of food that is still safe for consumption [6], [16]. Inefficiencies in the food supply chain represent another important cause of food loss and waste in the Republic of Moldova. Moldova's infrastructure remains inadequate in relation to the current complexity of market demands. The limited network of modern cold storage facilities causes a significant proportion of agricultural production, particularly fruits and vegetables, to deteriorate before reaching consumers. This situation is further aggravated by a fragmented and costly transport network [3].

Agricultural and climatic factors also contribute significantly to food loss and waste in the Republic of Moldova. Climate change represents an increasingly serious threat to the stability of agricultural production. Episodes of drought, late frost, and hail have affected harvests over consecutive years, generating substantial post-harvest losses. In addition, limited irrigation capacity and the continued use of traditional production technologies increase the vulnerability of the agricultural sector to meteorological risks [22].

Commercial standards and retail behaviour represent additional factors contributing to food waste generation. Products are frequently rejected by major distribution networks on purely aesthetic criteria such as size, shape, or colour, even when they remain perfectly edible. At the retail level, deliberate overstocking practices aimed at avoiding empty shelves often generate products that expire before being sold [4], [23].

Limited redistribution mechanisms also contribute to the persistence of food waste in the Republic of Moldova. The formal food redistribution system, including food banks and donation channels, remains insufficiently developed. Currently, less than 5% of surplus food is recovered through organised redistribution systems, reflecting both institutional deficiencies and the absence of adequate fiscal incentives for food donors [19]. The purpose of this paper is to analyse the magnitude, determinants and socio-economic implications of food loss and food waste in the Republic of Moldova, to assess their impact on food security and sustainable development, and to identify feasible

intervention measures for reducing waste through redistribution, infrastructure modernisation, circular economy approaches and policy alignment with European standards.

MATERIALS AND METHODS

The study was based on documentary and statistical research methods using secondary data obtained from both international and national institutions. The main sources of information included reports and databases provided by FAO, Eurostat, the Ministry of Agriculture of the Republic of Moldova, the Ministry of Environment, UNDP Moldova, the World Bank, as well as peer-reviewed scientific literature. The materials analysed included official statistical reports, policy documents, scientific publications, institutional databases, and national legislative documents related to food loss and food waste. The reference period covered mainly the years 2019–2025, depending on data availability, while the case study concerning the Food Bank of Moldova focused on the comparative analysis of the years 2019 and 2023. Several research methods were applied, including comparative analysis, descriptive statistical analysis, document analysis, case study methodology, and prospective scenario analysis. The collected data were processed through comparative interpretation of national and international datasets, synthesis of secondary information, estimation of food loss quantities and associated economic impacts, as well as scenario modelling for the period 2025–2030.

The main indicators used in the study were:

- annual food losses (thousand tons/year);
- food waste per capita (kg/year);
- distribution of losses along the food supply chain (%);
- estimated economic losses (MDL/year);
- redistributed food quantities (tons/year);
- number of beneficiaries;
- food donation and waste reduction rates (%).

Food waste per capita was estimated using the following formula:

$$\text{Food waste per capita (kg/year)} = \frac{\text{Total annual food waste (kg)}}{\text{Population}}$$

The economic losses were calculated with respect to the market values of wasted food products and the estimated institutional losses present.

RESULTS AND DISCUSSIONS

Dimension of the Problem: Data and Statistics

At a global level, there are many organisations that carry out programmes to reduce food losses and waste, offering advisory efforts and financial assistance. Among the most important international initiatives are the FAO Save Food programme, the UNEP Think.Eat. Save campaign, and the World Bank agri-modernisation support programmes [20], [24], [28]. The European Union provides funding and expertise on circular economy programmes in partner and neighbouring countries under the Green Deal and Farm to Fork strategies [10], [11]. The scale of food waste in the Republic of Moldova can be comprehensively understood through comparative international analysis. Table 1 synthesises the principal quantitative and financial indicators, contextualising the country within the European and global framework. Notwithstanding that the per capita waste reported by the Republic of Moldova is lower than the average for the European Union, the socio-economic impacts remain considerably more severe in relative terms [35].

Table 1. Comparative indicators of food waste: Republic of Moldova vs. EU and global level

Indicator	Republic of Moldova	EU Average	Global Average
Total annual food losses (thousand tons)	~180 thousand tons	—	—
Per capita food losses (kg/year)	~70	~88	~121
Estimated annual economic losses (MDL)	>19 billion	—	—

Source: Authors' synthesis, based on data from the Ministry of Agriculture of the Republic of Moldova (2023) [20], Eurostat (2023) [13], UNEP FAO Food Waste Index Report (2021) [29].

This situation is mainly associated with the reduced purchasing power of households, increased income vulnerability, and high sensitivity to food price fluctuations. In a context where a significant proportion of the population faces economic vulnerability and food insecurity, even relatively low levels of food waste represent substantial financial and nutritional losses. As such, food waste in Moldova should not be evaluated only in terms of numbers, but in terms of its social and economic implications, with special regard to the situation that is faced by the country's most vulnerable populations such as low-income households, pensioners, and large families. Further, inefficient food use increases costs on household finances and hampers the means to guarantee the stable supply of adequate nutrition. Therefore, reducing food waste may contribute to improving food security and strengthening social resilience.

In the Republic of Moldova, food waste has important socio-economic implications. In a context characterised by food insecurity and economic vulnerability, reducing food waste could improve resource efficiency, strengthen food security, and contribute to social resilience. These aspects reveal the contradiction between the agricultural potential of the country and the existing inefficiencies in food production, distribution, and consumption systems.

Distribution of Food Losses Across the Supply Chain

Analysis of food losses across the supply chain is essential for identifying the main intervention points. Contrary to the popular perception that waste occurs exclusively at the consumer level, empirical data reveal a shared responsibility — with varying intensities — at all stages of production and consumption. Table 2 highlights the main distribution patterns of food losses across the supply chain in the Republic of Moldova.

Households remain the main source of food waste, accounting for approximately 40–45% of total losses, reflecting consumer behaviour patterns, nutritional education levels, and household budget management practices.

Table 2. Distribution of food losses by supply chain segment in the Republic of Moldova

Supply chain segment	Share (%)	Est. quantity (thousand tons/year)	Main causes
Households (consumers)	40–45%	72–81	Over-purchasing, misreading expiry dates, excess cooking
Agricultural production	20–25%	36–45	Post-harvest losses, adverse climate conditions
Processing industry	~20%	~36	Strict quality standards, technical failures
Distribution and retail	~15%	~27	Aesthetic rejection, overstocking, inadequate transport
Total	100%	~180	—

Source: Authors, based on estimates derived from FAO (2019) [14], World Bank — Moldova Report (2022) [34], and available national data.

Agricultural production losses (20–25%) highlight the urgent need for the modernisation of storage and transport infrastructure.

The processing and distribution/retail sectors collectively account for around 35% of total losses, indicating systemic deficiencies in quality control and inventory management.

Food losses occur most frequently in the early stages of the food chain (production, post-harvest, and processing) and occur primarily due to technological limitations, logistics issues, and weather-related factors.

In contrast, food waste is generated predominantly at the retail and household levels, being influenced by purchasing behaviour, consumer habits, and market-related factors [26].

Case Study: The Food Bank of Moldova

The case of the Food Bank of Moldova illustrates the potential of food waste reduction through organised redistribution initiatives.

The project was launched in 2019, inspired by the European food bank model (FEBA) [8], with the objective of collecting surplus food from producers, processors and retailers and redistributing it to vulnerable persons through partner organisations [21]. The evaluation methodology relied on the collection of

quantitative data on redistributed food volumes, beneficiaries reached, partner companies engaged, and the economic value of saved food regarding volumes of food redistributed, beneficiaries reached, partner companies engaged, and the economic value of saved food. Data were collected through the organisation's periodic reports and validated through surveys administered to beneficiaries and donors. The comparative reference period was 2019 (inception phase) versus 2023 (project maturity phase) (Table 3).

Table 3. Comparative results of the Chisinau Food Bank initiative (2019 vs. 2023)

Parameter evaluated	Before (2019)	After (2023)
Food redistributed (tons/year)	Negligible	~450 tons
Number of beneficiaries	—	~12,000 persons
Partner donor companies	0	>35 companies
Waste reduction from partners (%)	0%	~18% of surplus
Value of food saved (MDL/year)	—	~4.5 million MDL
Beneficiary satisfaction rate	—	92% (survey-based)

Source: Illustrative data based on European food bank models; Eurostat (2022) [12], European Food Banks Federation – FEBA (2023)[8], UNDP Moldova (2022) [32].

One of the most significant developments was the increase in redistributed food volumes, which have gone from virtually negligible levels in 2019 to approximately 450 tons per year in 2023.

This substantial increase can be explained by the operational consolidation of the organisation, including logistics, cold storage, transport capacity, and the expansion of the donor partner network. These results suggest the existence of a considerably larger volume of surplus food that is not yet integrated into redistribution systems.

Approximately 12,000 beneficiaries were supported through the programme, highlighting its important social impact.

The redistribution of approximately 450 tons of food provided an average of around 37 kg per beneficiary annually, the initiative has been a valuable addition to the nutritional basket of vulnerable groups – large families, elderly people with low incomes, and homeless people.

The 92% beneficiary satisfaction indicates the relevance and quality of the service available.

The participation of more than 35 private companies as food donors demonstrates the increasing involvement of the business sector in food redistribution activities.

Surplus food redistribution is increasingly perceived not only as a social responsibility initiative, but also as an economically beneficial practice when supported by adequate fiscal incentives.

However, the absence of a clear legislative framework and adequate fiscal incentives continues to limit the expansion of food donation systems [19].

Such findings are consistent with similar studies conducted in other Eastern European countries [6], [16].

A major limitation of this case study is that the 450 tons redistributed accounts for less than 0.3% of the estimated 180,000 tons that are wasted in Moldova every year.

Although the initiative has important social and economic benefits, the redistributed quantities still represent a very small proportion of the estimated annual food waste generated in Moldova.

This highlights the need to expand redistribution systems through stronger institutional support and dedicated public policies.

From Waste to Value: Solutions and Recommended Measures

Effective reduction of food waste requires an integrated approach involving individual behaviour, food system infrastructure, and the institutional and legislative framework. Table 4 synthesises the main domains of intervention, recommended measures, responsible actors, and estimated impact.

Table 4. Integrated framework of measures for combating food waste in the Republic of Moldova

Domain	Recommended measure	Responsible actor	Estimated impact
Education	National awareness campaigns on food waste	Government, NGOs, schools	10–15% reduction in household waste
Infrastructure	Investment in cold storage and specialized transport	Private sector, EU funds	20% reduction in post-harvest losses
Redistribution	Expansion of food banks and digital platforms	NGOs, local authorities	Recovery of 15,000–20,000 tons/year
Circular economy	Conversion of food waste into compost, biogas, and animal feed	Private sector, authorities	Valorisation of 30,000+ tons of waste
Legislation	Tax incentives for donors and national anti-waste strategies	Parliament of RM, Government	EU alignment; 40% increase in food donations

Source: Authors' elaboration, based on the EU Farm to Fork Strategy (2020) [1-], FAO Best Practices (2022) [15], and UNDP recommendations for Moldova [32, 33].

Prevention and education. Public awareness campaigns at national level are the most cost-effective means of reducing household waste generation. The successful cases of France, Denmark, and Germany serve to illustrate that well-designed programmes can lead to a 10–20% decrease in food waste produced within 3–5 years [27]. In Moldova, such campaigns should be incorporated into school curricula, social assistance programmes, as well as public communication activities.

Infrastructure modernisation. Investment in cold storage, specialised transport, and processing capacities is essential for reducing post-harvest losses. European funds available through the Republic of Moldova's association agreements with the EU can be used for co-financing these investments, subject to adequate project management and clear allocation priorities [10], [11], [34].

Circular economy and energy recovery. Processing food waste into resources — compost in agriculture, animal feed or biogas for energy production — represents an important opportunity for resource valorisation and environmental protection. The development of separate collection systems for organic waste in major urban areas could reduce landfill volumes while supporting composting and anaerobic digestion activities, with positive effects for the agricultural sector [1], [3], [17].

Prospective Evolutionary Scenarios (2025–2030)

To evaluate possible medium-term developments in food waste reduction, four prospective scenarios for the period 2025–2030 were developed according to the intensity of interventions and the level of financial resources invested (Table 5).

The analysis of the four scenarios highlights several important implications for policy makers. In the absence of significant systemic interventions (baseline scenario), food waste reduction will remain limited — approximately 5% — and insufficient to address the scale of the problem.

Table 5. Future Scenarios for Food Waste Reduction in the Republic of Moldova (2025–2030)

Scenario	Estimated reduction (%)	Tons saved/year	Required investment (MDL)
Baseline (no major interventions)	5%	~9,000	Minimal
Moderate (education + redistribution)	20%	~36,000	50–80 million MDL
Ambitious (integrated measures)	40%	~72,000	150–250 million MDL
Optimal (full EU alignment by 2030)	50%	~90,000	300+ million MDL

Source: Authors' projections based on the European Commission food waste reduction targets for 2030, the Farm to Fork Strategy, and comparative evidence from Central and Eastern European countries. [7]

The moderate scenario, based on the combination of food education measures and the expansion of redistribution systems, could generate an estimated 20% reduction in food waste with relatively accessible investments (50–80 million MDL). Although the ambitious and optimal scenarios require considerably higher financial resources, they could support Moldova's alignment with European objectives regarding food waste reduction by 2030 [10].

CONCLUSIONS

Food waste in the Republic of Moldova represents a major national challenge, estimated at approximately 180,000 tons annually, equivalent to around 70 kg per capita. The study showed that households are the main contributors to food waste, accounting for approximately 40–45% of total losses, mainly as a result of consumer behaviour and inefficient consumption practices. The research also highlighted significant losses in agricultural production and post-harvest activities (20–25%), caused by limited storage capacity, logistical deficiencies, and the limited use of modern preservation technologies.

These findings indicate the need to improve post-harvest management and food distribution systems. The study also confirmed that the application of circular economy approaches, including composting, food redistribution, and biogas production, could reduce the environmental impact of food waste while improving resource efficiency and food recovery.

Additional priority measures for improving food waste management in the Republic of Moldova include the modernisation of redistribution infrastructure, the improvement of legislative implementation, the development of educational and awareness programmes for producers and consumers, and stronger cooperation between public authorities, private companies, and academic institutions.

Overall, the study demonstrates that effective food waste reduction in the Republic of Moldova requires an integrated approach based on infrastructure development, legislative support, education, and institutional cooperation to promote sustainable resource management and long-term environmental sustainability.

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SOIL HEALTH IN RURAL ENVIRONMENTS: DRIVERS OF DEGRADATION AND CONSERVATION STRATEGIES FOR SUSTAINABLE AGRICULTURE

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Abstract

Soil health refers to the capacity of soil to function as a living system, sustaining the organisms and ecosystems that depend on it. This paper synthesizes current scientific literature on the main drivers of soil degradation in rural environments, with a particular focus on Romania and Eastern Europe. Major degradation processes include erosion, compaction, organic matter depletion, salinization, acidification, pollution, and biological degradation resulting from inappropriate agricultural practices. These processes adversely affect soil structure, nutrient cycling, water regulation, and microbial activity. Furthermore, the study highlights conservation strategies aimed at improving soil health and promoting sustainable agroecosystems, such as conservation agriculture, crop rotation, organic amendments, and efficient water use. The reviewed case studies illustrate both soil vulnerability and the beneficial effects of regenerative agricultural practices. Integrated soil management and coordinated actions are essential to ensure long-term agricultural sustainability.

Key words**:** *pesticides, soil quality, soil health, ecosystem services, sustainable agriculture*

INTRODUCTION

Soil health is the vital foundation of agricultural and rural systems, defined as its ongoing ability to support the productivity of plants, animals, and people, while maintaining air and water quality (Stott, 2019; Mponela et al., 2025; Topa et al., 2025) [49, 29, 51]. Soil is not only a medium for crops, but also a finite and non-renewable resource on a human scale, providing almost all of the world's food resources and hosting approximately 60% of total terrestrial biodiversity (Dragović & Vulević, 2021; Topa et al., 2025; Arias-Navarro et al., 2024; Mishra & Dhar, 2004) [13, 51, 4, 28]. This multifunctionality of soil, which includes regulating nutrient cycles, storing carbon, and purifying water, is essential for addressing current existential challenges such as food security and climate change mitigation (Lal, 2011; Kopittke et al., 2025; Rinot et al., 2019; Bezner et al, 2021) [18, 16, 43, 7]. However, the constant pressure to increase production to meet the demands of a growing global population has led to the adoption of intensive and unsustainable agricultural practices (Topa et al., 2025) [51]. The widespread and excessive use of synthetic fertilizers and pesticides, the practice of monoculture, deep tillage and aggressive management have triggered a growing crisis of soil degradation, felt globally (Kumar et al., 2025) [17]. Its effects are reflected in processes such as erosion, compaction, salinization and a drastic decrease in organic matter, processes that affect the resilience of ecosystems and the ability of soil to function as a natural filter of the environment. (Popescu et al., 2022; Kopittke et al., 2025; Arias-Navarro et al., 2024) [38, 16, 4].

At the regional level, Romania and Eastern Europe face significant pressure on soil resources, being recognized as areas vulnerable to multidimensional degradation processes and incipient desertification trends (Popescu et al., 2022; Prăvălie et al., 2025; Rusu et al., 2019) [38, 39, 44]. In Romania, a considerable proportion of agricultural land is affected by water erosion, which manifests itself in many forms, leading to substantial annual losses of fertile soil, with direct effects on agricultural productivity and the functioning of rural ecosystems (Petrescu-

Mag et al., 2020; Ovreiu & Nedelcu, 2015; Mircea et al., 2010) [37, 33, 27]. Data from recent spatial inventories also indicate a worrying increase in soil compaction, which affects a significant part of the national agricultural area, while aridification processes and nutrient imbalances amplify the instability of the rural landscape (Prăvălie et al., 2025; Alnaimy & Elrys, 2025) [39, 1]. These trends have been accentuated in the post-communist period by excessive fragmentation of land ownership and a return to traditional slope-oriented, "uphill-downhill", cultivation practices, which favor surface runoff and nutrient loss (Lup et al., 2017; Niacsu et al., 2022) [23, 30].

In this context, this review article aims to provide an integrated synthesis of recent scientific literature on the main determinants of soil degradation in rural areas, with a particular focus on the pedoclimatic and socio-economic conditions in Romania and Eastern Europe. The paper seeks to identify the biophysical mechanisms underlying degradation processes and to analyse conservation and restoration strategies, including conservation agriculture, diversified crop rotations, and the use of organic amendments able of supporting the sustainable functioning of agroecosystems. The ultimate goal is to provide a solid information framework for decision-makers and farmers, supporting the transition to integrated soil management aimed at protecting soil capital for the benefit of future generations.

MATERIALS AND METHODS

The selection of the specialized literature for this study was carried out through a systematic approach, using recognized academic databases, such as Google Scholar, Scopus and Web of Science. The article search process was based on the following keywords: “soil health,” “soil degradation,” “soil conservation,” “sustainable agriculture,” and “rural environments.” The evaluation process included the analysis of articles in peer-reviewed journals, to identify the most current and relevant contributions in the field. Most articles were selected from the period 2010-2025, but relevant articles from the previous period were also included. In this research, we adopted an interdisciplinary perspective, integrating data from soil science, agronomy and environmental management with social perspectives on farmers’ perceptions of soil functions, thus ensuring a holistic approach to the analyzed topic.

RESULTS AND DISCUSSIONS

Soil health in rural agricultural systems

The modern concept of soil health goes beyond the simple notion of fertility, being defined as a state of balance that allows the soil to function as a living system (Petrescu-Mag et al., 2020; Topa et al., 2025) [37, 51]. This capacity is fundamental for maintaining plant and animal productivity, ensuring water and air quality, and supporting the health of organisms (Kumar et al., 2025; Topa et al., 2025) [17, 51]. In rural environments, healthy soil is not only a support for agricultural crops, but also the foundation of food security and ecosystem resilience (Petrescu-Mag et al., 2020; Lal, 2011; Bezner et al., 2021) [37, 18, 7].

Soil health results from the complex and synergistic interaction of three main pillars: physical, chemical, and biological properties (Lal, 2011; Hartmann & Six, 2022) [18, 14].

Soil structure is the basic physical component that supports the functioning of ecosystems, defined by the stability of aggregates: structural units formed by the association of mineral particles with organic matter. Their stability controls soil porosity, water infiltration, and gas exchange, while also helping to protect organic matter and reduce erosion. Organic matter is the main integrator of soil functions, its quantity and composition influencing cation exchange capacity, nutrient retention, and pH stability. The chemical fertility of the soil depends both on the presence of macronutrients and their availability, which is biologically mediated. Microbial activity and soil biodiversity complement this functional system. The soil hosts a high diversity of microorganisms and edaphic fauna that support biogeochemical

cycles, the mineralization of organic matter, and the maintenance of its physical structure (Stagnari et al., 2009; Osman, 2014; Hartmann & Six, 2022; Topa et al., 2025; Arias-Navarro et al., 2024; Mishra & Dhar, 2004) [47, 31, 14, 51, 4, 28].

The link between soil components and societal benefits is expressed through ecosystem services, classified into provisioning, regulating, supporting, and cultural services. Agricultural productivity is the most tangible provisioning service, supplying almost all of the food consumed worldwide. It depends directly on root depth, nutrient reserves, and available water capacity. Nutrient cycles are a vital supporting service, where microorganisms (such as nitrogen-fixing bacteria or mycorrhizal fungi) transform unavailable forms of elements into plant food. Water regulation and climate resilience are also fundamental services, with healthy soils acting as a natural sponge that absorbs rainfall and reduces the risk of flooding and erosion through efficient infiltration. Furthermore, soil plays a crucial role in carbon sequestration, contributing to climate change mitigation by storing massive amounts of organic carbon that would otherwise be released into the atmosphere as CO_2 (Rinot et al., 2019; Arias-Navarro et al., 2024; Kopittke et al., 2025; Lal, 2011; Kumar et al., 2025; Hartmann & Six, 2022; Palm et al., 2014) [43, 4, 16, 18, 17, 14, 34,].

Therefore, soil structural integrity determines resource flows, which support biodiversity, and this biodiversity governs the metabolic processes that provide the ecosystem services indispensable to sustainable agriculture (Mishra & Dhar, 2004) [28].

The main factors of soil degradation in rural environments

Soil degradation in agricultural environments is the result of the interaction between physical, chemical, and biological processes, which amplify each other and lead to the loss of ecosystem functionality. (Rusu et al., 2019; Lal et al., 1989) [44, 20].

Physical degradation is often the starting point, as damage to the soil structure affects the water regime and aeration. Erosion, whether water-borne, wind-borne, or induced by agricultural practices, is one of the most serious threats and results in the removal of the fertile topsoil. This often exceeds the natural capacity for regeneration, especially in hilly regions. At the same time, soil compaction, associated with intensive mechanization, reduces porosity, limits water infiltration and root development, and leads to significant declines in agricultural productivity. Intensive agricultural practices, such as deep plowing, accelerate these processes by destroying soil aggregates and fungal networks and promoting the formation of surface crusts. (Saljnikov et al., 2022; Berhe, 2019; Kopittke et al., 2025; Mponela et al., 2025; Osman, 2014; Hartmann & Six, 2022) [45, 6, 16, 29, 31, 14].

Chemical degradation refers to changes in soil composition that negatively affect the fertility and stability of ecosystems. The acidification process, exacerbated by the long-term application of mineral fertilizers and the loss of basic cations through leaching, leads to a decrease in nutrient availability and an increase in the mobility of potentially toxic elements. The phenomena of salinization and alkalization, resulting from improper irrigation and inadequate drainage, restrict the ability of plants to absorb water, especially in lowland areas. In intensive agricultural systems, nutritional imbalances and the depletion of natural reserves of fertilizing elements are common, given that the export of biomass is not counterbalanced by the return of organic matter to the soil. At the same time, contamination with heavy metals and pesticide residues, which often exhibit synergistic effects, represents a persistent source of pollution with a negative impact on non-target organisms and on population health, through the food chain (Tetteh, 2015; Saljnikov et al., 2022; Lal et al., 1989; Arias-Navarro et al., 2024; Prăvălie et al., 2025; Kopittke et al., 2025) [50, 20, 4, 39, 16].

Biological degradation, although less visible, is an essential component of the decline in soil quality and is manifested by the decrease in microbial biomass, enzymatic activity and soil biodiversity. The intensive use of chemicals and simple cropping systems due to their low cost disrupts the soil microbiome and,

therefore, generates dysfunctions in biogeochemical cycles and increased susceptibility to the action of pathogens. These phenomena are aggravated by the loss of organic matter, which leads to the destabilization of soil structure, the reduction of water retention capacity, and the decrease of the resistance of agroecosystems to climatic fluctuations. Monoculture intensifies biological degradation by restricting the diversity of ecological niches and by the inefficient use of natural resources (Hartmann & Six, 2022; Saljnikov et al., 2022; Popescu et al., 2022; Kopittke et al., 2025; Arias-Navarro et al., 2024; Kumar et al., 2025; Chaudhari et al., 2021; Rinot et al., 2019; Stagnari et al., 2009; Otiman, 2008) [14, 45, 38, 16, 4, 17, 9, 43, 47, 32].

The impact of soil degradation on agricultural productivity and ecosystem functioning

Soil degradation can be defined as a change in the health of the soil, which reduces its capacity to provide goods and services to those who depend on it. This has direct and profound consequences for agricultural productivity, production stability and the provision of ecosystem services, with major implications for food security and human health (Tetteh, 2015; Arias-Navarro et al., 2024) [50, 4].

One of the most visible effects is the reduction in agricultural yields, caused by the loss of the fertile superior soil layer through erosion, soil compaction, and chemical changes such as acidification. The removal of this superficial layer, rich in nutrients and organic matter, restricts plants' access to water and essential elements, prevents normal root development and can increase the toxicity of certain elements, which reduces both the productivity and profitability of agricultural systems. At the same time, the gradual depletion of nutrient reserves, in the absence of an adequate supply of organic matter, causes a decrease in the nutritional quality of agricultural products and continuous production losses (Kopittke et al., 2025; Ovreiu & Nedelcu, 2015; Costantini et al., 2018; Kopittke et al., 2025; Osman, 2014; Lal, 2011; Saljnikov et al., 2022; Li et al., 2009; Bezner et al., 2021) [16, 33, 10, 16, 31, 18, 45, 21, 7].

Degraded soils lose their ability to act as a natural buffer against climate variability, making agricultural production increasingly unstable, especially in rainfed systems. Low organic matter availability reduces water storage capacity and water use, and increases crop vulnerability to drought and alternating hydrological extremes. As a result, unsustainable agricultural production has increased in the long term, increasing economic risks for farmers and agri-food chains (Kumar et al., 2025; Lal, 2011; Li et al., 2009; Soares et al., 2023; Tóth et al., 2023) [17, 18, 21, 46, 52].

Beyond its impact on crop production, soil degradation compromises essential ecosystem services. Degraded soils lose their ability to regulate the climate, transforming from carbon sinks into net sources of greenhouse gas emissions. Chemical degradation nullifies the soil's filtering function, facilitating the transfer of agricultural pollutants to groundwater and surface water and affecting the quality of water resources. At the same time, the loss of soil biodiversity reduces natural pest and disease control mechanisms, with indirect effects on human health through nutritional imbalances and exposure to contaminants mobilized in degraded soils (Kopittke et al., 2025; Mircea et al., 2010; Kumar et al., 2025; Arias-Navarro et al., 2024; Palm et al., 2014; Rinot et al., 2019) [16, 27, 17, 4, 34, 43]. Overall, soil degradation triggers a spiral of socio-economic decline, in which pressure on resources accelerates environmental degradation, encourages land abandonment, and generates economic losses and systemic risks to the stability of society (Pani, 2020; Ananda, & Herath, 2003) [35, 2].

Soil conservation and management strategies for sustainable agriculture

The transition from conventional agriculture, heavily dependent on chemicals and mechanization, to sustainable systems is essential to halt soil degradation and ensure long-term food security. Sustainable soil management involves the rational use of resources so that its physical, chemical, and

biological functions are maintained or improved, without compromising the ability of future generations to produce food (Popescu et al., 2022; Yunibandhu & Hallinger, 2025; Petrescu-Mag et al., 2020; Dragomir et al., 2024; Bezner et al., 2021; Stockdale et al., 2019) [38, 53, 37, 12, 7, 48].

A central pillar of this transition is conservation agriculture, which is based on reducing mechanical disturbance of the soil, maintaining permanent vegetation cover, and diversifying crop rotations. Limiting intensive tillage helps preserve soil structure, reduce erosion, and slow organic carbon loss. Adopting methods that involve minimal soil disturbance promotes aggregate stability and the functioning of underground biological networks. At the same time, covering the soil with plant residues or cover crops protects the surface from erosion, maintains moisture, and creates favorable conditions for microbial activity, while diversified rotations prevent nutrient depletion and reduce pest pressure (Chaudhari et al., 2021; Stagnari et al., 2009; Kumar et al., 2025; Topa et al., 2025; Prăvălie et al., 2025; Popescu et. al., 2022; Osman, 2014; Hartmann & Six, 2022) [9, 47, 17, 51, 39, 38, 31, 14].

Restoring soil health mainly requires increasing the organic matter content, which is considered the main integrator of soil functions (Raupp et al., 2024) [41]. Applying compost, manure, or vermicompost improves cation exchange capacity, water retention, and nutrient availability, while also stimulating biological activity. Reintegrating plant residues into the soil and using crops for green manure helps restore carbon stocks and reduce dependence on synthetic fertilizers. At the same time, diversifying production systems through agroecological practices, such as intercropping or agroforestry, optimizes resource use, enhances carbon sequestration and increases the resilience of agroecosystems to climate stress. In addition, establishing vegetated strips and buffer zones at the edges of cultivated areas promotes functional biodiversity, supporting pollination and biological pest control. (Kumar et al., 2025; Topa et al., 2025; Popescu et al., 2022; Angelova et al., 2013; Prăvălie et al., 2025) [17, 51, 38, 3, 39].

Water and salinity management, in turn, becomes a critical element in the context of climate change, as it is necessary to optimize infiltration and prevent salt accumulation in the root zone. Efficient irrigation systems, along with adequate drainage and the use of corrective amendments where necessary, can limit salinization and sodification processes (Tetteh, 2015; Osman, 2014; Lal, 2011; Popescu et al., 2022; Petrescu-Mag et al., 2020; Meena et al., 2023) [50, 31, 18, 38, 37, 26].

Overall, modern strategies emphasize that preventing soil degradation is much more economically and ecologically efficient than restoring already affected land, which requires very long periods for complete functional recovery (Stagnari et al., 2009; Lal, 2015; Hufnagel et al., 2020) [47, 19, 15].

Case studies and regional evidence from Romania and Eastern Europe

Eastern Europe, and Romania in particular, has high agricultural potential due to the existence of very fertile soils, such as Chernozems, Phaeozems, and Kastanozems, which are favorable for intensive agriculture (Arias-Navarro et al., 2024; Dragomir et al., 2024) [4, 12].

However, regional data indicate a heightened vulnerability of this soil capital, as a significant proportion of agricultural land is affected by water erosion, and recent spatial inventories confirm multiple pressures converging towards accelerated degradation (Petrescu-Mag et al., 2020; Prăvălie et al., 2025) [37, 39].

Recent studies based on multi-degradation indices have identified critical hotspots in the Romanian rural landscape, where the effects of natural factors are amplified by inadequate management. The Moldavian Plateau is a prime example, as erosion rates frequently exceed sustainability thresholds, while in the Curbură area of the Subcarpathians soil loss values are well above the natural capacity for regeneration. In the Western Plain, soil compaction is reaching alarming levels, and in the Romanian Plain and Dobrogea, accelerated aridification and declining

groundwater levels are exacerbating the instability of agroecosystems (Niacsu et al., 2022; Lup et. Al. 2017; Prăvălie et al., 2025; Alnaimy & Elrys, 2025) [30, 23, 39, 1]. At a broader regional level, similar processes are also reported in other Eastern European countries, such as Ukraine, where land degradation is amplified by other socio-political factors, mainly the recent armed conflict, which has introduced new forms of damage, such as heavy metal pollution from ammunition and extreme compaction caused by heavy military vehicles (Arias-Navarro et al., 2024) [4].

In Romania, the post-communist socio-economic transition contributed to the intensification of land degradation through excessive fragmentation of property and a return to traditional up-and-down slope cultivation practices, which promote surface runoff and soil loss. The intensive use of the mouldboard plough has led to the formation of compact impermeable layers, affecting water infiltration and the functioning of underground biological networks. These practices have also had negative consequences for agricultural biodiversity, reducing the diversity of spontaneously growing plant species on agricultural land and the overall stability of agroecosystems, including niche crops such as viticulture, where compaction and loss of chemical fertility have been associated with major declines in productivity (Niacsu et al., 2022; Popescu et al., 2022; Baude et al., 2019; Costantini et al., 2018) [30, 38, 5, 11].

In contrast to these trends, case studies from Romania and other Eastern European countries demonstrate that adopting regenerative and ecological practices can lead to the gradual restoration of soil health. Medium-term experiments indicate increases in humus content and productivity after transition periods, while technological innovations adapted to local conditions, such as no-till equipment, reduce compaction and energy consumption. Although conversion to ecological systems may involve initial production losses, the economic and ecological benefits become evident in the medium and long term. It is noteworthy that integrated strategies, such as strip cropping and the expansion of forest vegetation, have proven effective in reducing erosion and stabilizing slopes. Overall, this evidence indicates that although soil degradation remains an active and severe process in Romania and Eastern Europe, integrated management combining modern technology with agroecological principles offers a realistic path to long-term sustainability for rural communities (Manea et al., 2023; Popescu et al., 2022; Niacsu et al., 2022; Hartmann & Six, 2022; Mărin et al., 2025) [24, 38, 30, 14, 25].

Soil health indicators and monitoring approaches

Soil health assessment requires an integrated approach that goes beyond simply measuring agricultural productivity and focuses on its capacity to support essential ecosystem services. Given the complexity of the soil system and the high costs of comprehensive monitoring, the literature recommends the use of a minimum data set (MDS), consisting of indicators that are sensitive to management changes and relevant to key ecosystem processes (Rinot et al., 2019; Topa et al., 2025) [43, 51]. Physical indicators provide fundamental information on soil structure and water regime, including bulk density as a measure of compaction, aggregate stability as an expression of structural strength, infiltration and water retention capacity, and penetration resistance, which indicates the presence of impermeable layers that limit root development. The chemical component complements the assessment with data on long-term fertility and risks of imbalance or contamination. Soil organic carbon content is considered a central indicator due to its role in structural stability, fertility and buffering capacity. pH significantly influences nutrient availability and the mobility of toxic elements, while cation exchange capacity reflects the potential of the soil to retain and supply essential nutrients. Electrical conductivity is used to monitor salinization processes, and the level of available nutrients provides an insight into the current nutritional status of the soil. Biological indicators are considered the most dynamic and sensitive,

reflecting the functioning of the soil as a living system. Microbial biomass and soil respiration provide information on the intensity of metabolic activity and the state of microbial communities, while enzymatic activities associated with the carbon, nitrogen, phosphorus and sulfur cycles serve as early signs of deterioration or the success of measures to restore ecosystem functions. Analyses of microbial biodiversity and soil fauna, including the presence of earthworms, complement this functional perspective. Integrating biological indicators with physical and chemical indicators allows for early detection of degradation, before more stable structural or chemical changes become evident. To transform analytical data into operational information, assessment frameworks are used that convert indicators into interpretive scores (Reynolds, 2002; Stagnari et al., 2009; Angelova et al., 2013; Hartmann & Six, 2022; Rinot et al., 2019; Mponela et al., 2025; Prăvălie et al., 2025; Raghavendra et al., 2020) [42, 47, 3, 14, 43, 29, 39, 40].

These include the Soil Management Assessment Framework, which provides assessments adapted to local conditions and soil types, the Cornell Comprehensive Assessment of Soil Health, oriented towards practical applications at the farm level, the European LUCAS system, which allows for continent-wide trend analysis, and multi-degradation indices, used for the synergistic assessment of multiple pressures acting simultaneously on rural landscapes. (Arias-Navarro et al., 2024; Stott, 2019) [4, 49].

Challenges and opportunities for sustainable soil management

The transition to sustainable soil management in rural areas is a complex process shaped by economic, structural, cognitive, and political factors, which can act as both barriers and drivers of change. Although the long-term benefits of soil health conservation are well documented, the implementation of regenerative practices is often limited by short-term economic constraints and perceived financial risks. Adopting conservation-regenerative systems often involves significant initial investments in specialized technologies and transition costs associated with possible temporary declines in yields until agroecosystems stabilize functionally. Limited access to organic inputs and additional labor costs also reduce the feasibility of these practices, especially for small and medium-sized farms. (Kumar et al., 2025; Topa et al., 2025) [17, 51].

In Romania, these difficulties are amplified by the excessive fragmentation of land ownership resulting from post-communist restitution processes, which hinders the implementation of coherent large-scale conservation measures. The high degree of fragmentation has encouraged a return to slope-oriented cultivation practices, intensifying water erosion, while inadequate rural infrastructure contributes to the concentration of surface runoff and accelerated degradation of hilly land. An additional obstacle is limited access to specialized agricultural advice, with many extension systems still focusing predominantly on immediate productivity, with little attention paid to soil biological health and adaptation to climate change. This situation creates a gap between farmers' objectives, which are focused on short-term profitability, and public policies that focus on environmental protection and long-term sustainability (Niacsu et al., 2022; Petrescu-Mag et al., 2020; Buzatu et al., 2023; Mponela et al., 2025; Kumar et al., 2025) [30, 37, 8, 29, 17].

However, the current context offers significant opportunities for protecting and valorizing soil capital. New European legislative frameworks aim to harmonize standards for soil monitoring and resilience, and the Common Agricultural Policy provides financial support mechanisms for agroecological and organic practices. In the medium and long term, the transition to such systems can generate substantial economic benefits, which compensate for the initial costs. At the same time, farmer education, „citizen science" projects, and the development of precision technologies facilitate knowledge transfer and optimize resource use. Capitalizing on these opportunities depends on close collaboration between the scientific community, farmers,

and decision-makers as an essential premise for soil security and the long-term sustainability of rural systems. (Kopittke et al., 2025; Mponela et al., 2025; Arias-Navarro et al., 2024; Popescu et al., 2022; Dragomir et al., 2024; Otiman, 2008; Bezner et al., 2021; Păceșilă et al., 2025) [16, 29, 4, 38, 12, 32, 7, 36].

Future prospects and research needs

Although recent scientific advances have elucidated many of the mechanisms involved in soil degradation, translating this knowledge into effective integrated management policies still requires overcoming major gaps. The future of sustainable agriculture depends on the ability of research to evolve from isolated studies to systemic, interdisciplinary and regionally tailored approaches (Popescu et al., 2022; Prăvălie et al., 2025; Rinot et al., 2019) [38, 39, 43].

A major limitation in assessing the effectiveness of regenerative practices is the lack of data from long-term experiments, which are the only solid basis for quantifying organic matter dynamics and setting realistic carbon sequestration targets. Future research should focus on continuous monitoring systems based on repetitive and harmonised sampling, capable of capturing soil health trends over relevant time intervals. Standardizing sampling and analysis methodologies by defining a minimum set of indicators that are comparable across regions is essential for transforming scientific data into operational tools that are useful to farmers and decision-makers. (Saljnikov et al., 2022; Kumar et al., 2025; Arias-Navarro et al.) [45, 17, 4].

In Eastern Europe and Romania, there is a need to develop integrated studies that synergistically analyze the degradation processes acting simultaneously on the soil, such as erosion, compaction, and salinization, phenomena that have been insufficiently investigated at the national level. At the same time, new priority risks are emerging, including soil degradation associated with armed conflicts, characterized by heavy metal pollution and extreme compaction, as well as the impact of emerging contaminants, such as microplastics, pharmaceutical residues, and complex pesticide mixtures, on microbial biodiversity and ecosystem functionality. (Prăvălie et al., 2025) [39].

The approach to soil health must become deeply interdisciplinary, transcending the boundaries of classical agronomy and integrating economic and social dimensions. Future management strategies must include farmers' perspectives and local constraints, as the adoption of sustainable practices is conditioned by factors such as property structure, lease security, and economic viability. The development of econometric models that directly correlate soil health indicators with farm economic performance and ecosystem service provision is essential for the real assessment of soil capital. At the same time, progress in understanding the soil microbiome must evolve from general descriptions to targeted applications capable of harnessing microbial communities to increase crop resilience to climate stress. Overall, future research must converge towards complex predictive models that connect microscopic biochemical processes with agricultural landscape dynamics, ensuring the soil's ability to support food systems in an increasingly unstable climate. (Lichtenberg, 2024; Kopittke et al., 2025; Petrescu-Mag et al., 2020; Rinot et al., 2019; Hartmann & Six, 2022; Saljnikov et al., 2022; Mponela et al., 2025) [22, 16, 37, 43, 14, 45, 29].

CONCLUSIONS

Soil degradation is one of the most pressing environmental challenges at the global and regional levels, reflecting the exceeding of the resilience capacity of a living ecosystem subjected to continuous anthropogenic pressures. A critical review of the literature reveals that physical, chemical, and biological degradation processes act synergistically, diminishing the capacity of soil to provide essential ecosystem services and amplifying risks associated with food security, climate stability, and the long-term functioning of agroecosystems. In Romania, water erosion and soil compaction emerge as dominant threats to the rural landscape, exacerbated by

intensive agricultural practices that accelerate the loss of organic matter and the decline of microbial biodiversity. This progressive deterioration, often invisible in the short term, represents a true "silent crisis" of soil capital. In contrast, the evidence synthesized in this paper demonstrates that conservation and restoration strategies, including conservative agriculture, diversified rotations, and the use of organic amendments, can reverse negative degradation trajectories. Although the transition to these systems often involves initial costs and temporary adjustments to production, the cumulative benefits become evident in the medium and long term by improving soil structure, increasing water retention capacity, and stabilizing agricultural productivity. Regional case studies confirm that regenerative approaches can lead to both the restoration of humus content and the increase in the economic viability of farms, including substantial financial advantages in the case of conversion to organic systems. Overall, the results highlight the imperative nature of implementing integrated soil management capable of overcoming the singular functional paradigm focused exclusively on biomass production. Such an approach must correlate biophysical dimensions with socio-economic and institutional ones, supported by long-term monitoring, coherent policies, and effective knowledge transfer mechanisms. Strengthening collaboration between researchers, farmers, and decision-makers is essential for the adoption of innovations and for protecting soil capital as the foundation of agricultural sustainability and the well-being of future generations.

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ANALYSIS OF THE IMPACT OF EUROPEAN FUNDING PROGRAMS FOR YOUNG FARMERS IN THE NORTH-EAST REGION OF ROMANIA

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Abstract

This study analyses the impact of European funding programs for young farmers on the development of the agricultural sector in northeastern Romania. Given the need for generational renewal in agriculture, these programs represent an essential support tool. The research methodology adopts a quantitative approach, based on the analysis of official statistical data regarding the implementation of the National Rural Development Program 2014–2020. The study primarily focuses on the dynamics and results related to Sub-measure 6.1, dedicated to supporting the establishment of young farmers. The analysis was conducted using relevant indicators, such as the number of projects submitted and selected, the rate of fund absorption, and the level of implementation. The results highlight a high level of interest in accessing funding, as well as increased efficiency in the implementation process. Furthermore, a high degree of financial absorption is observed, indicating the efficient use of available resources. The research results attest to the significant contribution of the analyzed programs to the capitalization and modernization process of farms run by young farmers.

Key words*: *European funding, young farmers, rural development, agricultural competitiveness, funds absorption

INTRODUCTION

In Romania, agriculture plays a central role in the structure of rural environment [7], influencing both economic and social organization through the concentration of workforce, resources, and infrastructure. Other complementary activities, such as silviculture, fishing, aquaculture, and rural tourism, also gravitate around this sector, contributing to the local economy and providing alternative sources of income for the population. However, rural areas continue to face limited employment opportunities and high unemployment [5,17].

Migration is an essential part of life for many young adults around the world. Today, in many regions, especially rural and isolated ones, the movement of young people from rural areas to cities has become a common phenomenon and is considered natural [9], creating a need to identify and implement solutions designed to support and encourage young people to remain in rural areas, while also developing the rural environment.

The rural environment in Romania has undergone numerous transformations, currently having a special importance due to the high share of the population living in these areas. These changes became more evident with Romania's accession to the European Union, when the rural area began to benefit from dedicated programs and various support measures [8].

Starting a business, regardless of the field of activity, is a complex process that involves numerous constraints and often requires government support. These forms of support are even more important for young entrepreneurs, who typically face limitations in accessing financial and informational resources and have limited professional experience.

Starting up agricultural holdings generates multidimensional challenges, together with risk factors of atypical nature of sectoral

activities [1]. In this context, the generational crisis in agriculture is systematically correlated with the demographic trends of senescence of the farming population in the European Union, representing a strategic vulnerability for rural development [19]. Therefore, subsidizing newly established farms becomes an imperative to guarantee sustainability and sectoral competitiveness. In the paradigm of European agriculture, facilitating generational succession is a strategic priority, being enshrined as a fundamental objective in the architecture of the Common Agricultural Policy [1].

The implementation framework, represented by the National Rural Development Program (NRDP) 2014–2020, benefited from the initial validation of the European Commission on 26 May 2015, subsequently undergoing an extensive optimization process that culminated in the 20th version, ratified on 12 November 2025. This program involved a comprehensive plan for the development of the rural environment in Romania, benefiting from a total allocation of 9.363 billion Euro, of which 8.015 billion Euro came from the European Agricultural Fund for Rural Development (EAFRD), and 1.347 billion Euro from own contributions. In its initial form, the NRDP included 14 financing measures and was implemented over a period of 7 years [6, 10, 12].

Moreover, two more years were added after 2020, resulting in the NRDP 2021-2022 for the transition to the CAP PLAN 2023-2027 FOR ROMANIA. The budget was a smaller one comparing to the NRDP 2014-2020: 3,26 billion Euro (2.84 billion Euro from EAFRD - European Agricultural Fund for Rural Development and 420 million Euro from own contributions). From the 2.84 billion Euro, 692.1 million Euro were from EURI (European Union Recovery Instrument) funds and from these funds, Sub-measure 6.1 received 100 million Euro [11].

Given that the European Union's state resources are already integrated into consolidated production structures, support mechanisms for the installation of young farmers, established through the Common Agricultural Policy, become indispensable tools for facilitating the access of new generations to the sector and for stimulating the process of generational renewal [16].

In order to elucidate the configuration of accessing funds within the PNDR, except for Sub-measure 6.1, this analysis adopts a dual approach, quantifying both the volume of financing contracts/decisions (in progress or completed) and their aggregate value. From the perspective of access frequency, Sub-measure 17.1 (Crop, animal and plant insurance premiums) stands out, with the imperative mention that it does not target capital investment projects, but a form of direct support through the aid scheme.

In the segment intended for investment projects, Sub-measure 6.3 (Support for the development of small farms) records the highest penetration rate, totaling a total of 19,334 contracts. Simultaneously, Sub-measure 4.1 (Investments in agricultural holdings) is defined as one of the main financing vectors, with 4,718 active or completed contracts. In terms of value, however, Sub-measure 4.1 holds the financial supremacy, totaling commitments worth 2.27 billion euros, which reflects the complexity and technological scope of the projects financed through this channel [13]. In addition to the agricultural sector, promoting the development of non-agricultural activities in rural areas is a strategic priority for Romania, as it has the potential to reduce underemployment, improve the use of local resources, and increase the income of the rural population, thereby contributing to an improvement in the overall standard of living [18]. In this context, Sub-measure 6.2 (Support for setting-up non-agricultural activities in rural areas) - RNDP 2014–2020 has facilitated the financing of non-agricultural projects in rural areas, supporting the diversification of economic activities and stimulating the sustainable development of rural areas.

Access to European funds for young farmers offers significant opportunities for generational change in agriculture, serving as an effective mechanism for establishing and developing their own farms [16].

Given the interest of young farmers in funds allocated for establishing new agricultural businesses in rural areas, this paper aims to analyze the number of projects implemented in North-East Development Region under Sub-measure 6.1 of the 2014–2020 National Rural Development Program, including during the 2021–2022 transition period.
At the same time, the study aims to compare these results with the national average and the average of projects contracted in other Development Regions.

MATERIALS AND METHODS

This study is based on quantitative research based on the analysis of statistical data regarding the implementation of European funding programs for young farmers. The approach used allows for an objective assessment of the effectiveness of these programs through measurable and comparable indicators.
The empirical framework of this research is based on the processing and analysis of data provided by the managing authorities responsible for the administration of European funds, in particular the Agency for Financing Rural Investments (AFIR) and the Ministry of Agriculture and Rural Development (MADR). The dataset covers the procedural development of projects — from the submission and selection stage, to contracting and completion — related to the National Rural Program 2014–2020, including the transition period 2021–2022. Particular attention is paid to Sub-measure 6.1, as a central support instrument for the installation of young farmers.
The impact assessment of the funding programs was carried out by quantifying performance and efficiency indicators, namely: the volume of funding applications submitted, the selectivity rate, the number of contracts committed and completed, the aggregate value of financial support, the absorption rate of funds and the share of terminations. This matrix of indicators allows not only to measure the degree of interest of the beneficiaries, but also to rigorously evaluate the sustainability and effectiveness of the implementation process.
The data processing was carried out using descriptive statistical techniques, facilitating the identification of evolutionary trends and correlations between the analyzed variables. The interpretation of the results is subordinated to the central objective of the study: assessing the impact of financial interventions on the modernization of the agricultural sector and generational renewal at the level of the North-East Development Region of Romania.

RESULTS AND DISCUSSIONS

The configuration of the implementation of the PNDR 2014–2020 at the time reference of April 2, 2026 is systematized in Table 1. According to the 20th version of the program, the total contracted financial envelope amounts to approximately 12.7 billion euros.
Within this mechanism, Sub-measure 6.1 (Support for the installation of young farmers) has an allocation of approximately 444 million euros, holding a share of 3.5% of the total amount of PNDR resources.
A specific component, Sub-measure 6.1 – ITI (Integrated Territorial Investments), dedicated to the Danube Delta Biosphere Reserve area, benefits from a budget of 10 million euros, representing a marginal share of 0.08% of the total funds.
Simultaneously, Sub-measure 6.1 – Next Generation EU (EURI), introduced in the 2021–2022 transition phase in response to the new economic recovery paradigms, amounts to EUR 119.4 million, equivalent to 0.94% of the program budget. This funding line reflects efforts to strengthen resilience among young entrepreneurs by mobilizing European recovery funds [13].
According to the data extracted from the official report of 2 April 2026, the implementation process is at a stage of quasi-total completion, highlighting a residual volume of projects under execution. Thus, for Sub-measure 6.1, a number of 26 active projects are recorded, while in the case of component 6.1 – ITI, the execution was fully completed. Regarding Sub-measure 6.1 –

Next Generation EU, a number of 36 unfinished projects are observed, reflecting the transitional stage of these interventions financed from EURI funds. These figures indicate or the high rate of completion of contractual commitments at the level of the entire program [13].

Table 1. Stage of implementation of Sub-measures 6.1 (NRDP 2014-2022), Euro

Sub-Measure	NRDP Public Allocations Version 20.0 on 02.04.2026	Funding Applications Submitted		Funding Applications Selected		Contracts / Funding Decisions						Payments made
						Contracts / Funding Decisions Ongoing and Completed		Contracts / Funding Decisions Completed		Contracts / Funding Decisions Cancelled		
		No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	
6.1	444 mil.	15,143	622.56 mil.	10,878	446.42 mil.	10,557	433.18 mil.	10531	432.25 mil.	245	10 mil.	439.2 mil.
	3.5% share	11.01 % share	4.72% share	10.55 % share	5.68% share	10.59 % share	6% share	10.78 % share	6.5% share	7.72% share	1.99% share	3.7% share
6.1-ITI Danube Delta	10 mil.	233	9.51 mil.	204	8.3 mil.	197	8 mil.	197	8 mil.	4	0.16 mil.	8.13 mil.
	0.08% share	0.17% share	0.07% share	0.2% share	0.11% share	0.2% share	0.11% share	0.2% share	0.12% share	0.13% share	0.03% share	0.07% share
6.1-Next Generation EU (EURI)	119.4 mil.	4,277	199.16 mil.	2,839	130.89 mil.	2,540	117.29 mil.	2,504	115.4 mil.	51	2.6 mil.	118.12 mil.
	0.94% share	3.11% share	1.51% share	2.75% share	1.67% share	2.55% share	1.62% share	2.56% share	1.74% share	1.61% share	0.52% share	1% share
TOTAL	12,703 mil.	13,748.3	13,186.19 mil.	10,314.9	7,855.89 mil.	9,970.7	7,222.58 mil.	9,773.2	6,649.32 mil.	3,174	502 mil.	11,865.88 mil.
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: Calculation after [13].

According to the data shown in Table 1, the results of Sub-measure 6.1 show massive interest from young farmers, with funding requests significantly exceeding the available budget. The 15,143 projects submitted total 622.56 million Euro, while the public allocation was approximately 444 million Euro.

Ultimately, 10,878 projects were selected, totaling 446.42 million Euro, indicating a selection rate of approximately 71.8% and genuine competition for funding [13].

The implementation phase confirms the program's success with a completion rate of 97%. Of the 10,557 contracts signed (433.18 million Euro), 10,531 projects have already been successfully completed, totaling 432.25 million Euro. The fact that nearly all projects initiated were successfully completed demonstrates both the farmers' commitment and efficient administrative management, with minimal risk of delays [13].

Financial efficiency is equally robust, with a fund absorption rate of 98.9%, and actual payments totaling 439.20 million Euro. These figures show that European funds did not remain merely on paper but were transformed into real investments in farms. From the perspective of the generated impact, the analyzed indicators reveal that Sub-measure 6.1 played a decisive role in facilitating the installation of young farmers and in the structural consolidation of agricultural holdings.

The magnitude of the financing request, corroborated with an optimal implementation rate and a high degree of capital absorption, attests to the adequacy of the financial instrument to the stringent needs of the sector. These results confirm the effectiveness of the program in reducing entry barriers to the agricultural sector, stimulating the integration of the new generation into productive flows and contributing to the long-term viability of the rural area [13].

To implement the regional development policy, eight development regions have been established, covering the entire territory of Romania. Each development region consists of several counties. Development regions are not administrative-territorial units. They do not have legal personality, as they are the result of a voluntary agreement between county and local councils [15].

The North-East Development Region (Map 1) is a complex territorial unit, made up of the

counties of Bacău, Botoșani, Iași, Neamț, Suceava and Vaslui. It covers a total area of 36,850 km^2, with a population of approximately 3.22 million inhabitants recorded at the beginning of 2024.

From a macroeconomic perspective, in the financial year 2023, the region generated a Gross Domestic Product (GDP) of 32.8 billion euros, which corresponds to a GDP per capita of 10,296 euros.

Evaluated in terms of purchasing power parity (PPP), this indicator reveals a level of development of approximately 44% of the European Union average, highlighting the persistence of structural gaps in relation to community standards. In 2017, the region's GDP was 19.04 billion Euro [2, 4].

A substantial increase is observed, but inflation plays an important role in terms of purchasing power.

Map 1. North-East Development region
Source: [14].

This study aims to quantitatively analyze the impact of european funding programs for young farmers (Sub-measure 6.1 of the RNDP) on the development of the agricultural sector in the North-East Development Region of Romania.

Table 2 shows the proportion of projects selected in the North-East Development region compared to the country as a whole.

The total number of funding applications selected at the national level includes projects submitted in the Danube Delta [3,13].

A small share is observed both in terms of number (4.61% of all projects) and requested value (4.72% of the total amount allocated to funded projects).

Nationwide, 13,921 projects were selected, totaling 585.61 million Euro, and in the North-East Development region, 642 projects were selected, totaling 27.65 million Euro [3,13].

Table 2. Selection rate of Sub-measure 6.1 in the North-East Development region

Funding Applications Selected (National)		Funding Applications Selected (NE Region)		Share	
No.	Value	No.	Value	No.	Value
13921	585,61 mil. Euro	642	27,65 mil. Euro	4,61%	4,72%

Source: Calculation after [3,13].

Table 3 illustrates the distribution of projects selected for funding, revealing a significant imbalance among regions, with a massive concentration in the NV Region, which accounts for 24.76% of the total number (3,447 applications) and 25.18% of the total value (147.44 million Euro).

While five regions exceed the average of 1,734 projects, the NE Region (642 applications) and Central Region (621 applications) underperform, accounting for only 4.61% and 4.46%, respectively.

This fragmentation is accentuated by the situation of the BIF Region, whose symbolic share of 0.18% (26 selected applications) confirms the program's strategic focus on less developed areas.

This marginal share of the BIF Region can be explained by its specific configuration, as it consists exclusively of the municipality of Bucharest and Ilfov County, areas with economic dynamics that differ significantly from the rest of the country.

While Bucharest is a massive urban centre, Ilfov County, although undergoing rapid real estate and industrial expansion, has limited space that is unsuitable for large-scale agricultural activities.

Thus, although the regional average value is 73.16 million Euro, the reality shows a polarized absorption, dominated by the West and the South-Muntenia Region (113.29 million Euro), while Moldova and Central

Transylvania remain well below the average funding level.

Table 3. Percentage analysis of the 8 Development regions in Romania (selected)

Funding Applications Selected	Parameters		Share
National	No.	13,921	100%
	Value	585.61 mil. Euro	100%
NE Region	No.	642	4.61%
	Value	27.65 mil. Euro	4.72%
SE Region	No.	1,979	14.22 %
	Value	83.65 mil. Euro	14.28 %
S-Muntenia Region	No.	2,764	19.85 %
	Value	113.29 mil. Euro	19.35 %
SV Region	No.	2,289	16.44 %
	Value	94.17 mil. Euro	16.08 %
V Region	No.	2,102	15.10 %
	Value	89.87 mil. Euro	15.35 %
NV Region	No.	3,447	24.76 %
	Value	147.44 mil. Euro	25.18 %
Central Region	No.	621	4.46%
	Value	28.14 mil. Euro	4.81%
BIF Region	No.	26	0.19%
	Value	1.08 mil. Euro	0.18%

Source: Calculation after [3,13].

The analysis of the implementation of Sub-measure 6.1, based on the data summarized in Table 4, indicates a high rate of absorption of European funds.

At national level, the program's success is confirmed by an success rate of 95.50% in contractual terms (13,294 projects completed or in progress) and 95.37% in financial terms, with 558.49 million Euro spent.

In this analytical framework, the North-East Development Region integrates a portfolio of 602 projects, whose aggregate value reaches the threshold of 25.71 million euros, which attests to a remarkable capacity for capital absorption and a sustained investment interest in the agricultural sector at the local level.

From a comparative perspective, the analysis reveals a contribution of the North-East Region to the national indicators of 4.53% in terms of the volume of contracted projects, respectively 4.60% in terms of the financial mass committed.

These weights reflect a close correlation between the number of entrepreneurial initiatives and the budgetary allocations captured, consolidating the agricultural profile of the region in the national hierarchy of PNDR implementation.

Although the regional success rate shows a slight deviation from the national average, standing at 93.77% for the number of contracts and 92.98% for the absorbed value, the figures highlight rigorous monitoring of payments and efficient administrative management at the local level.

These results demonstrate that financial support has been channeled sustainably, facilitating the transformation of budget allocations into functional farms capable of ensuring the integration of young farmers into the region's active economic cycle.

Table 4. Ongoing and completed rate of Sub-measure 6.1 in the North-East Development region

Funding Applications Ongoing and Completed (National)		Funding Applications Ongoing and Completed (NE)		Share	
No.	Value	No.	Value	No.	Value
13,294	558.49 mil. Euro	602	25.71 mil. Euro	4.53%	4.60%
Success rate					
95.50%	95.37%			93.77%	92.98%

Source: Calculation after [3,13].

An analysis of Table 5 shows that the North-East Region ranks at the bottom of the national ranking, accounting for only 4.53% of the total number of projects (602 out of a total of 13,294) and 4.60% of the total funding (25.71 eperformance places the region in sharp contrast to the absorption leaders, particularly the North-West Region, which dominates implementation with a 25.28% share (3,361 projects) and a value of 142.39 million Euro—more than five times that of the NE region. Considerable differences also persist compared to the South-Muntenia (19.76%, or 107.18 million Euro) and South-West (16.23%, or 88.21 million Euro) regions, indicating a massive

concentration of the program's success in the western and southern parts of the country.

Table 5. Percentage analysis of the 8 Development regions in Romania (ongoing and completed)

Funding Applications Ongoing and Completed	Parameters		Share
National	No.	13,294	100%
	Value	558.49 mil. Euro	100%
NE Region	No.	602	4.53%
	Value	25.71 mil. Euro	4.60%
SE Region	No.	1,879	14.13%
	Value	78.89 mil. Euro	14.13%
S-Muntenia Region	No.	2,627	19.76%
	Value	107.18 mil. Euro	19.19%
SV Region	No.	2,158	16.23%
	Value	88.21 mil. Euro	15.79%
V Region	No.	2,035	15.31%
	Value	86.46 mil. Euro	15.48%
NV Region	No.	3,361	25.28%
	Value	142.39 mil. Euro	25.50%
Central Region	No.	594	4.47%
	Value	26.48 mil. Euro	4.74%
BIF Region	No.	25	0.19%
	Value	1.03 mil. Euro	0.18%

Source: Calculation after [3,13].

Compared to the other regions, the Northeast is competitive only with the Central Region, which holds similar shares of 4.47% in terms of volume (594 projects) and 4.74% in terms of value (26.48 million Euro).

It is noteworthy that, although the North-East region surpasses the Central Region by 8 projects, the value absorbed by the latter is higher by 0.77 million Euro, suggesting a higher average funding amount per beneficiary in the central area.

Excluding the specific case of the Bucharest-Ilfov region, which holds a marginal share of less than 0.2%, the North-East Region ranks at the bottom of the national implementation list, highlighting a major discrepancy compared to the agricultural dynamics in regions such as the West (15.31%) or the South-East (14.13%).

CONCLUSIONS

Government support and European funds are vital for offering young people a real alternative in agriculture, thereby countering migration to cities and rural unemployment. Overcoming financial barriers through dedicated programs enables this sector to become a driving force for local economic development, tailored to the needs of the new generation of entrepreneurs.

Ensuring generational renewal in agriculture is a priority of the Common Agricultural Policy, as it is vital for countering the aging of the rural population.

The success of the National Rural Development Program (PNDR) in developing new businesses, supporting small farms and non-agricultural activities has provided young people with the necessary tools to overcome difficulties in accessing resources.

In the North-East Development Region, 642 projects worth approximately 27.65 million Euro have been selected for funding. There are 602 projects currently being finalized or already completed, with a total value of 25.71 million Euro. The success rate is below the national average but stands at over 92%, reflecting the effective local and national management of funds.

Taking into account the other development regions in Romania, the North-East region ranks among the lowest in terms of fund absorption, with a rate of approximately 4.5% of contracted projects out of the total national projects, which confirms that the Moldova region is in a phase of underdevelopment compared to the rest of Romania.

Nevertheless, the dynamics of fund absorption confirm that, despite financial barriers and limited experience, European funds have provided young people with the necessary tools to transform budget allocations into functional agricultural operations.

In conclusion, government and EU support remain fundamental pillars for rural development, directly contributing to keeping young people rooted in local communities and to balancing regional economic disparities.

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STUDY ON THE IMPACT OF IMPLEMENTING AN AGRIP PROJECT ON INTRA-COMMUNITY TRADE CHANGES OF ROMANIA`S DAIRY PRODUCTS WITH GREECE AND CYPRUS

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Abstract

The paper seeks to highlight the extent to which the Project, individualized by the acronym EU Dairies and ID 101021932, contributed to improving Romania`s trade balance with Greece and Cyprus, by analysing the situation of exports and imports of dairy products. The project ran from 01.01.2021 to 31.12.2021 and had a budget of € 755,654. The study refers to the trade balance situation in the period 2018-2023, and the available statistical data highlighted an improvement in the case of 2022 (decrease in the deficit with Cyprus to € 2,963 thousand and increase in the surplus with Greece to € 47,034 thousand - in the case of live animals and animal products). It can be considered that the impact of the project was variable in the case of relations with the two partners, which requires a better approach to the implementation of this type of activity.

Key words**:** *dairy products, balance trade, surplus, deficit*

INTRODUCTION

For the Romanian agricultural sector, the need to promote products on foreign markets is quite pronounced, starting from the observation that Romania has a deficit trade balance for most products. In this context, the impact of actions to promote agricultural products on international markets can be tracked, which can be highlighted by analysing the effects of the Program for the Promotion of Agricultural Products - AGRIP.

The program is addressed to various associations and organizations, bodies in the agri-food sector, producer organizations, professional and inter-professional bodies adjacent to the agricultural sector.

For Romanian agriculture, especially for livestock production, milk production is of great importance, ranking second after meat production [12, 6]. In Romania, milk production has a recognized tradition, starting at least from the specific natural framework [27].

Milk production is directly correlated with the levels of properly administered and managed inputs, and this activity can be considered a profit generator [29].

Milk can be considered a staple food worldwide, a strategic food product, given that it is frequently consumed by over 80% of the world's population, in various forms as proved by statistics [24].

Milk contributes adequately to maintaining the health of the population, having a positive influence in the improvement of various conditions (cardiovascular, obesity, skeletal system conditions, etc.) [1, 26].

Milk can be consumed in various forms, from what is considered fresh milk to fermented, acidified products, etc. [3]. The quality of these products is directly influenced by the fat content of the milk, which must meet appropriate standards [13].

Currently, population growth, increased milk production volume, and changes in consumption habits are generating an increase in the market volume for milk products [6, 7].

In this context, at the national level, for the period 2018-2022, milk and dairy products recorded the highest consumption, while in terms of production per capita, milk ranked second after cereals [14, 16].

The availability of milk for marketing is influenced, in addition to the annual production per animal, by the number of animals but also by the consumption of calves [28]. In addition, marketed milk and price are close connected to milk quality [30].

New efforts should be done to grow milk production and sustain consumption [20, 21]. More than this, diversification of dairy production could contribute to an improved offer in the market [5].

It should be emphasized that Romania cannot achieve an adequate level of economic and social development under conditions of massive imports of consumer products, in a situation where exports are dominated by raw materials and not by processed products [3].

Unfortunately, Romania, although it has exceptional agricultural potential (which is not adequately exploited), depends on imported agri-food products to adequately satisfy its domestic demand [2]. As a result, some authors estimate that Romania imports more than 50% of its food needs [4].

Export operations are a means of improving the agri-food trade balance [17]. Romanian exports are concentrated at the European Union level and as such producers must adapt appropriately to the specific requirements of this market in order to obtain appropriate foreign exchange contributions [7].

Since part of the milk production is intended for on-farm consumption, and the quantities sold to the processing sector are decreasing, there is a need for imports to form an adequate supply on the national market [25].

Starting from these aspects, we sought to identify the impact of the Information Project for the promotion of halloumi cheese and organic milk on the internal market (Romania, Greece and Cyprus), for the Romanian market. The project bears the acronym EU Dairies and the ID 101021932. The project ran from 01.01.2021 to 31.12.2021, had a total budget of € 755,654, of which € 642,305.70 were community funds. Organic dairy products such as organic milk, organic cheeses, other organic dairy products from Romania and halloumi cheese from Cyprus were monitored, as well as their promotion in Romania, Greece and Cyprus. As a goal, it is noted: public awareness and recognition of the organic logo in Romania (by increasing consumer interest); improving the situation of halloumi cheese and organic milk at the level of specific markets; normalizing market conditions for halloumi in Cyprus and Greece. The action carried out was of the Agri-Multi-Internal Market type and the partners were the Association of Operators from Ecological Agriculture Bio Romania (54.34% of the budget) and M-P.O.AI LTD Cyprus (45.66% of funds) (European Commission, https://ec.europa.eu/info, 2025; http://www.developmentaid.org, 2025 [8, 9].

We further mention that halloumi cheese, according to some legislative provisions, must be obtained in Cyprus. The first information about it dates back to 1554 [31]. The following ingredients are used: pasteurized sheep's, cow's and goat's milk; salt; vegetable rennet; dried mint. The product has a dry fat content of about 43% [14]. The average nutritional value varies from 320 to 370 kcal/100 g. The product is rich in calcium, phosphorus and vitamins B2, D and B12. However, halloumi should be consumed in moderation by people with various heart conditions, due to its relatively high salt content [19]. Halloumi cheese is suitable for various dishes, being easy to prepare on the grill, in a pan or even in the oven [15, 22]. It maintains its shape and does not melt after preparation, unlike other types of cheese [18].

MATERIALS AND METHODS

To achieve the purpose of this study, we started by presenting some indicators (exports, imports, trade balance - determined as the difference between the value of exports and the value of imports [4], which were analyzed as follows: at the general national level, at the level of the group of live animal products and animal products, for the group of dairy products - total and by component items (cow cheese, processed cheese, yogurt with

additives, buttermilk, raw cow milk, skimmed cow milk, ghee cow milk, sweetened concentrated whole milk, unsweetened concentrated whole milk, skimmed cow milk powder, whole cow milk powder, dairy products, whey fresh, powdered whey, cream, butter from cow's milk). It is worth noting that where only export or import operations were recorded, the tables presented only these values, and the trade balance was equal to their level (+ or -, as the case may be).

For the presentation and analysis of the situation, related to the period 2018-2023, the existing information at the level of the National Institute of Statistics [22, 23] and at the level of the Food and Agriculture Organization of the United Nations –FAO [10, 11] was used. This information was processed using the comparison and percentage method. All indicators referred to Romania's trade relations with Cyprus and Greece, respectively.

RESULTS AND DISCUSSIONS

Table 1 presents the situation of Romania's trade balance with Cyprus and Greece.

In the case of trade with Cyprus, Romania recorded only surplus levels of the trade balance, ranging between 30,414 and 120,791 thousand $, in 2018 and 2021 respectively (Fig. 1), which in dynamics represented a 2.79 times advance of the reporting base.

Table 1. Romania's trade balance with the targeted countries -general level- (thousands $)

Year	Cyprus			Greece		
	Export *	Import **	Trade balance ***	Export *	Import **	Trade balance ***
2018	83,368	52,954	+30,414	1,178,504	1,131,985	+46,519
2019	90,593	51,023	+39,570	955,974	1,140,737	-184,763
2020	99,853	42,447	+57,406	798,091	1,264,943	-466,852
2021	170,242	49,451	+120,791	1,051,627	1,644,291	-592,664
2022	176,759	60,925	+115,834	1,133,836	1,711,411	-577,575
2023	191,464	106,426	+85,038	1,181,620	1,966,981	-155,361
2023/ 2018 (%)	229.66	200.98	279.60	100.26	149.92	-

Source: National Institute of Statistics, online data base, *http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table, EXP101B - Export value (FOB) by partner countries (Accessed on 23.12.2025), **http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table, EXP102C - Import value (CIF) by European Union countries and sections according to the Combined Nomenclature (CN) (Accessed ON 23.12.2025), ***own calculation [23, 24].

This state of affairs is generated by the fact that exports constantly outpace imports, for the analyzed period.

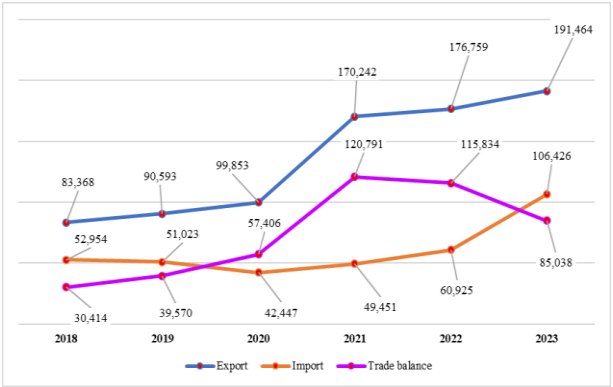

Fig. 1. Romania's trade with Cyprus – general level (thousands $),

Source: National Institute of Statistics and own calculation [24].

Exports increased from one year to another, so that the extremes were the years 2018 and 2023 (83,368 and 191,464 thousand $ - relative increase by 129.66%), while imports decreased from 2018 to 2020 (from 52,954 to 42,447 thousand $), after which they increase to 106,426 thousand $ in the case of 2023 (+100.98% compared to the first analyzed period - Fig. 1).

In relation to Greece, Romania recorded variable exports, which evolved unevenly, decreasing from 1,178,504 thousand $ in 2018 to 798,091 thousand $ in 2020, after which they increased to a maximum of 1,181,620 thousand $ in 2023 (Fig. 2).

As for imports, it is noted that they did not fall below 1,000,000 thousand $, registering

increases from one year to another, during the analyzed period (Fig. 2 – extreme values of 1,131,985 and 1,966,981 thousand $ in 2018 and 2023 respectively).

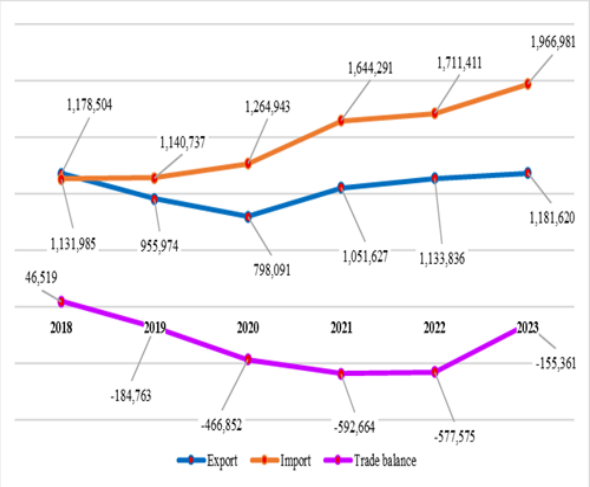

Fig. 2. Romania's trade with Greece – general level (thousands $),
Source: National Institute of Statistics and own calculation [24].

The trade balance was in surplus only in 2018 (+46,519 thousand $) and in deficit for the rest of the components of the dynamic series (Fig. 2), the level of the deficit increasing from 2019 to 2022, after which it decreases in 2023. From a dynamics point of view, it can be noted that in 2023 imports exceeded the first term of the dynamic series by 49.92%, while for exports the increase was only 0.26%.

Table 2 presents Romania's trade balance for the group of live animals and animal products (thousands of $), in the relationship with Cyprus and Greece, respectively.

Romanian exports to Cyprus ranged from 1,932 to 2,920 thousand $ in 2023 and 2018, respectively, with an uneven evolution over time, taking place decreases from 2018 to 2020, recoveries in 2021, after which decreases are manifested in 2022 and 2023 (Fig. 3).

Table 2. Romania's trade balance with the targeted countries -live animals and animal products- (thousands $)

Year	Cyprus			Greece		
	Export *	Import **	Trade balance ***	Export *	Import **	Trade balance ***
2018	2,920	8,949	-6.029	103,168	25,452	+77,716
2019	2,366	9,953	-7.587	102,057	29,996	+72,061
2020	1,998	8,359	-6,361	85,138	37,871	+47,267
2021	2,485	6,303	-3.818	92,298	49,642	+42,656
2022	2,127	5,193	-3.066	95,250	48,216	+47,034
2023	1,932	7,804	-5,872	115,872	49,499	+66,373
2023/ 2018 (%)	66.16	87.20	97.39	112.31	194.47	85.40

Source: National Institute of Statistics, online data base, *http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table, EXP101D - Export value (FOB) by European Union countries and sections according to the Combined Nomenclature (CN) (Accessed on 23.12.2025), **http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table, EXP102C - Import value (CIF) by European Union countries and sections according to the Combined Nomenclature (CN) (Accessed on 23.12.2025), ***own calculation. [23, 24].

Imports ranged between 5,000 and 10,000 thousand $ (limits of 5,193 and 9,953 thousand $ in 2022 and 2019 respectively – Fig. 3), the evolution of the indicator being uneven (increase in 2019 compared to 2018, decreases until 2022, increase in 2023).

Under these conditions, the trade balance was strictly deficient, below 5,000 thousand $ in 2021 and 2022, between 5,000 and 8,000 thousand $ for the rest of the terms of the dynamic series (Fig. 3).

From a relative point of view, 2023 recorded decreases compared to 2018 as follows: -33.84% for exports, -12.80% for imports and -2.61% for the trade balance.

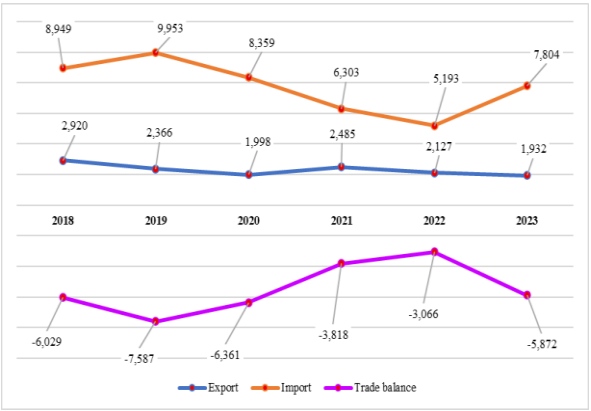

Fig. 3. Romania's trade with Cyprus – live animals and animal products (thousands $),
Source: National Institute of Statistics and own calculation [24].

Romania exported products to Greece with values ranging from 85,138 thousand $ in 2020 to 115,872 thousand $ in 2023 (Fig. 4). A period of decrease in the indicator can be observed from 2018 to 2020, after which it is on an upward trend.

Imports did not exceed the threshold of 50,000 thousand $, ranging between 25,452 and 49,642 thousand $ in 2018 and 2021, respectively (Fig. 4).

The evolution of the indicator was uneven, increasing from 2018 to 2021, decreasing to the level of 2022 and recording an increase for 2023.

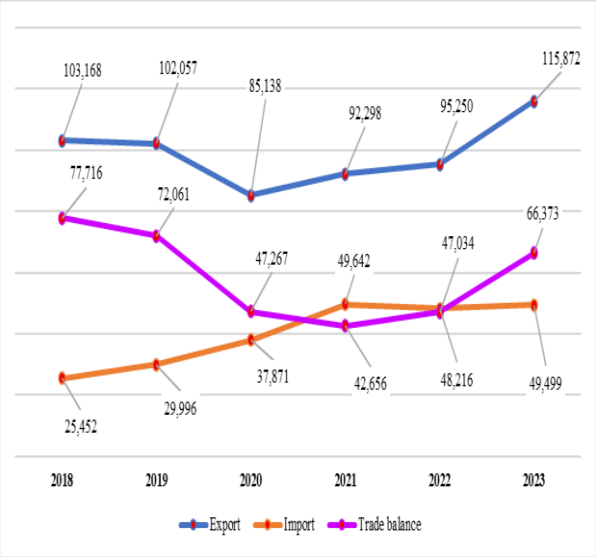

Fig. 4. Romania's trade with Greece – live animals and animal products (thousands $),
Source: National Institute of Statistics and own calculation [24].

The trade balance was in surplus, with limits of 42,656 and 77,716 thousand $ in 2021 and 2018, respectively (Fig. 4), its evolution being fluctuating.

If we compare the specific situation of 2023 with that recorded in 2018, we find that both exports and imports increased (+12.31 and +94.47%), while the trade balance decreased by 14.60%.

Table 3 presents information related to Romania's international trade in dairy products (general level), for the period 2018-2023.

In general, Romania exported dairy products worth between 150,000 and 200,000 thousand $, with the exception of 2023 when the indicator reached 234,827.41 thousand $. These decreased from 2018 to 2020 (minimum level –153,761.42 thousand $), after which they increased until 2023.

For 2023, there is an increase in exports by 49.20% compared to 2018.

Romanian imports of dairy products did not fall below the 500,000 thousand$ threshold, but did not exceed 1,000,000 thousand $ either.

These have increased continuously from 2018 to 2023 (limits of 543,755.01 and 995,244.88 thousand $ respectively), with annual growth rates being somewhat variable (from 1.01 times in 2023 compared to 2022, to 1.21 times in 2021 compared to 2020). In 2023, imports increased by 83.03% compared to the specific situation in 2018.

Table 3. Romania's international trade in dairy products (thousands $)

Specification	**Year**						**2023/ 2018 (%)**
	2018	2019	2020	2021	2022	2023	
Exports *	157,386.83	156,690.69	153,761.42	177,764.42	197,607.84	234,827.41	149.20
Imports *	543,755.01	588,897.96	668,097.39	812,292.94	977,455.71	995,244.88	183.03
Trade balance **	-386,368.18	-432,207.27	-514,335.97	-634,528.52	-779,847.87	-760,417.47	196.81

Source: FAO, online database, *https://www.fao.org/faostat/fr/#data/TCL (Accessed on 22.12.2025), **own calculation [11].

As a result of the specific situations of exports and imports, there are strictly negative annual trade balances for dairy products. The trade deficit has increased (in general) from one year to another, its limits being -386,368.18 and 779,847.87 thousand $ in 2018 and 2022, respectively. In this context, the specific deficit for 2023 exceeds the situation in 2018 by 1.96 times.

Table 4 contains information related to Romanian exports of dairy products to Cyprus. In the first instance, it is worth noting that there were nine export items, two of which can be considered less important – skimmed cow's milk (416 and 63 thousand $ for 2021 and 2022, respectively) and sweetened concentrated whole milk ($1 thousand in 2023).

Table 4. Dairy products – Romania's exports to Cyprus (thousands $) *

Specification	Year						2023/ 2018 (%)
	2018	2019	2020	2021	2022	2023	
Cottage cheese	166	152	164	453	417	568	3.42 times
Processed cheese	69	50	51	55	31	15	21.74
Yogurt	38	6	14	16	24	54	142.11
Buttermilk	1	-	1	4	20	88	88.0 times
Raw cow's milk	898	1027	906	643	74	9	1.01
Skimmed cow's milk	-	-	-	416	63	-	-
Sweetened concentrated whole milk	-	-	-	-	-	1	-
Cream	72	47	2	3	5	24	33.33
Cow's milk butter	6	4	4	5	7	4	66.67
Total **	1,250	1,286	1,142	1,595	641	763	61.04

Source: FAO, online database, *https://www.fao.org/faostat/fr/#data/TM (Accessed on 22.12.2025), **own calculation [11].

The rest of the products appeared as export items throughout the analyzed period. Cottage cheese recorded values from 152 to 568 thousand $ (2019 and 2023, respectively), the evolution of the indicator being (generally) an ascending one. For processed cheese, variable levels of the indicator are observed, from 31 thousand $ in the case of 2022, to 69 thousand $ for 2018, the evolution of the indicator being a non-uniform one from 2018 to 2021, after which a definite downward trend is observed.

In the case of yogurt, the value of exports was 38 thousand $ in 2018, after which it drops dramatically to only 6 thousand $ in 2019, subsequently until 2023, a definite upward trend is manifested (14 thousand $ in 2010, 54 thousand $ in 2023). Buttermilk exports were absent in 2019, were 1 thousand $ in 2018 and 2020, 4 thousand $ in 2021, 20 thousand $ in 2022 and 88 thousand $ for 2023. Raw cow's milk recorded export values from 9 thousand $ in 2023, up to 1027 thousand $ in 2019, the evolution the indicator being uneven, with certain downward trends especially after 2021. For sour cream, exports were some reduced in 2020, 2021 and 2022 (2, 3 and 5 thousand $) and some somewhat acceptable in the rest (24, 47 and 72 thousand $ in 2023, 2019 and 2018 respectively), the evolution of the indicator being uneven (decreases from 2018 to 2020, then increases until 2023). In the case of butter, exports ranged from 4 to 7 thousand $ (specific minimum level for three years – 2019, 2020 and 2023, maximum level in 2021), the evolution being irregular. If we look at total exports, there are four values that exceeded 1,000 thousand $ (1,595, 1,286, 1,250 and 1,142 thousand $ for 2021, 2019, 2018 and 2020 respectively) and two values below this threshold (763 and 641 thousand $ for 2023 and 2022 – Fig. 5).

Table 5. Dairy products – Romania's imports from Cyprus (thousands $)*

Specification	The product		Total **
	Cottage cheese	Yogurt	
2018	1,081	4	1,085
2019	909	-	909
2020	1,445	1	1,446
2021	2,517	-	2,517
2022	1,506	-	1,506
2023	1,759	-	1,759
2023/2018 (%)	162.71	-	162.11

Source: FAO, online database, *https://www.fao.org/faostat/fr/#data/TM (Accessed on 22.12.2025), **own calculation [11].

In the case of a parallel between the first and last term of the dynamic series, three supra-unitary levels (cottage cheese, yogurt and buttermilk) and five sub-unitary levels (processed cheese, raw cow's milk, sour cream, butter and for total operations) are found.

Table 5 presents Romania's dairy product imports from Cyprus (Fig. 5).

It is noted that there are only two imported products: cottage cheese and yogurt, with the specification that the second product appears only in 2018 and 2020 with values of 4 and 1 thousand $, respectively.

Cottage cheese is predominant with levels that usually fall between 1,000 and 2,000 thousand $ (1,081, 1,445, 1,506 and 1,759 in 2018, 2020, 2022 and 2023), with the exception of 2019 and 2021 (the first with a value of 909 thousand $, the second with 2,517 thousand $).

The dynamics are uneven, characterized by a decrease from 2018 to 2019, followed by

increases until 2021, after which we have a decrease and an annual increase for 2022 and 2023. It can be seen that the year 2023 exceeds the level of the first term of the dynamic series by 1.62 times.

Table 6 presents Romania's trade balance with Cyprus for dairy products.

Table 6. Dairy products – Romania's trade balance with Cyprus (thousands $) *

Specification	Year						2023/ 2018 (%)
	2018	2019	2020	2021	2022	2023	
Cottage cheese	-915	-757	-1,281	-2.064	-1.089	-1,191	130.16
Processed cheese	69	50	51	55	31	15	21.74
Yogurt	34	6	13	16	24	24	70.59
Buttermilk	1	-	1	4	20	88	88.0 times
Raw cow's milk	898	1027	906	643	74	9	1.01
Skimmed cow's milk	-	-	-	416	63	-	-
Sweetened concentrated whole milk	-	-	-	-	-	1	-
Cream	72	47	2	3	5	24	33.33
Cow's milk butter	6	4	4	5	7	4	66.67
Total **	+165	+377	-304	-922	-865	-996	-

*own calculation.

Cottage cheese is the only traded product that records a balance of payments deficit (from -757 to -2,064 thousand $ in the case of 2019 and 2021, respectively). The indicator evolved fluctuatingly, with alternating periods of decrease and increase, so that at the end of the analyzed period the deficit increased by 30.16% compared to the situation specific to the first year of the dynamic series.

For yogurt, the trade surplus varied from 6 to 34 thousand $ (2019 and 2018, respectively), the indicator registering a decrease in 2019 compared to 2018 (-82.36%), after which the situation recovers, based on successive annual increases in 2020 (2.17 times), 2021 (1.23 times) and 2022 (1.50 times), and for 2023 the situation is equiunitary compared to the previous year. For the rest of the products, the surplus commercial is equal to the value Romanian exports achieved and presented previously.

At a general level, there are two years with a trade surplus (2018 and 2019 – 165,000 and 377,000 thousand $ respectively), and four years with a deficit (-304, -922, -865 and -996 thousand $ in the case of 2020, 2021, 2022 and 2023 respectively – Fig. 5).

The evolution of the trade balance is not favorable for the Romanian side.

Table 7 contains information on the value of Romanian dairy exports to Greece.

The export of 16 products is noteworthy, from processed cheese to butter, from sour cream to yogurt and milk - in various forms.

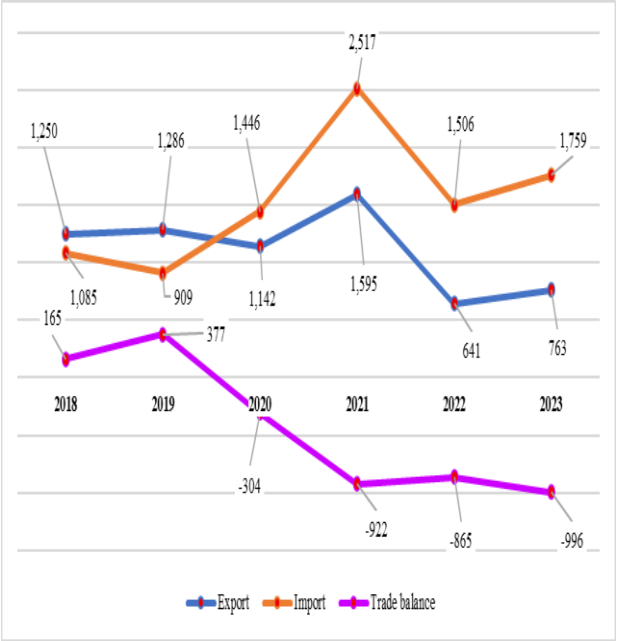

Fig. 5. Romania's trade with Cyprus – dairy products (thousands $),
Source: own calculation.

For cow's milk ghee, concentrated whole milk and fresh whey, transactions occur for two and three years respectively, for powdered whey and other dairy products we have one year in which there were no exports, the rest of the products being exported every year.

The main export item is cottage cheese, which exceeded 17,000 thousand $ annually (years 2021, 2019, 2020 and 2023 with values up to 20,000 thousand $; years 2022 and 2018 with values above this level). The indicator evolved unevenly over time, with alternating periods of decreases and increases, but in

2023 the indicator represented only 8.80% of the value specific to 2018.

Table 7. Dairy products – Romania's exports to Greece (thousands $)

Specification	Year						2023/ 2018 (%)
	2018	2019	2020	2021	2022	2023	
Cottage cheese	22,111	18,239	18,595	17,290	20,787	18,971	85.80
Processed cheese	21	25	409	1,095	1,371	1,972	93.90 times
Yogurt	5,773	4,832	3,974	2,471	2,972	6,544	113.36
Buttermilk	68	356	530	51	44	74	108.82
Raw cow's milk	20,402	22,278	16,522	6,369	6,928	8,473	41.53
Skimmed cow's milk	433	260	540	736	369	452	104.39
Cow's milk ghee	-	-	201	2	-	-	-
Concentrated whole milk sweetened	1	-	-	343	7	-	-
Concentrated whole milk unsweetened	2,223	1,965	1,308	1,528	2,886	2,674	120.29
Skimmed cow's milk powder	51	1	224	65	7	2	3.92
Whole cow's milk powder	1,546	874	903	387	416	668	43.21
Dairy products	74	4	261	33	1	-	-
Fresh whey	-	43	13	1	-	-	-
Whey powder	96	1	-	9	70	51	53.13
Cream	1,055	1,287	1,303	85	1,141	3,378	3.20 times
Cow's milk butter	1	1	3	1,132	1,035	725	725.0 times
Total **	53,855	50,166	44,786	31,597	38,034	43,984	81.67

Source: FAO, online database, *https://www.fao.org/faostat/fr/#data/TM (Accessed on 22.12.2025), **own calculation [11].

In second place is raw cow's milk, with traded values of over 15,000 thousand $ in 2018, 2019 and 2020, values that ranged between 6,000 and 9,000 thousand $ for the rest of the years - unfortunately a fluctuating - decreasing evolution (-58.47% in 2023 compared to 2018). Yogurt is in third place with exported values of over 2,400 thousand $ (from 2,471 to 6,544 thousand $ in 2021 and 2023, respectively), and in 2023 it exceeds the situation specific to 2018 by 13.36%.

We then discuss unsweetened concentrated whole milk, which recorded transactions between 1,300 and 2,900 thousand $ (extreme levels of 1,308 and 2,886 thousand $ in 2020 and 2022, respectively), in 2023 exceeding the situation specific to 2018 by 20.29%.

Cream recorded four trading levels between 1,000 and 2,000 thousand $, one level that exceeded 3,000 thousand $ (2023 - 3,378 thousand $) but also one below $100 thousand (2021 - 85 thousand $), so that the end of the period is 3.20 times ahead of the situation in 2018.

For the rest of the products, we still encounter transactions of over 1,000 thousand $ on a specific date (2021, 2022 and 2023 for processed cheese, 2021 and 2022 for butter, 2018 for whole milk powder).

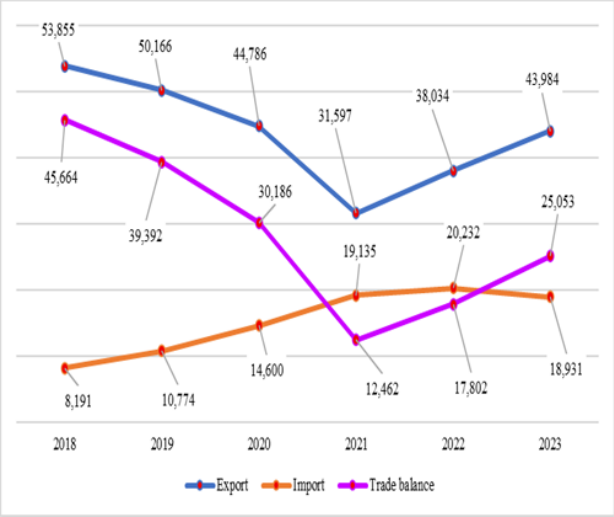

Fig. 6. Romania's trade with Greece – dairy products (thousands $),
Source: own calculation.

If we refer sequentially to the specific situations of 2023 compared to 2018, the following can be noted: sub-unit positions in the case of skimmed milk powder, whole milk powder, processed cheese and whey powder; supra-unit positions for skimmed cow's milk, cream and butter. The total annual level of imports was variable, as follows: below 40,000 thousand $ in 2021 and 2022, between 40,001 and 50,000 thousand $ in 2020 and 2023, above 50,001 thousand $ for 2018 and 2019 (Fig. 6). The indicator evolved downward from 2018 to 2021, after which recovery trends appear. Table 8 presents the situation of Romanian imports of dairy products from Greece. As in the case of exports, imports are found at the level of 16 products, with the specification that operations are not carried out at the level of all components of the assortment range for skimmed cow's milk (five terms), processed cheese and fresh whey (three terms each), ghee cow's milk, sweetened concentrated whole milk (one term each). The main import item is represented by cottage cheese (from 3,999 thousand $ in 2019, up to 9,981 thousand $ in 20230), for which the evolution was uneven, with decreases in 2019 compared to 2018, after which increases in the indicator level occur until 2023 (2.38 times ahead of the situation specific to 2018). In second place was butter, a product for which imports ranged from 1,667 thousand $ in 2023 to 3,513 thousand $ in 2022, the evolution -over time- being an upward one from 2018 to 2022, after which a decrease occurs in the case of 2023 (it decreased by 15.56% compared to the first term included in the analysis).

Table 8. Dairy products – Romania's imports from Greece (thousands $)

Specification	Year						2023/ 2018 (%)
	2018	2019	2020	2021	2022	2023	
Cottage cheese	4,182	3,999	7,895	9,520	9,045	9,981	238.66
Processed cheese	4	5	-	-	13	-	-
Yogurt	950	894	1,051	1,718	2,126	2,722	286.52
Buttermilk	102	109	58	109	190	299	293.13
Raw cow's milk	174	569	996	1,605	993	641	3.68 times
Skimmed cow's milk	-	-	-	1	-	-	-
Cow's milk ghee	-	32	1	4	2	2	-
Concentrated whole milk Sweetened	-	11	9	6	2	1	-
Concentrated whole milk Unsweetened	1	76	4	0	2,579	319	319.0 times
Skimmed cow's milk powder	116	298	44	832	402	319	275.0
Whole cow's milk powder	18	1,337	547	46	148	457	25.39 times
Dairy products	84	180	97	404	90	158	188.09
Fresh whey	-	4	-	-	8	13	-
Whey powder	174	318	119	117	155	46	26.43
Cream	412	444	1,079	1,347	966	2,306	5.59 times
Cow's milk butter	1,974	2,498	2,700	3,426	3,513	1,667	84.44
Total **	8,191	10,774	14,600	19,135	20,232	18,931	231.12

Source: FAO, online database, *https://www.fao.org/faostat/fr/#data/TM (Accessed on 22.12.2025), **own calculation [11].

Yogurt recorded imports exceeding 1,000 thousand $ over four years (2020, 2021, 2022 and 2023), this threshold being exceeded for raw milk in 2021 (1,605 thousand $), unsweetened concentrated whole milk in 2022 (2,579 thousand $), whole milk powder in 2019 (1,337 thousand $) and for sour cream in 2020, 2021 and 2023 (1,079, 1,347 and 2,306 thousand $ respectively). For the rest of the products and for the rest of the years, imports did not reach this value, there were also situations in which the level was insignificant (see the case of fresh whey and processed cheese - under 14 thousand $, buttermilk under 301 thousand $, ghee milk under 33 thousand $, unsweetened concentrated whole milk under 12 thousand $, skimmed milk powder under 833 thousand $, dairy products under 405 thousand $, powdered whey under 319 thousand $). Total imports increased from 8,191 thousand $ in 2018 to 20,232 thousand $ in 2022, for the rest of the terms analyzed

discussing values between 10,000 and 20,000 thousand $ (Fig. 6). If we analyze the situation of 2023 compared to the situation of 2018, for most products, there are overruns (in very variable proportions from 1.88 times in the case of dairy products to 319 times in the case of unsweetened concentrated whole milk). It is worth noting that the very sharp overruns were manifested for products that in 2018 presented quite low transaction values. Decreases in imports, apart from those mentioned above, also occurred in powdered whey (-73.57%).

Table 9 contains information regarding Romania's balance of payments with Greece, in the case of dairy products.

Table 9. Dairy products – Romania's trade balance with Greece (thousands $) *

Specification	Year						2023/ 2018 (%)
	2018	2019	2020	2021	2022	2023	
Cottage cheese	+17,929	+14,240	+10,700	+7,770	+11,742	+8,990	50.14
Processed cheese	+17	+20	+409	+1.095	+1,358	+1,972	116.0 times
Yogurt	+4,823	+3,938	+2,923	+753	+846	+3,822	79.24
Buttermilk	-34	+247	+472	-58	-146	-225	6.62 times
Raw cow's milk	+20,228	+21,709	+15,526	+4,764	+5.935	+7,832	38.72
Skimmed cow's milk	+433	+260	+540	+735	+369	+452	104.38
Cow's milk ghee	-	-32	+201	-2	-2	-2	-
Concentrated whole milk Sweetened	+1	-11	-9	+337	+5	-1	-
Concentrated whole milk Unsweetened	+2,222	+1,889	+1,304	+1,528	+307	+2.355	105.98
Skimmed cow's milk powder	-65	-297	+180	-767	-395	-317	4.87 times
Whole cow's milk powder	+1,528	-463	+356	+341	+268	+211	13.80
Dairy products	-10	-176	+164	-371	-89	-158	15.80 times
Fresh whey	-	+39	+13	+1	-8	-13	-
Whey powder	-78	-317	-119	-108	-85	+5	-
Cream	+643	+843	+224	-1.262	+175	+1,072	166.72
Cow's milk butter	-1.973	-2,497	-2.697	-2,294	-2,478	-942	47.74
Total **	+45,664	+39,392	+30,186	+12,462	+17,802	+25,053	54.86

Source: *own calculation.

If we analyze, as a whole, the trade balance situation, it can be observed that: for six products it was strictly in surplus (cow cheese - from 7,770 to 17,929 thousand $ in 2021 and 2018, processed cheese - between 17 and 1,972 thousand $ in 2018 and 2023, yogurt - 753 to 4,823 thousand $ in 2021 and 2018, raw cow's milk - 4,764 to 21,709 thousand $ in 2021 and 2019, skimmed cow's milk - 260 to 735 thousand $ in 2019 and 2021, unsweetened concentrated whole milk - 307 to 2,355 thousand $ in 2022 and 2023, respectively); for one product it was strictly deficient (butter – from -942 to -2,697 thousand $ in 2023 and 2020 respectively); for the remaining products (nine) surplus and deficit situations alternated in different proportions, as follows: for cream there are five surplus situations (643, 843, 224, 175 and 1,072 thousand $ for 2018, 2019, 2020 2022 and 2023 respectively) and one deficit (-1,262 thousand $ in 2021); for whole milk powder there are four surpluses (1,528, 356, 341, 268 and 211 for 2018, 2020, 2021, 2022 and 2023 respectively) and one deficit (-463 thousand $ in 2019); in the case of fresh whey there are three surpluses (39, 13 and 1 thousand $ in 2019, 2020 and 2021 respectively) and two deficits (-8 and -13 thousand $ in 2022 and 2023 respectively); for buttermilk there are two surplus situations (247 and 472 thousand $ in 2019 and 2020 respectively) and four deficit situations (-34, -58, -146 and -225 thousand $ in 2018, 2021, 2022 and 2023 respectively) ; there is one surplus and four deficits in the case of ghee milk (201 thousand $ in 2020; -32 and -2 thousand $ in 2019 respectively for the years 2021, 2022 and 2023), skimmed milk powder (180 thousand $ in 2020; -65, -297, -767, -395 and -317 thousand $ in 2018, 2019, 2021, 2022 and 2023 respectively) and dairy products (164 thousand $ in 2020; -10, -176, -371, -89 and -158 thousand $ in 2018, 2019, 2021, 2022 and 2023 respectively); for powdered whey we have a surplus (5 thousand $ in 2023) and five deficit situations (-78, -317, -119, -108 and -85 thousand $ in 2018, 2019, 2020, 2021 and 2022 respectively). Overall, the balance of payments was strictly in surplus, its level

decreasing from 2018 (45,664 thousand $) to 2021 (12,462 thousand $), after which it recorded an upward trend until 2023 (25,053 thousand $ - Fig. 6).

CONCLUSIONS

In the relationship with Cyprus, Romania recorded a general trade balance surplus (an average of 74,842 thousand $, a positive aspect also highlighted by the fact that exports grew at a faster rate than imports), while the general trade balance with Greece was a deficit (-321,783 thousand $, a negative aspect as exports grew at a slower rate than imports).
If we refer to the trade balance for live animals and animal products, we find an opposite situation to that presented previously, the balance being in deficit with Cyprus (-5,456 thousand $) and in surplus with Greece (58,851 thousand $).
For dairy products, Romania recorded a deficit trade balance (-584,617.55 thousand $), given that imports exceed exports by 4.25 times (averages of 764,290.65 and 179,673.10 thousand $, respectively). This state of affairs must be remedied by applying appropriate sequential policies for the livestock production sector, but also for the way these products are marketed on the foreign market.
Romanian dairy exports to Cyprus recorded a total average of 1,112.83 thousand $ (predominating as export items are raw cow's milk and cottage cheese – 592.83 and 320 thousand $ respectively - shares of 53.27 and 28.76%), while imports reached 1,537 thousand $ (dominated authoritatively by cottage cheese). The average trade balance was -424.17 thousand $, with the mention that this deficit character was imprinted by the specific situation for cottage cheese, for the rest of the items the indicator being surplus.
Romania exported dairy products to Greece worth 43,737 thousand $, mainly cottage cheese and raw cow's milk (44.20 and 30.85% - 19,332 and 13,495.33 thousand $ respectively), while imports were 15,311 thousand $, dominated by cottage cheese and butter (7,437 and 2,630 thousand $ - shares of 48.57 respectively 17.17% of the total). From the point of view of evolution, more pronounced increases are noted in 2023 for products with lower traded values in 2018. Although, overall, exports were down and imports were up, the trade balance was strictly in surplus (an average of 28,426 thousand $).
It can be concluded that the analyzed project (identified by the acronym EU Dairies and ID 101021932) was, based on the processed data, somewhat beneficial for Cyprus in its relationship with Romania (significant increases in cheese exports in 2021 - 1.74 times compared to 2020), while in its relationship with Greece the situation did not evolve strictly positively, with Romania recording decreases in general exports in 2021 and some recovery in 2022 and 2023. It can be said that it is necessary to carry out much more aggressive campaigns to promote its own products in the two reference markets.

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STUDY ON THE IMPACT OF IMPLEMENTING AN AGRIP PROJECT ON INTRA-COMMUNITY TRADE OF ROMANIAN FRUITS WITH SWEDEN AND BULGARIA

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Abstract

Romania`s foreign trade in agricultural products suffers mainly because we mostly export raw products, which generally fetch lower unit prices compared to the situation where products with a certain degree of processing are exported. In these conditions, we are talking about a generally deficient national trade balance, which can be improved by the adequate exploitation, on foreign markets, of agricultural products that present adequate food safety, traceability, authenticity, labelling, and nutrition. In the case of fresh fruit, a Project with the acronym EU FFAdv and ID 101021941 was implemented between 01.03.2021 and 28.02.2022, which had a total budget of € 825,478. The paper refers to the period 2018-2023, and the information related to Romania`s trade balance with agricultural products, in relations with Bulgaria and Sweden, highlights an improvement in the deficit for the last year analysed (decrease to € 19,246 and € 398 thousand respectively. As a first observation, it can be appreciated that, in the case of vegetable products, the project had a somewhat positive effect, and producers must aim for the superior capitalization of the existing national potential in this branch of production.

Key words**:** *fresh fruit, balance trade, surplus, deficit*

INTRODUCTION

Fruits represent an important food group, being essential for an adequate diet, due to their nutritional value but also for the food industry as a source of raw materials [3]. The importance of fruits for health is highlighted through polyphenols, which have antioxidant properties [9].

The usefulness of fruits for constituting a balanced diet is also underlined by their appreciable content in bioactive substances as shown by the large variety of fruits [27, 6]. This aspect is also underlined by the fact that fruits are frequently consumed by 81% of Romanians [16]. It is worth noting that, in recent times, Romanians have experienced changes in the structure of their food ration, as a result of the increased use of fruits [29].

Fruit quality is essential for stimulating consumption and increasing consumer satisfaction, and in this regard, appropriate practices can be used to maintain product quality during storage, processing and transport, which lead to a decrease in the degree of perishability [15]. At the same time, consumption is also influenced by aspects related to the origin of the fruits, and their accessibility is also linked to the price level [24]. From a structural point of view, there is an increase in demand for fruits from indigenous varieties from apples to nuts and exotic fruits [18].

The main fruit species cultivated in Romania are represented by plum, apple, pear, but there are also less important species, such as quince which occupies about 2% of the total orchard area [25]. In this context, Romania stands out as an important producer of plums, worldwide (2nd place after China, but before Serbia – 3rd place) [33]. Starting from this observation, we can say that the European Union, thanks to its member states, also plays an important role on the international market for this product [35].

Even though Romania has favorable conditions for fruit trees plantation agricultural production, it is found that it depends on imports of agri-food products [3, 23] due to climate change which affect flowering and pollination [28]. The situation is manifested in the conditions in which Romania uses 55% of the land in agriculture, a level that certainly exceeds the European level (39.1%) [27]. This may also be generated by the fact that certain constraints (which acted in the past) could not be overcome, or perhaps due to aspects related to the specific level of corruption, which led to a less adequate motivation and involvement of producers in the respective sector [5].

Export operations of agricultural products can contribute to improving the agri-food trade balance, but there is a need for Romanian exporters to obtain better prices on the international market [17].

The vast majority of Romanian exports and imports target the EU market, and rising imports highlight the increase in consumer demand and the limited performance of domestic producers [7]. This aspect is also noted by other authors, who show that fruit imports come from partners in the European Union [30, 31, 32].

This state of affairs is also due to the fragmentation of exploited areas, an aspect that is common to Romania and Bulgaria [20].

In Romania, despite the tradition in fruit growing, currently, as a result of the aging of the fruit growing heritage, satisfying domestic fruit consumption is based on significant imports that clearly exceed exports (aspects that will be emphasized later in the paper) [8, 37].

If we specifically refer to some fruits, we can mention that Romania records appreciable performance in the case of trade in shelled walnuts, an aspect that is not manifested for walnuts in shell [2].

Romania must focus on covering domestic consumption more effectively from its own production, in order to improve the trade balance [36].

In the case of Bulgaria, a negative trade balance is observed for fruit [1]. However, there are also positive aspects highlighted by increased competitiveness in the case of cherries, apricots and peaches [34]. In the relationship with Romania, watermelons may also be important [26], but things are not as in the case of other countries where they are exported in a proportion of 90%.

Since information also appears related to the trading of fresh bananas, it is worth emphasizing that in their case, good exploitation is linked to the adequate completion of the stages of the exploitation chain [14].

The analyzed project, entitled information project for the promotion of fresh fruit to restore market conditions on the internal market of Romania, Sweden and Bulgaria, is individualized by the acronym EU FFAdv and the ID 101021941. This project was carried out during the period 01.03.2021 - 28.02.2022, with a total budget of 825,478 €, of which 701,656.05 € were community funds. As objectives, the project proposed, among others: improving the competitiveness and consumption of agricultural products in the European Union; increasing the share of internal consumption of products based on specific characteristics (food safety, traceability, authenticity, labeling, nutrition); bringing the fresh fruit market to ante-pandemic parameters for Romania, Sweden and Bulgaria. The project was of the type: Agri-Multi-Internal Market. The partners included: the Southern Fruit Producers Association Fructprod (Romania 50.80% of community funds) and Kentriki Enosi Epimelitirion (Greece 49.20% of total community funds) (European Commission, 2025; https://freshfruitsadventure.eu, 2025) [10, 11, 38].

MATERIALS AND METHODS

In order to carry out the work, we started by analyzing the situation of Romania in relation to the two countries included in the project as targets: Bulgaria and Sweden (period 2018-2023). Consequently, the situation of Romania's trade with the two partners is presented and analyzed, at a general level, for

plant products (National Institute of Statistic, http://colectaredate.insse.ro/metadata, 2025; National Institute of Statistic, http://statistici.insse.ro:8077/tempo-online, 2025) and for fruits [21, 22]. As such, reference is made to the value of exports and imports (thousands of $), on the basis of which the trade balance is determined (Litvin et al., 2025) [19]. In situations where only export or import operations occurred, the trade balance was equal to their volume, registering surpluses or deficits. At the same time, it is worth noting that the two countries also carry out export operations for fruits that are not specific to their own area, only their transit from external suppliers to other external customers. Starting from the content of the analyzed project, in Romania's relations with Bulgaria and Sweden, only the situation of fresh fruits was analyzed, starting from the information available at the level of the databases consulted (FAO, Database, https://www.fao.org/faostat/fr/#data/TM, Matrices du commerce detailed, 2025) [12, 13]. It should be noted that, prior to presenting the analytical situation of Romanian trade exchanges with the two partners, Romania's general trade balance in the case of fruits is also presented (FAO, Database, https://www.fao.org/faostat/fr/#data/TCL, Cultures and animal products, 2025) [12, 13]. FAO presents 60 products as components of the fruit group, which refer to both fresh fruits (including forest fruits, exotic fruits, citrus fruits, melons, grapes), and dried fruits, respectively fruit juices. The paper uses, as working tools, the comparison method and the percentage method.

RESULTS AND DISCUSSIONS

Table 1 presents the situation of Romania's trade balance with Bulgaria and Sweden.
For trade with Bulgaria, Romania only presents deficit levels of the trade balance, varying from -106.681 to -5,413,917 thousand $, at the level of 2018 and 2022 respectively (Fig. 1). The deficit increased from 2018 to 2022, after which in 2023 it decreased (the level in 2023 exceeded the situation specific to 2018 by 18.48 times).

Table 1. Romania's trade balance with the targeted countries -general level- (thousands $)

Year	Bulgaria			Sweden		
	Export *	Import **	Trade balance ***	Export *	Import **	Trade balance ***
2018	2,600,044	2,706,725	-106,681	692,785	539,637	+153,148
2019	2,712,984	2,843,801	-130,817	630,032	489,328	+140,704
2020	2,583,677	2,864,194	-280,517	604,832	498,317	+106,515
2021	3,455,512	4,775,162	-1,319,650	738,231	605,396	+132,835
2022	3,750,153	9,164,070	-5,413,917	812,966	736,997	+75,969
2023	4,182,908	6,155,349	-1,972,441	811,315	796,773	+14,542
2023/2018 (%)	160.87	227.40	18.48 times	117.11	147.64	9.50

Source: National Institute of Statistics, online data base, *http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table, EXP101B - Export value (FOB) by partner countries (Accessed on 23.12.2025), **http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table, EXP102C - Import value (CIF) by European Union countries and sections according to the Combined Nomenclature (CN) (Accessed on 23.12.2025), ***own calculation [21, 22].

This state of affairs is generated by the fact that imports constantly exceed exports, during the analyzed period.
Exports increased from 2018 to 2019, decreased in 2020, and then until 2023 they are on an upward trend (extreme levels of 2,583,677 and 4,182,908 thousand $, in the case of 2020 and 2023 respectively, the year 2023 exceeded the situation in 2018 by 60.87%), and imports evolved upward from 2018 to 2022 (2,706,725 and 9,164,070 thousand $ respectively), after which they decrease in the case of 2023 (6,155,349 thousand $ - +127.40% compared to 2018 - Fig. 1). In relations with Sweden, Romania presents variable exports, which have evolved fluctuating, decreasing from 692,785 thousand $ in 2018 to 604,832 thousand $ in 2020, then they increased to a maximum of 812,966 thousand $ in 2022 and decreased in 2023 to 811,315 thousand $ (Fig. 2).

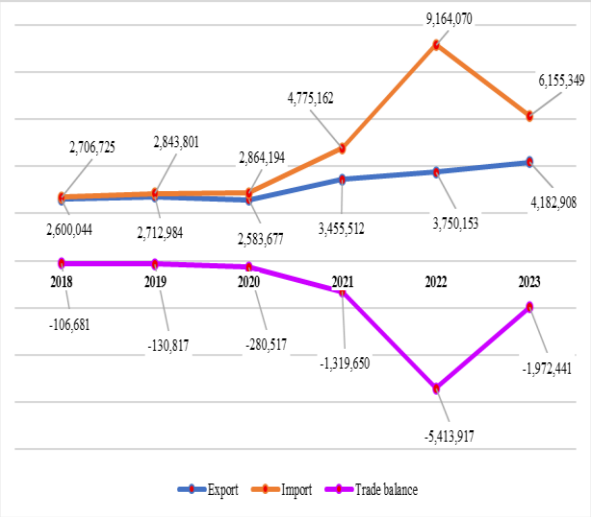

Fig. 1. Romania's trade with Bulgaria – general level (thousands $),
Source: National Institute of Statistics and own calculation [21, 22].

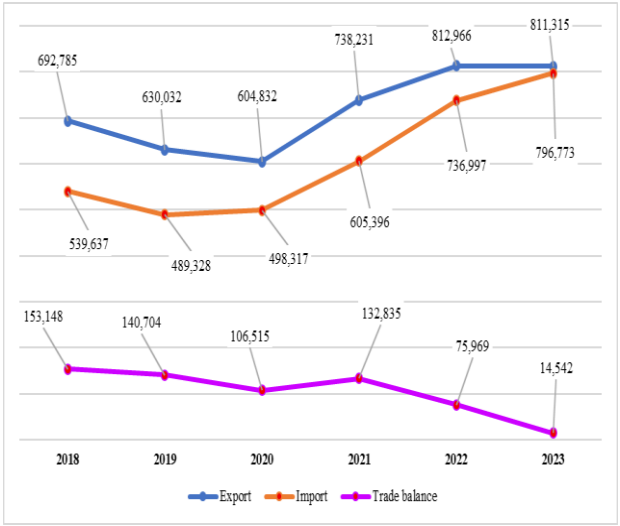

Fig. 2. Romania's trade with Sweden – general level (thousands $),
Source: National Institute of Statistics and own calculation [21, 22].

At the level of imports, levels below 800,000 thousand $ are noted, levels that evolved unevenly from year to year, during the analyzed period (Fig. 2 – extreme values of 489,328 and 796,773 thousand $ in 2019 and 2023 respectively).
The balance of payments was strictly in surplus, decreasing from 153,148 thousand $ in 2018 to 14,542 thousand $ in 2023 (Fig. 2 – downward trend).

In terms of dynamics, it can be seen that in 2023 imports exceeded the first term of the dynamic series by 47.64%, exports increased by 17.11%, while the trade balance decreased very sharply (decrease of 90.50%).
Table 2 presents Romania's trade balance for the group of vegetable products (thousands of $), in trade with Bulgaria and Sweden, respectively.

Table 2. Romania's trade balance with the targeted countries - vegetable products - (thousands $)

Year	Bulgaria			Sweden		
	Export *	Import **	Trade balance ***	Export *	Import **	Trade balance ***
2018	136,485	323,494	-187,009	349	224	+125
2019	181,664	329,434	-147,770	213	432	-219
2020	228,552	365,179	-136,627	359	1766	-1,407
2021	328,899	476,007	-147,108	290	464	-174
2022	287,309	388,805	-101,496	526	4078	-3.552
2023	248,145	267,391	-19,246	527	925	-398
2023/2018 (%)	181.81	82.65	10.29	151.01	4.12 times	-

Source: National Institute of Statistics, online data base, *http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table, EXP101D - Export value (FOB) by European Union countries and sections according to the Combined Nomenclature (CN) (Accessed on 23.12.2025), **http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table, EXP102C - Import value (CIF) by European Union countries and sections according to the Combined Nomenclature (CN) (Accessed on 23.12.2025), ***own calculation [21, 22].

Romania's exports to Bulgaria ranged from 136,485 to 328,899 thousand $ in 2018 and 2021, respectively, showing a fluctuating evolution over time, with increases from 2018 to 2021 and then decreases until 2023 (Fig. 3). Imports ranged between 267,000 and 477,00 thousand $ (extremes of 267,391 and 476,007 thousand $ in 2023 and 2021 respectively – Fig. 3), the evolution of the indicator being uneven (increases from 2018 to 2021, decreases in 2022 and 2023). As a result of the above, it is noted that the trade balance was strictly in deficit (from -19,246 to -187,009 thousand $ for the years 2023 and 2018 respectively - Fig. 3, the trend of decreasing the deficit being a certain one). The year 2023 recorded decreases compared to 2018 of -17.35% in the case of imports and

-89.71% for the trade balance, and exports increased by 81.81%.

Romania exported vegetable products to Sweden with values below 530 thousand $, extremes of 213 and 527 thousand $ in 2019 and 2023 respectively (Fig. 4).

The indicator decreased in 2019 compared to 2018 (-136 thousand $), increased in 2020 compared to the previous year (+146 thousand $), decreased in 2021 (-69 thousand $) compared to 2020, increases by 236 thousand $ in 2022 compared to the previous year, and for 2023 it decreases by 1 thousand $. Imports did not exceed the threshold of 1,000 thousand $ except in 2020 and 2022 (1,766 and 4,078 thousand $ respectively), otherwise they ranged between 925 thousand $ in 2023 and 224 thousand $ for 2018, which denotes an uneven evolution over time (Fig. 4).

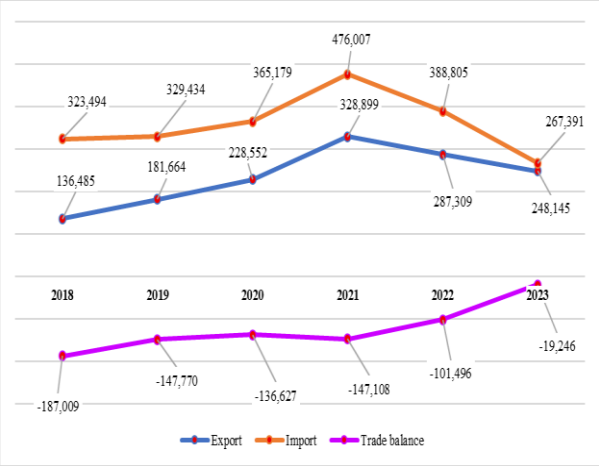

Fig. 3. Romania's trade with Bulgaria – vegetable products (thousands $),
Source: National Institute of Statistics and own calculation [21, 22].

The trade balance was in surplus only in 2018 (125 thousand $), for the rest of the terms analyzed it was in deficit, from -174 thousand $ in 2021, to 3,552 thousand $ in 2022 (Fig. 4), its evolution being variable. If we compare the specific situations of 2023 and 2018, we find that exports increased by 51.01%, while imports increased by 4.12 times.

Table 3 presents data related to Romania's international trade in fruit, for the period 2018-2023.

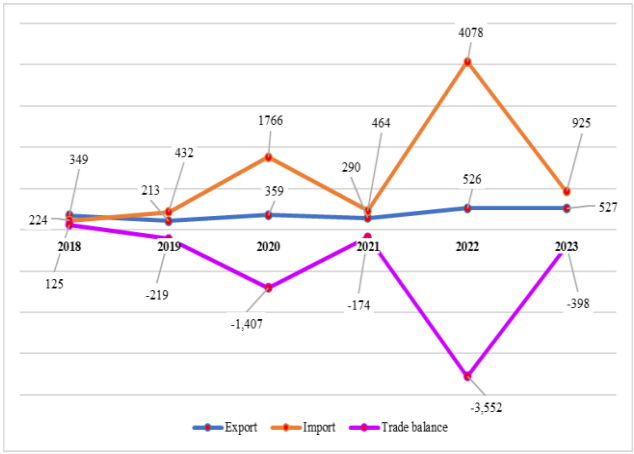

Fig. 4. Romania's trade with Sweden – vegetable products (thousands $)
Source: National Institute of Statistics and own calculation [21, 22].

Romania exported fruits with values ranging between 66,000 and 116,000 thousand $ (three years were below 100,000 thousand $, and three years exceeded this threshold). They decreased from 2018 to 2019 (from 72,370.97 to 66,893.84 thousand $), after which they increased until 2022 (115,262.63 thousand $) and decreased in 2023 (101,687.54 thousand $). In the case of 2023, there is an increase in export operations by 40.51% compared to 2018. Fruit imports did not fall below the threshold of 760,000 thousand $ and exceeded the level of 1,000,000 thousand $ only in 2023. They decreased in 2019 compared to 2018 (764,856.90 and 797,831.11 thousand $, respectively), after which they increased until 2021 (846,181.40 and 932,837.40 thousand $ for 2020 and 2021, respectively), decreased in 2022 (930,996.70 thousand $) and increased in 2023 ($1,079,583 thousand) - a fluctuating evolution from year to year.

Table 3. Romania's international trade in fruits (thousands $)

Specification	Year						2023/ 2018 (%)
	2018	2019	2020	2021	2022	2023	
Exports *	72,370.97	66,893.84	80,386.44	104,124.07	115,262.63	101,687.54	140.51
Imports *	797,831.11	764,856.90	846,181.40	932,837.40	930,996.70	1,079,583	135.31
Trade balance **	-725,460.14	-697,963.06	-765,794.96	-828,713.33	-815,734.07	-977,895.46	134.79

Source: FAO, online database, *https://www.fao.org/faostat/fr/#data/TCL (Accessed on 22.12.2025), **own calculation. [12, 13].

In 2023, imports increased by 35.31% compared to the situation characteristic of 2018.

Based on the situation of exports and imports, there were strictly deficit annual balances of payments. The indicator was decisively influenced by the value of imports (limits of -697,963.06 and 977,895.46 thousand $ in the case of 2019 and 2023 respectively). The deficit evolved unevenly, from year to year, with certain increasing trends. As a result, the specific deficit for 2023 is 1.34 times higher compared to the specific situation for 2018.

Table 4 contains information related to Romanian exports to Bulgaria.

It should be emphasized that there were 18 traded export items, which presented variable importance, depending on the values generated and the number of years in which the exchanges were carried out.

Table 4. Fresh Fruits – Romania's Exports to Bulgaria (thousands $)

Specification	Year						2023/ 2018 (%)
	2018	2019	2020	2021	2022	2023	
Apricots	-	-	-	20	8	-	-
Pineapple	-	1	198	3	1	-	-
Other fruits	-	100	37	5	3	1	-
Bananas	42	336	6,001	6,103	4,868	371	8.83 times
Cranberry	-	-	-	-	15	6	-
Cherries	46	-	-	9	19	36	78.26
Lemons and limes	40	97	87	25	2	343	8.58 times
Dates	-	-	-	9	-	-	-
Mango	-	-	-	-	2	1	-
Blueberries	14	-	-	-	85	337	24.07 times
Oranges	-	-	5	3	-	13	-
Pomelo	11	-	26	46	11	165	15.0 times
Watermelons	17	8	2	-	-	-	-
Pears	1	-	-	-	-	-	-
Apples	29	-	-	-	-	6	20.69
Peaches and nectarines	-	-	-	-	-	10	-
Grapes	168	35	4	5	2	18	10.71
Mandarins and clementines	-	12	3	2	-	8	-
Total **	368	589	6,363	6,230	5,016	1,315	3.57 times

Source: FAO, online database, *https://www.fao.org/faostat/fr/#data/TM (Accessed on 26.12.2025), **own calculation [12, 13].

Thus, bananas, lemons and limes, and grapes (transactions carried out annually) can be considered of major importance.

Banana exports were recorded from 42 to 6,103 thousand $ (2018 and 2021, respectively), the indicator evolves variably (increases from 2018 to 2021, decreases to the level of 2023). In 2023, an 8.83 times increase in the indicator compared to 2018 is noted.

For lemons and limes, exports were reduced in value (below 100 thousand $ - limits of 2 and 97 thousand $ for 2022 and 2019 respectively), with the exception of 2023 when a value of 343 thousand $ was reached. The evolution of the indicator was uneven with alternating growth and decline trends, some even accentuated (2022 - decrease, 2023 - increase).

In the case of grapes, exports ranged from 2 to 168 thousand $ (2022 and 2018, respectively). The trend of variation of the indicator was fluctuating (decreases from 2018 to 2022, after which an increase was observed in 2023). Compared to 2018, in 2023 exports represented only 10.71%.

Next is another group of products for which transactions were recorded for at least half of the six years analyzed: pineapple, other fruits, cherries, blueberries, oranges, pomelos, watermelons, tangerines and clementines.

Thus, four transactions appear for pineapple (three symbolic ones of 1 thousand $ each in 2019 and 2023, 3 thousand $ in 2021; one more important one –198 thousand $ in 2020).

For other fruits, the value of exports decreased from 2019 (100 thousand $) to 2021, 2022 and 2023 (5, 3 and 1 thousand $ respectively).

For cherries, transactions occur in 2018, 2021, 2022 and 2023. Thus, it starts from 46 thousand $ in 2018, reaches 9 thousand $ in the case of 2021, after which it reaches 19 and 36 thousand $ respectively in 2022 and 2023 (fluctuating evolution). The year 2023

achieved only 78.26% of the level specific to the first term of the dynamic series.

Blueberries presented export operations in 2018 (14 thousand $), 2022 (85 thousand $) and 2023 (337 thousand $, 24.07 times increase compared to 2018).

In the case of oranges, there are two years with symbolic transactions (5 and 3 thousand $ in 2020 and 2021, respectively) and one year with a higher value of the indicator – 2023 (13 thousand $).

Pomelo presents five years of transactions, with none in 2019. Thus, values of 11 thousand $ were reached in 2018 and 2022, 26 thousand $ for 2020, 46 thousand $ in 2021 and 165 thousand $ in 2023 (15 times ahead of the situation specific to 2018).

Romania exported watermelons in 2018, 2019 and 2020, with the level of transactions decreasing, from 18 to 8 and 2 thousand $ respectively.

Tangerines and clementines are not found as export items in 2018 and 2022, the value of operations decreased from 12 thousand $ in 2019 to 3 and 2 thousand $ respectively for 2020 and 2021, and then increased to 8 thousand $ in 2023.

The rest of the products are of lesser importance: apricots (20 and 8 thousand $ in 2021 and 2022, respectively); cranberries (15 and 6 thousand $ in 2023 and 2023, respectively); dates (9 thousand $ in 2021); mangoes (2 and 1 thousand $ in 2022 and 2023, respectively); persimmons (1 thousand $ for 2018); apples (29 thousand $ in 2018 and 6 thousand $ in 2023); peaches and nectarines (10 thousand $ in 2023).

The overall level of exports ranged between 368 and 6,363 thousand $ in 2018 and 2020, respectively (Fig. 5). The indicator recorded an upward trend for the period between 2018 and 2020, after which the trend was downward until 2023 (in 2023 it exceeded the situation specific to 2018 by 3.57 times).

Table 5 presents Romania's imports of fresh fruit products from Bulgaria.

It is noted that there are 29 imported products, from fruits obtained in Bulgaria to fruits that only transited this country. Of the 29 products, for 23 of them, transactions took place throughout the entire period under observation, with only 6 cases showing transactions for shorter periods of time.

For apricots, the indicator ranged from 39 to 176 thousand $ (2018 and 2021, respectively), the dynamics being fluctuating (alternating increases and decreases), and at the end of the period, exports increased by 15.38% compared to the first year presented.

In the case of other forest berries, values below 100 thousand $ are predominantly observed (four years – 2018, 2019, 2020 and 2023 – 62, 13, 27 and 92 thousand $ respectively), a level that was exceeded in 2021 and 2022 (149 and 164 thousand $ respectively - uneven evolution). In relative units, it is noted that the specific level for 2023 exceeded the specific state of affairs for 2018 by 48.38%.

For other fruits, there are two years with considerable import levels (2021 and 2022 – 276 and 345 thousand $ respectively) and four years with low to modest levels (2019 – 5 thousand $, 2023 – 22 thousand $, 2020 – 26 thousand $, 2018 – $38 thousand). Under these conditions, the indicator has fluctuated (2023 recorded a decrease of 32.11% compared to 2018).

Bananas recorded imports ranging between 387 and 1,239 thousand $ in 2020 and 2018, respectively.

The evolution of the indicator was uneven, characterized by decreases from 2018 to 2020, after which successive increases and decreases occurred until 2023. In 2023, the indicator represented only 38.25% of the level reached in 2018.

In the case of cantaloupes and other melons, the level of transactions started at 31 thousand $ in 2018, reached 19 thousand $ in 2019, 4 thousand $ in 2020, 11 thousand $ in 2021, 52 thousand $ in 2022 and 161 thousand $ in 2023, which indicates a variable evolution.

For cherries, limits of 110 thousand $ were recorded in 2018 and 500 thousand $ in 2021. During the analyzed period, the value of imports recorded an upward trend from 2018 to 2021, after which the trend was downward until 2023 (the year 2023 exceeded the situation specific to 2018 by 1.99 times).

For lemons and limes, there were three years in which the value of exports exceeded 1,000

thousand $ (1,603, 1,168 and 2,744 thousand $ in 2018, 2022 and 2023 respectively) and three years positioned below this threshold (690, 679 and 572 thousand $ in 2021, 2019 and 2020 respectively). An increase of the indicator in 2023 by 71.17% is noted compared to the first year included in the study.

Table 5. Fresh Fruits – Romania's Imports from Bulgaria (thousands $)

Specification	Year						2023/ 2018 (%)
	2018	2019	2020	2021	2022	2023	
Apricots	39	150	64	176	119	45	115.38
Pineapple	-	3	-	6	25	76	-
Other fruits Forest	62	13	27	149	164	92	148.38
Other fruits	38	5	26	276	345	22	57.89
Other citrus fruits	-	6	-	-	-	1	-
Bananas	1,239	725	387	522	438	474	38.25
Cantaloupe and other melons	31	19	4	11	52	161	5.19 times
Black and red currants	-	-	-	-	8	5	-
Cherries	110	351	436	500	311	219	199.09
Lemons and limes	1,603	679	572	690	1,168	2,744	171.17
Quince	9	12	1	3	8	67	7.44 times
Dates	1	1	3	12	23	62	62.0 times
Figs	-	-	-	-	1	1	-
Strawberries	886	905	447	90	16	438	49.43
Raspberry	-	-	1	21	128	126	-
Kiwi	119	119	101	178	141	160	134.45
Mango	19	34	70	106	55	110	5.78 times
Blueberries	-	-	2	6	61	3	-
Oranges	653	560	480	192	195	290	44.41
Pomelo	404	153	211	142	208	270	66.83
Watermelons	522	682	423	187	942	1,107	212.06
Pistachio in shell	63	32	26	257	121	97	153.96
Kakis	-	-	-	13	8	-	-
Pears	1	14	26	33	72	81	81.0 times
Apples	58	171	291	274	121	115	198.27
Plums	195	66	212	125	74	50	25.64
Peaches and nectarines	272	313	214	266	222	56	20.58
Grapes	299	958	1,183	1,706	1,270	1,620	5.41 times
Mandarins and clementines	1,287	1,371	917	1,178	833	1,521	118.18
Total **	7,910	7,342	6,124	7,119	7,129	10,013	126.58

Source: FAO, online database, *https://www.fao.org/faostat/fr/#data/TM (Accessed on 26.12.2025), **own calculation [12, 13].

The coins were traded throughout the entire time interval, but modest values prevailed (1, 3, 8, 9 and 12 thousand $ in 2020, 2021, 2022, 2018 and 2019 respectively), only the year 2023 presenting a higher value (67 thousand $ - a level 7.44 times higher than that of 2018).

For dates, imports were modest in 2018 (1 thousand $), 2019 (1 thousand $) and 2020 (3 thousand $), after which they increased in 2021 (12 thousand $), 2022 (23 thousand $) and 2023 (62 thousand $) For strawberries, we are talking about import variation limits, from 16 thousand $ in 2022, to 905 thousand $ in 2019. The indicator level has fluctuated, showing increases from 2018 to 2019 and from 2022 to 2023, while in the 2019-2022 interval there are downward trends. However, in 2023, Romania imported only 49.43% of the specific level of 2018.

Romania imported kiwis in the range of 101 to 178 thousand $ (2020 and 2021, respectively), the indicator fluctuated uniformly from 2018 to 2019, after which alternating decreasing and increasing trends appear (+34.45% in 2023 compared to 2018).

Trading values for mangoes were less than 100 thousand $ in four cases (2018, 2019, 2020 and 2022 – 19, 34, 70 and 55 thousand $ respectively) and exceeded this threshold in 2021 and 2023 (106 and 110 thousand $ respectively). For oranges, imports decreased from 653 thousand $ in 2018 to 192 thousand $ in 2021, after which they recovered (195 thousand $ in 2022, 290 thousand $ in 2023).

However, there is a decrease in the indicator by 55.59% in 2023 compared to 2018.

If we refer to the specific situation for pomelo, we can state that imports have fluctuated, decreasing from 404 thousand $ in 2018 to 153 thousand $ in 2019, then increasing in 2020 (211 thousand $), decreasing in 2021 (142 thousand $), and recovering in 2022 and 2023 (208 and 270 thousand $). Watermelons represented an important import item for Romania, with the value of transactions ranging between 187 and 1,107 thousand $ in 2021 and 2023, respectively. The indicator recorded a downward trend from 2018 to 2021, after which the trend was upward until 2023 (the value in 2023 exceeded the comparison period by 2.12 times - 2018). As an import item, pistachios in shell generated trade below 100 thousand $ in four years (2018, 2019, 2020 and 2023 – 63, 32, 26 and 97 thousand $ respectively) and above this level in two years (2021 and 2022 – 257 and 121 thousand $ respectively). The year 2023 is characterized by a 53.96% exceedance of the level specific to the first term analyzed.

For pears, imports ranged from 1 thousand $ (2018) to 81 thousand $ (2023), the indicator showing a strictly upward trend.

Apples are characterized by imports that generally exceeded 100 thousand $, with the only exception being 2018 – 58 thousand $.

Plum imports were below 100 thousand $ in 2019, 2022 and 2023 (66, 74 and 50 thousand $ respectively), but exceeded this level in 2018, 2020 and 2021 (195, 212 and 125 thousand $ respectively), which indicates an uneven evolution of the indicator. The year 2023 saw a 74.36% reduction in imports made in 2018. Peaches and nectarines are notable for imports that consistently ranged between 200 and 315 thousand $ (the case of 2018, 2029, 2020, 2021 and 2022), with the exception of 2023 (56 thousand $, which represented a 79.42% decrease compared to the first term analyzed - 2018).

The value of grape imports was below 1,000 thousand $ in 2018 and 2019 (299 and 958 thousand $, respectively) and above this threshold in the rest of the years (1,183, 1,706, 1,270 and 1,620 thousand $ in 2020, 2021, 2022 and 2023, respectively). Under these conditions, the indicator evolved upward from 2018 to 2021, after which for the years 2022 and 2023 the evolution is variable. It is worth noting the 5.41-fold increase of the indicator in 2023 compared to 2018.

For mandarins and clementines, imports ranged from 833 thousand $ in 2022 to 1,521 thousand $ in 2023, with the indicator showing alternating increases and decreases.

In the case of less important products, pineapple recorded four trading values (3 thousand $ in 2019, 6 thousand $ for 2021, 25 thousand $ in 2022 and 76 thousand $ for 2023), other citrus fruits two values (6 thousand $ in 2019 and 1 thousand $ for 2023), black and red currants two values (8 and 5 thousand $ for 2022 and 2023 respectively), figs two values (1 thousand $ each for 2022 and 2023), raspberries four values (1 thousand $ for 2020, 21 thousand $ in 2021, 128 thousand $ for 2022 and 126 thousand $ in 2023), blueberries four values (2, 6, 61 and 3 thousand $ for 2020, 2021, 2022 respectively 2023), kakis two values (13 thousand $ in 2021 and 8 thousand $ in 2022).

At a general level, we are talking about imports that exceeded 6,000 thousand $, as follows (Fig. 5): 6,124 thousand $ in 2020, 7,119 thousand $ for 2021, 7,129 thousand $ in 2022, 7,342 thousand $ for 2019, 7,910 thousand $ in 2018 and 10,013 thousand $ in the case of 2023 (downward evolution from 2018 to 2020 and then upward until 2023). Under these conditions, 2023 exceeded the specific state of affairs of 2018 by 26.58%.

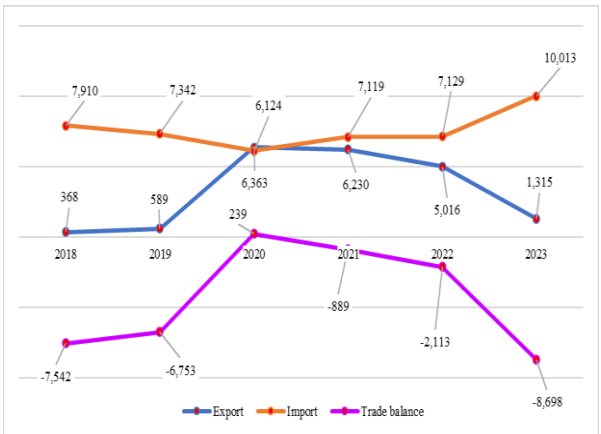

Fig. 5. Romania's trade with Bulgaria – fresh fruit (thousands $),
Source: own calculation.

Table 6 presents Romania's trade balance with Bulgaria for fresh fruit.

As we have specified, within the methodology, in the case of products where only export or import operations were carried out, the level of the trade balance is equal to their level, but with a changed sign in the case of situations where we only have import operations. This situation (strictly import operations) manifests itself for the following products: other berries, other citrus fruits, cantaloupes and other melons, black and red currants, quinces, figs, strawberries, raspberries, kiwi, pistachios in shell, persimmons and plums. As such, Romania presents strictly deficit balances for these products, equal to the value of imports.

There is also a situation when only export operations determine the surplus balance of a product – the case of cranberries.

For apricots, a strictly deficit balance is observed, which ranged from -39 to -156 thousand $ in 2018 and 2021 respectively. The indicator has fluctuated, with trends of increasing and reducing the trade deficit manifesting themselves alternately.

For pineapple, there is a surplus level in 2020 (198 thousand $) and four deficit levels (-2, -3, -24 and -76 thousand $ in 2019, 2021, 2022 and 2023 respectively).

The trade balance is predominantly in deficit for other fruits (-38, -271, -342 and -91 thousand $ in 2018, 2021, 2022 and 2023 respectively). There are also two surplus balances in 2019 and 2020 (5 and 11 thousand $ respectively). If we refer to the specific situation of bananas, there are quite significant limits of variation in the trade balance from +5,614 thousand $ in the case of 2020, to -1,197 thousand $ in 2018. In addition to 2020, surpluses are also observed in 2021 and 2022 (5,581 and 4,430 respectively), and deficits also appear in 2019 and 2023 (-389 and -103 thousand $).

Table 6. Fresh Fruits – Romania's Trade Balance with Bulgaria (thousands $)

Specification	Year						2023/ 2018 (%)
	2018	2019	2020	2021	2022	2023	
Apricots	-39	-150	-64	-156	-111	-45	115.38
Pineapple	-	-2	+198	-3	-24	-76	-
Other berries	-62	-13	-27	-149	-164	-92	148.38
Other fruits	-38	+95	+11	-271	-342	-21	55.26
Other citrus fruits	-	-6	-	-	-	-1	-
Bananas	-1,197	-389	+5,614	+5,581	+4,430	-103	8.60
Cranberry	-	-	-	-	+15	+6	-
Cantaloupe and others melons	-31	-19	-4	-11	-52	-161	5.19 times
Black and red currants	-	-	-	-	-8	-5	-
Cherries	-64	-351	-436	-491	-292	-183	285.93
Lemons and limes	-1.563	-582	-485	-665	-1,166	-2,401	153.61
Quince	-9	-12	-1	-3	-8	-67	7.44 times
Dates	-1	-1	-3	-3	-23	-62	62.0 times
Figs	-	-	-	-	-1	-1	-
Strawberries	-886	-905	-447	-90	-16	-438	49.43
Raspberry	-	-	-1	-21	-128	-126	-
Kiwi	-119	-119	-101	-178	-141	-160	134.45
Mango	-19	-34	-70	-106	-53	-109	5.73 times
Blueberries	+14	-	-2	-6	_+24	+334	23.86 times
Oranges	-653	-560	-475	-189	-195	-277	42.41
Pomelo	-393	-153	-185	-96	-197	-105	26.71
Watermelons	-505	-674	-421	-187	-942	-1.107	219.20
Pistachio in shell	-63	-32	-26	-257	-121	-97	153.96
Kakis	-	-	-	-13	-8	-	-
Pears	-	-14	-26	-33	--72	-81	-
Apples	-29	-171	-291	-274	-121	-109	3.75 times
Plums	-195	-66	-212	-125	-74	-50	25.64
Peaches and nectarines	-272	-313	-214	-266	-222	-46	16.91
Grapes	-131	-923	-1,179	-1,701	-1,268	-1.602	12.22 times
Mandarins and clementines	-1,287	-1,359	-914	-1.176	-833	-1.513	117.56
Total **	-7.542	-6.753	+239	-889	-2,113	-8,698	115.32

* own calculation.

Romania recorded, strictly, trade deficits in the case of cherries, deficits that ranged between 64 and 491 thousand $ (years 2018 and 2021 respectively). For the rest of the terms, the dynamic series, is notes variable deficits, which accentuate the uneven evolution of the indicator.

It showed increases from 2018 to 2021, after which it shows decreasing trends.

In the case of lemons and limes, the trade deficit was permanent, in three years it was below 1,000 thousand $ (2019, 2020 and 2021), and in three years it exceeded this level (2018, 2022 and 2023), aspects that highlight a downward evolution from 2018 to 2020 and an upward trend after this year until 2023.

For dates, the deficit balance was acceptable in the first four years (1 thousand $ each in 2018 and 2019, 3 thousand $ each for 2020 and 2021), after which it increases, quite sharply in 2022 and 2023 (23 thousand $ and 62 thousand $ respectively).

For mango, the deficit increases from 2018 to 2021 (from 19 to 106 thousand $), after which it decreases in 2022 (53 thousand $), but increases again in 2023 (109 thousand $).

Blueberries present two deficit levels of the trade balance (2020 and 2021 – 2 and 6 thousand $ respectively) and three surplus levels (two relatively low in value – 14 and 24 thousand $ in 2018 and 2022, one more pronounced – 334 thousand $ in 2023).

Oranges strictly have trade deficits that decreased from 2018 to 2021 (from 653 to 189 thousand $), but then increased by the end of the period (277 thousand $ in 2023).

In the case of watermelons, the deficits recorded were some lowers in 2021 (187 thousand $), some somewhat moderate in 2018, 2019 and 2020 (505, 674 and 421 thousand $ respectively) and some accentuated for 2022 and 2023 (942 and 1,107 thousand $ respectively).

The pears presented five trade deficits ranging between 14 and 81 thousand $, starting from 2019 to 2023, the evolution of the indicator being less favorable.

The deficit for apples was only 29 thousand $ in 2018, after which its level was equal to the value of imports.

Peaches and nectarines present a smaller deficit in 2023 (46 thousand $), for the rest of the terms of the dynamic series its level being identical to the level of imports.

In the case of grapes, the balance of payments deficit exceeded 1,000 thousand $ in 2020, 2021, 2022 and 2023, for 2019 it was close to this level (923 thousand $), and in 2018 it was acceptable (131 thousand $).

For mandarins and clementines, the deficits were below 1,000 thousand $ in the case of 2020 and 2022 (914 and 833 thousand $), but exceeded this level in the rest (1,287 thousand $ in 2018, 1,359 thousand $ for 2019, 1,176 thousand $ in 2021 and 1,513 thousand $ in 2023.

At the general level, of the product group, there is a single balance of payments surplus (2020 – 239 thousand $) and five deficit situations (-7,542, -6,753, -889, -2,113 and -8,698 thousand $ in the case of 2018, 2019, 2021, 2022 and 2023 respectively – Fig. 5). It can be noted the less convenient position of the Romanian side in the framework of trade with Bulgaria.

For the products reviewed, by comparatively analyzing the situations in 2023 and 2018, the following can be noted: variable advances of the reporting base at the general level (1.15 times) and for 15 products (apricots, other berries, cantaloupes and other melons, cherries, lemons and limes, quinces, dates, kiwi, mangoes, blueberries, watermelons, pistachios in shell, apples, grapes, tangerines and clementines); decreases compared to the reference term for 7 products (other fruits, bananas, strawberries, oranges, pomelos, plums, peaches and nectarines).

Seven products are traded, of which only watermelons have export and import operations, with the rest of the products showing either only export or only import operations. It is worth noting that there is no product that has been traded for more than two years.

Table 7 contains information on trade in fresh fruit between Romania and Sweden. It is noted that in 2019, 2020 and 2021 no export or import operations were recorded.

Romania carried out export operations for other fruits in 2023 (18 thousand $), lemons

and limes also in 2023 (3 thousand $), blueberries in 2022 and 2023 (37 thousand $ and 13 thousand $ respectively).

Table 7. Fresh fruit – Trade with Sweden (thousands $)

The product	Specification	Year		
		2018	2022	2023
Other fruits	Export *	-	-	18
Bananas	Import *	1	-	-
Lemons and limes	Export *	-	-	3
Dates	Import *	-	9	7
Blueberries	Export *	-	37	13
Papaya	Import *	-	-	5
Watermelons	Export *	-	-	1
	Import *	1	-	-
	Trade balance **	-1	-	+1
Total **	Export	-	37	35
	Import	2	9	12
	Trade balance	-2	+28	+23

Source: FAO, online database, *https://www.fao.org/faostat/fr/#data/TM (Accessed on 26.12.2025), **own calculation [12, 13].

Imports targeted bananas in 2018 (1 thousand $), dates in 2022 and 2023 (9 thousand $ and 7 thousand $, respectively), and papaya in 2023 (5 thousand $).

In the case of watermelons, exports were made in 2023, and imports only for 2018 (values of 1 thousand $, in each case).

At the general level of the product group, Romanian exports totaled 37 thousand $ in 2022 and 35 thousand $ in 2023, imports reached 2 thousand $ for 2018, 9 thousand $ in 2022 and 12 thousand $ for 2023. Under these conditions, the trade balance was in deficit in 2018 (2 thousand $) and in surplus in 2022 and 2023 (28 thousand $ and $23 thousand, respectively).

CONCLUSIONS

Romania's trade with Bulgaria is characterized by an average of total exports of 3,214,213 thousand $, an average of imports of 4,751,550 thousand $, aspects that led to an average deficit balance of -1,537,337 thousand $, the aspect being also determined by a more pronounced increase in imports than in exports (2.27 compared to 1.60 times).

Trade with Sweden recorded an average trade surplus (103,952 thousand $), with average exports of 715,02 thousand $ and imports of 611,075 thousand $. However, it is worth highlighting the negative aspect that imports increased more than exports in 2023 - compared to 2018.

For vegetable products, Romania has an average trade balance deficit with Bulgaria (-123,209 thousand $), while exports reached 235,176 thousand $ and imports reached 358,385 thousand $. There is also a positive aspect to this issue, namely the fact that in 2023 imports decreased by 17.35% compared to 2018, while exports increased by 81.81%.

Romania has not managed to maintain a trade surplus with Sweden since 2018, after which it has been in a deficit with variations from one year to the next. This is due to the sometimes-sharp increase in imports, while exports grow at a slower pace.

Romania's international fruit trade presents an average deficit in the balance of payments (-801,926.83 thousand $), the aspect being a consequence of the fact that average exports (90,120.92 thousand $) represent only 10.10% of average imports (892,047.75 thousand $).

Romania's fresh fruit exports to Bulgaria reached an average of 3,313.50 thousand $, while imports were 7,606.17 thousand $ (2.29 times higher), resulting in a deficit of 4,292.67 thousand $. The main export item was bananas (2,953.50 thousand $ - 89.13), while the main import items were lemons and limes (1,242.67 thousand $ - 16.34%), tangerines and clementines (1,194.50 thousand $ - 15.71%) and grapes (1,172.67 thousand $ - 15.42%).

Trade between Romania and Sweden, with fresh fruit, was more punctual, taking place only in 2018, 2022 and 2023, involved a small number of products (seven), the average trade balance being in surplus of 16.33 thousand $, given that exports reached 24 thousand $ and imports 7.67 thousand $.

It can be stated that on the relationship with Bulgaria. The project (individualized by the acronym EU FFAdv and ID 101021941) did not have a significant impact (Romania exporting mainly transited fruits – bananas), while on the relationship with Sweden the impact was obvious, with exports in 2022 and 2023 being dominated by locally obtained products (blueberries). It can be recommended to continue, more strongly, the activities to promote fresh fruits.

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CRITICAL ANALYSIS OF THE EFFECTIVENESS OF EUROPEAN DIGITAL INNOVATION HUBS (EDIHS) IN THE AGRI-FOOD SECTOR

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Abstract

European Digital Innovation Hubs (EDIHs) are mandated to accelerate digital transformation across sectors, yet their effectiveness within small-scale agribusiness remains insufficiently examined. This study assesses the impact of EDIH services in Bulgaria, Romania, Slovenia, Greece, Spain, and Turkey, focusing on return on investment, operational efficiency, and sustainability, while identifying barriers that limit access for small farms. Methodologically, the research utilizes a comprehensive qualitative framework, synthesizing performance data from EU programs with a review of relevant academic literature. To ground findings in practice, the analysis integrates case studies of agri-focused hubs across the examined regions, revealing a notable dichotomy. Results show that while EDIHs reduce adoption risks and strengthen digital capabilities through training and "test-before-invest" services, agricultural participation remains low due to connectivity gaps, limited digital literacy, and financial constraints. Yet emerging low-cost and open-source tools validated by these hubs offer promise for improved decision-making and reduced production costs. The study concludes that targeted support measures aligned with rural needs are essential to ensure long-term EDIH viability and promote resilient, inclusive agri-food systems.

Key words**:** *agriculture, digitalization, EDIHs, return on investment, sustainability*

INTRODUCTION

Digital transformation has become a strategic priority in European agriculture, as the sector is increasingly expected to respond to productivity pressures, environmental constraints, market volatility, labour shortages, and rising demands for traceability and resilience.

In this context, digital technologies such as precision farming systems, sensor-based monitoring, artificial intelligence, farm management software, and data-driven decision-support tools are presented as key enablers of smarter and more sustainable agri-food systems.

However, the practical uptake of such technologies remains uneven, especially among small and medium-sized farms, where adoption is often constrained by high investment costs, uncertain economic returns, limited digital skills, fragmented production structures, and insufficient access to advisory support (Wolfert et al., 2017; Klerkx & Rose, 2020) [23, 14].

Within this policy and technological context, European Digital Innovation Hubs (EDIHs) have emerged as one of the main instruments through which the European Union seeks to accelerate digital transformation across sectors.

Designed under the Digital Europe Programme as one-stop support structures, EDIHs are intended to provide access to technical expertise, testing facilities, digital skills development, advisory support, innovation networking, and guidance on access to finance (European Commission, 2021; Kalpaka et al., 2020) [6, 13].

Their institutional logic is particularly relevant for agriculture, where digital adoption rarely depends on technology availability alone, but also on whether potential users can test solutions under realistic conditions, understand their expected value, and integrate them into everyday

managerial practice. The agri-food sector presents a particularly demanding environment for the assessment of EDIHs effectiveness. Unlike many industrial settings, agriculture is shaped by biological variability, seasonal dependence, climate exposure, fragmented farm structures, and considerable diversity in technological readiness. As a result, the adoption of digital tools in agriculture is not simply a technical decision, but an economic, organizational, and often behavioural one (Klerkx & Rose, 2020) [14]. Farms and agri-food enterprises, especially smaller ones, frequently require demonstration activities, practical experimentation, trusted intermediation, and continuing support before digital technologies become operationally useful.

Scholarly and policy analysis increasingly point to the need for a more rigorous examination of how digital innovation support reaches agriculture. Although the agri-food sector holds strategic importance for food security, rural sustainability, and economic development, it occupies a comparatively peripheral position within the broader digital innovation landscape, lagging behind manufacturing and ICT-intensive industries (Toma-Constantin et al., 2025) [21]. This discrepancy generates an important analytical tension. European policy frameworks, including the Common Agricultural Policy and related digitalisation programmes, consistently elevate agriculture as a priority domain for the green and digital transitions (European Commission, 2021; FAO, 2022) [6, 10]. Yet empirical evidence suggests that agricultural actors remain substantially underrepresented within digital innovation support structures, and that hub initiatives diverge markedly in their territorial positioning, strategic orientation, and governance configurations (Miörner et al., 2019; Hervás-Oliver et al., 2021; Rissola & Sörvik, 2018) [15, 12, 16].

This question becomes even more important when the focus is placed on small farms and small agri-food enterprises. Many digital solutions continue to be developed with assumptions that do not fully correspond to the realities of smaller agricultural users. High upfront costs, uncertain return on investment, low interoperability, weak connectivity, insufficient digital literacy, and limited organizational capacity often prevent these actors from benefitting from innovation support to the same extent as larger and better-resourced firms (Wolfert et al., 2017; FAO, 2022; U.S. Government Accountability Office, 2024) [23, 10, 22]. In this respect, the effectiveness of EDIHs must also be examined through the lens of accessibility and inclusion.

A further reason for critical assessment is that the expected benefits of agricultural digitalization are not automatic. Digital tools may improve operational efficiency, support better use of inputs, enhance traceability, and contribute to environmental monitoring, but these outcomes depend heavily on the conditions under which technologies are introduced and used. In practice, the economic credibility of adoption remains one of the most important unresolved issues, as farmers and agri-food enterprises are often reluctant to invest when the return on investment is difficult to estimate in advance or when the benefits are highly context-specific (Klerkx & Rose, 2020) [14].

Against this background, the present paper examines the effectiveness of EDIHs in the agri-food sector through a critical analytical perspective. Rather than treating EDIHs as inherently successful instruments of digital policy, the study evaluates the extent to which their service model responds to the specific needs and structural constraints of agricultural users across six countries - Bulgaria, Romania, Slovenia, Greece, Spain, and Turkey, selected as a comparative field in which agri-food digitalization support is present but unevenly developed. Despite the expanding policy relevance of EDIHs, rigorous comparative analysis of how effectively their service architecture is tailored to the structural characteristics of the agri-food sector — and particularly to small farms and smaller agri-food businesses — remains limited. This paper therefore aims to critically assess the potential of EDIHs to support digital transition in the agri-food sector across six national contexts, examining specifically

economic viability, operational efficiency, environmental sustainability, and the inclusiveness of access for smaller agricultural actors.

The contribution of the paper is twofold. First, it shifts the discussion from a general description of EDIHs toward a more evaluative assessment of their practical relevance in agriculture. Second, it positions EDIHs within the wider debate on rural innovation, digital inclusion, and the governance of agri-food transformation in Europe. In doing so, the paper argues that EDIHs have real potential to support agricultural modernization, but that their current effectiveness remains partial, uneven, and strongly conditioned by sector-specific adaptation, local ecosystem capacity, and the ability to reach smaller agricultural users under real-world constraints.

Beyond the well-established observation that small farms face difficulties in accessing digital technologies, the paper focuses on the specific institutional mechanisms through which EDIHs may influence agricultural digital adoption. The analysis examines whether the EDIH service model can reduce uncertainty before investment, support experimentation through test-before-invest services, strengthen digital capabilities through sector-relevant training, and connect agricultural users with innovation networks and financing opportunities. These mechanisms are assessed in relation to the structural conditions of small farms rather than against generic SME assumptions. In this way, the discussion moves from the general problem of small-farm digital exclusion towards a more specific assessment of whether EDIHs are sufficiently adapted to agri-food realities.

MATERIALS AND METHODS

This study employs a qualitative comparative methodology to examine how effectively EDIHs can support the digital transition of the agri-food sector. The analytical design combines a systematic review of peer-reviewed literature with critical analysis of institutional and policy documents concerning agricultural digitalisation and the European innovation support infrastructure in which EDIHs are embedded.

The analytical framework integrates two complementary sources of information. First, a structured review of scientific literature on digital agriculture, innovation ecosystems, and technology adoption in the agri-food sector was conducted to identify the main conceptual approaches relevant to the study. The review focused primarily on sources published between 2020 and 2025, while selected earlier studies were included where they provided foundational conceptual insights on digital agriculture, innovation ecosystems, and technology adoption. Sources were selected based on relevance to at least one of the following dimensions: EDIH service models, agricultural digitalization, innovation ecosystems, digital adoption barriers, or the accessibility of digital support services for farms and agri-food SMEs. Bibliographic discovery was conducted through search environments such as Google Scholar, while additional academic materials were identified through publisher platforms, including MDPI, and through articles published in Scopus-indexed journals. Research Gate was used selectively as an access and retrieval channel for publications already identified as relevant. Second, the study examines institutional and policy documents related to European digital innovation initiatives, including strategic frameworks, programme documentation, and reports describing the objectives and operational mechanisms of EDIHs. This combination makes it possible to connect conceptual interpretation with policy-oriented analysis.

The empirical scope focuses on six countries: Bulgaria, Romania, Slovenia, Greece, Spain, and Turkey. The six countries were selected as a purposive comparative sample reflecting variation in agri-food specialization, EDIH visibility, ecosystem maturity, and regional institutional context. The inclusion of both EU Member States and an associated regional economy provides a broader comparative perspective on how EDIH-related initiatives interact with agricultural systems under different structural conditions.

Bulgaria and Romania reflect agricultural systems in which digitalisation is still developing and where small and fragmented farms face strong structural barriers. Slovenia and Greece represent intermediate contexts with more visible agri-food-oriented digital innovation initiatives and stronger links between agriculture and innovation support. Spain illustrates a more mature agri-food innovation ecosystem operating within denser institutional networks, while Turkey provides a relevant comparative case of an emerging regional economy with active modernisation agendas around AgriFood 4.0. This typological diversity makes it possible to identify recurring patterns and limitations in EDIH effectiveness across different agricultural and institutional settings. The design therefore does not claim statistical representativeness for the entire European agri-food sector, but supports analytical comparison across contrasting cases.

To structure the comparison, the study applies four principal analytical indicators: economic viability, operational efficiency, sustainability outcomes, and accessibility for smaller agricultural actors. These indicators were interpreted comparatively across the six country cases in order to identify patterns in how EDIH service models interact with agricultural sector structures and digital adoption conditions. Economic viability refers to expected return on investment and cost efficiency. Operational efficiency concerns improvements in farm management, decision-support processes, and resource optimization. Sustainability outcomes are assessed in relation to environmental monitoring, more efficient input use, and enhanced resilience of agricultural production systems. Accessibility refers to the extent to which small farms and rural enterprises are able to reach innovation support services and integrate digital solutions into their practices. Across the six country cases, the comparison examined how these indicators were reflected through hub specialization, service orientation, ecosystem maturity, and the likely accessibility of support for smaller farms and agri-food SMEs. In addition, the study considers structural barriers that may influence digital adoption in agriculture, including limited digital literacy, insufficient broadband connectivity in rural areas, financial constraints, and the fragmented structure of many agricultural holdings. These contextual factors are included to support a more careful interpretation of the practical relevance and likely effectiveness of EDIH services under real-world conditions.

RESULTS AND DISCUSSIONS

The available academic and institutional evidence indicates that EDIHs have introduced a potentially relevant support architecture for the digital transformation of the agri-food sector, yet their practical relevance remains uneven across countries, user groups, and forms of agricultural activity. At the policy level, EDIHs are conceived as one-stop support structures combining technical expertise, technology testing, digital skills development, innovation networking, and support in identifying investment opportunities (European Commission, 2021) [6]. This service logic is particularly relevant to agriculture, where digital adoption depends not only on technology availability, but also on whether users can test solutions, understand their value, and integrate them into farm management routines.

A first key finding concerns the mismatch between the formal presence of agri-food in the EDIH network and the actual intensity of sectoral participation. According to Toma-Constantin et al. (2025) [21], agricultural users accounted for only approximately 1.7% of all EDIH beneficiaries as of late 2024, while manufacturing represented close to 28% (Toma-Constantin et al., 2025) [21]. As of May 2025, the EDIH network had grown to 254 hubs in total, of which 93 - approximately 36% - provided some form of agri-food-related support, and only 12, representing roughly 5%, operated with an exclusive agricultural mandate (European Digital Innovation Hubs Network, 2025) [7]. In parallel, the wider network had engaged over 200,000 participants through approximately 5,000 events and processed upwards of 18,000 service interactions by September

2024 (Carpentier et al., 2025) [3]. Taken together, these data indicate that the core obstacle is not network inactivity but rather the relatively shallow penetration of EDIH services into agricultural practice.

The overall picture thus warrants a measured reading: while EDIHs offer a structurally promising platform for advancing agricultural digitalisation, both the intensity of sector-specific engagement and the breadth of inclusive outreach continue to fall short of their stated objectives.

A second analytical issue concerns the practical relevance and likely effectiveness of EDIH services in addressing the main constraints of agricultural digital adoption. The service model is well aligned with several barriers identified in previous research, including uncertainty before investment, insufficient digital skills, weak advisory support, and limited interaction between technology providers and agricultural users (European Commission, 2021; Kalpaka et al., 2020; Gavkalova et al., 2024) [6, 13, 11].

Among these functions, test-before-invest appears particularly important. Farmers often hesitate to adopt digital technologies when expected economic returns are uncertain or highly context-dependent. Experimentation environments provided by EDIHs can therefore reduce perceived risk by allowing technologies to be tested under realistic farm conditions, which may support more credible investment decisions (Wolfert et al., 2023) [24].

Training and digital skills development represent a second important dimension of effectiveness. The usefulness of digital tools depends heavily on users' capacity to interpret data, integrate technologies into farm routines, and adapt management practices. EDIHs address this need through training, mentoring, and advisory services. Their practical value, however, appears stronger where such support is adapted to farmers and agri-food SMEs rather than delivered in generic formats (European Commission, 2021; Wolfert et al., 2023) [6, 24].

A third dimension concerns innovation intermediation and access to finance. EDIHs can connect agricultural actors with funding opportunities, investment instruments, and innovation networks, helping bridge the gap between technological interest and practical implementation (Crupi et al., 2020; Sassanelli et al., 2022; Serrano-Ruiz et al., 2025) [4, 17, 18]. In this sense, their role is not limited to service delivery alone, but extends to the coordination of broader support environments that can facilitate adoption.

Economic viability remains one of the most difficult dimensions in evaluating agricultural digitalization. Digital technologies may improve monitoring, input allocation, decision-making, labour efficiency, and traceability, yet these outcomes are not automatic and depend strongly on local production conditions, technology selection, and managerial capability. Empirical evidence shows that digital tools can generate economic benefits when technologies are well matched to farm needs, but adoption often remains constrained by high costs, interoperability challenges, and uncertainty regarding long-term returns (Boehlje & Langemeier, 2021; Dhoubhadel et al., 2021; Finco et al., 2023) [2, 5, 9]. From this perspective, EDIHs may contribute most effectively when they help agricultural users distinguish between suitable and unsuitable investments under farm-specific conditions.

Operational efficiency, sustainability, and resilience should be interpreted in a similarly careful way. Digital tools can enhance information use, resource allocation, traceability, and environmental monitoring, but such improvements appear more likely where experimentation, advisory support, and managerial adaptation are combined within a supportive institutional environment (Ayre et al., 2019; Stoeva et al., 2021; Wolfert et al., 2023) [1, 19, 24]. The practical contribution of EDIHs therefore lies less in guaranteeing such outcomes than in creating conditions under which they become more plausible.

Accessibility for small farms is a central condition of EDIH effectiveness in agriculture. Although the EDIH model is formally designed to support SMEs, practical accessibility depends on whether services remain affordable, intelligible, and usable for smaller agricultural actors operating under

tighter financial, organizational, and infrastructural constraints (European Commission, 2021) [6].

Among the barriers identified in the analysis, financial constraints appear to have the greatest practical impact on the adoption of digital technologies in agriculture. Limited digital skills and uneven rural infrastructure remain important obstacles, but the high upfront cost of digital tools, uncertainty regarding return on investment, and limited access to finance most directly affect the decision-making capacity of small and medium-sized farms. In practice, financial barriers often determine whether agricultural users are able to move from awareness and interest to actual experimentation and adoption. This also explains why test-before-invest services are particularly relevant in the EDIH model, as they can reduce perceived investment risk before farmers commit their own financial resources.

Beyond this hierarchy, small farms often face multiple barriers simultaneously. The literature consistently highlights uneven broadband connectivity in rural areas, limited digital skills, financial constraints, and fragmented farm structures as persistent obstacles to digital transformation (EU CAP Network, 2025) [8]. Work on rural digital innovation hubs also emphasizes that sustainable support depends on business models and service designs adapted to local needs rather than transferred in generic form (Stojanova et al., 2022) [20].

The practical implication is that the relevance of EDIH services cannot be inferred from formal availability alone. A service may be institutionally present and still remain difficult to use if technologies are too costly, too complex, or weakly adapted to everyday farm realities.

A related risk is that EDIH-supported digitalisation may unintentionally favour better-resourced farms or agri-food SMEs within the eligible target groups. Although EDIHs are designed to support SMEs and other eligible organisations, equal formal access does not necessarily ensure equal practical uptake. Better-resourced agricultural users usually have greater investment capacity, stronger managerial capacity, and higher digital readiness, which allows them to benefit more rapidly from testing, training, and innovation support. Smaller farms, by contrast, often lack the financial reserves, specialised staff, and time required to convert such services into practical implementation. As a result, EDIH-supported digitalisation may still produce uneven outcomes unless services are adapted to the structural conditions of small agricultural actors (Fig. 1).

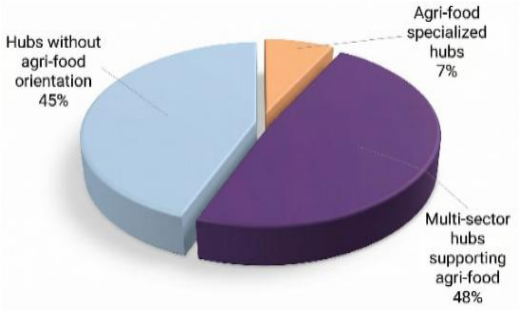

Fig. 1. Distribution of EDIHs by agri-food orientation (2025)
Source: Authors' own elaboration based on Toma-Constantin et al. (2025) [21]; European Digital Innovation Hubs Network (2025) [7].

For this reason, accessibility should be treated not as a secondary social concern, but as a core analytical criterion in assessing likely effectiveness. These broader analytical dimensions become clearer when examined through comparative national contexts.

The comparative positioning of the six cases is summarized in Figure 1.

The six-country comparison suggests that EDIH effectiveness in agriculture is shaped less by the formal existence of hubs alone and more by the interaction between agri-food specialization, service articulation, ecosystem maturity, and the practical accessibility of services for smaller agricultural actors (Table 1).

Bulgaria, Greece, and Slovenia present the clearest examples of explicit agri-food positioning. In these cases, hub missions and services are framed more directly around agricultural digitalization, including precision farming technologies, demonstration environments, and sector-specific training activities. Such specialization improves the visibility of hubs for potential users and

reduces the interpretive distance between institutional programmes and farm-level needs. Spain illustrates a different configuration in which effectiveness appears to depend strongly on the maturity of the surrounding innovation ecosystem. Spanish hubs operate within denser networks connecting research institutions, technology providers, competence centres, and public programmes. In this context, the hub functions less as an isolated service provider and more as a coordination platform facilitating experimentation, training, and access to financing.

Turkey represents an emerging ecosystem model. Strategic narratives emphasize agricultural modernization, AgriFood 4.0, and ecosystem building, indicating a strong ambition to integrate agriculture into digital innovation networks. However, this model appears to be in a phase of institutional consolidation in which experimentation and capability formation remain especially important.

Romania presents the most heterogeneous configuration. Although substantial digital capabilities exist, agriculture is less consistently articulated as the central focus of hub identity. In several cases, agricultural applications appear within broader digitalization portfolios covering manufacturing, smart cities, healthcare, or public administration. This does not necessarily reduce institutional capacity, but it may weaken the visibility of digital support pathways for agricultural users.

Table 1. Comparative overview of EDIHs supporting the agri-food sector in selected countries

Country	Main EDIH	Sector specialization	Type of model	Key services
Bulgaria	AgroDigiRise	Agriculture	Sector-specialized	Precision farming, digital skills
Greece	DigiAgriFood	Agriculture	Sector-specialized	Innovation brokerage, training
Slovenia	DIH AGRIFOOD	Agriculture	Sector-specialized	Living labs, technology transfer
Spain	Andalucía Agrotech	Agri-food ecosystem	Ecosystem-driven	Coordination, scaling
Turkey	AgrInnovate	Agri-food	Emerging ecosystem	AgriFood 4.0 transition
Romania	Multiple hubs	Multi-sector	Mixed configuration	General digitalization

Source: Author's analysis based on official data

Source: Authors' analysis based on the official data.

Slovenia occupies an important intermediate position because it combines both specialized and multi-sector support structures. A dedicated agri-food hub provides stronger visibility and clearer targeting for agricultural users, while broader multi-sector hubs may offer access to a wider technological resource base and cross-sector innovation spillovers.

Taken together, the country comparison shows that the most important divide is structural rather than purely national. This structural divide reflects differences in sectoral specialization, institutional coordination, and the capacity of innovation ecosystems to translate digital technologies into practical agricultural solutions. EDIH support appears more likely to be effective where a clear agri-food mission is combined with sector-relevant service translation, stronger ecosystem embedment, and lower access barriers for smaller farms and agri-food SMEs.

Across the reviewed evidence, EDIHs emerge as potentially valuable intermediary structures for agricultural digitalization, but not as automatically effective instruments. Their practical relevance appears stronger where services are translated into concrete agricultural use cases, where experimentation is linked with advisory and training support, and where smaller agricultural actors can realistically engage with the support offered.

Conversely, where hub missions remain broad, services generic, or access barriers high, the distance between formal institutional presence and practical agricultural value becomes wider. This helps explain why the effectiveness of EDIHs depends not simply on the presence of hubs, but on the combination of specialization, ecosystem maturity, and real accessibility for smaller agricultural actors.

Taken together, the comparative evidence supports several conclusions. First, EDIH effectiveness in agriculture appears stronger where hubs demonstrate clearer agri-food specialization and translate services into sector-relevant applications.

Second, ecosystem maturity and institutional embedding strongly influence the capacity of hubs to support digital adoption. Third, structural barriers affecting smaller farms remain a significant constraint on inclusive digital transformation.

A conceptual positioning of EDIH institutional models for agricultural digitalization in selected countries is presented in Fig. 2.

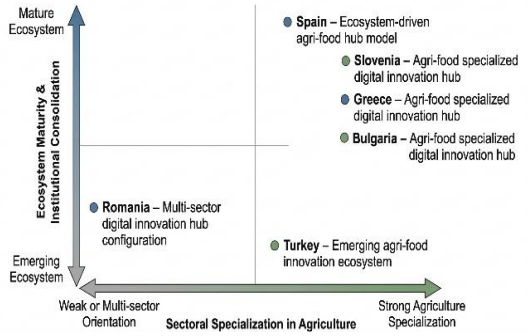

Fig. 2. Conceptual positioning of EDIH institutional models for agricultural digitalization in selected countries

Source: Authors' own elaboration based on Toma-Constantin et al. (2025) [21] and Rissola & Sörvik (2018) [16].

Overall, the findings suggest that EDIHs have meaningful potential to support agricultural digitalization. However, their contribution depends heavily on sector-specific adaptation, ecosystem capacity, and the ability to reduce the practical barriers that limit digital adoption among smaller agricultural actors.

CONCLUSIONS

European Digital Innovation Hubs constitute a structurally significant policy instrument for advancing the digital transformation of the agri-food sector, yet the evidence examined in this study demonstrates that their practical impact is distributed unevenly across national contexts and user categories.

Despite its recognised strategic importance in EU policy agendas, the agri-food sector remains considerably underrepresented within the EDIH ecosystem as a whole. This pattern reveals that institutional availability of digital support structures does not, by itself, generate meaningful or widespread sectoral uptake.

The effectiveness of EDIHs in agriculture depends strongly on the adaptation of services to farm realities. Experimentation environments, advisory support, and user-oriented service design are central for translating technological opportunities into practical agricultural use.

Accessibility for small farms is a decisive condition for inclusive digital transformation. Where services remain too costly, complex, or weakly adapted, smaller agricultural actors face difficulties in benefiting from available innovation support.

This finding should be interpreted not only as a restatement of a known general problem, but also as an evaluative criterion for assessing how well EDIH services are adapted to agricultural realities. In this respect, EDIHs can support more inclusive digitalisation only when their services are sector-specific, affordable, practically intelligible, and connected to the actual decision-making conditions of smaller agricultural actors.

The comparison of Bulgaria, Romania, Slovenia, Greece, Spain, and Turkey shows that EDIH effectiveness is shaped by the interaction between agri-food specialization, ecosystem maturity, and local institutional embedding. Countries differ less in the existence of hubs than in how clearly agricultural services are articulated and operationalized.

From a policy perspective, more inclusive agricultural digitalization requires stronger sector-specific specialization, improved affordability for smaller users, and closer coordination between digital innovation hubs, rural advisory systems, infrastructure development, and financing mechanisms.

These findings also suggest that EDIH effectiveness in agriculture depends on multi-level governance alignment. At the EU level, common frameworks are needed to ensure that EDIHs remain connected to broader digital transformation and competitiveness objectives. At the regional level, hub activities need to reflect the specific structure of local agricultural systems, including farm size, sectoral specialisation, and ecosystem maturity. National policy is essential for operationally embedding these services in farm-level realities, including links to advisory and rural infrastructure systems. Without such alignment, EDIHs risk remaining visible as policy instruments while having uneven practical effects across different agricultural contexts.

The study is limited by the uneven availability

of public evidence on individual hubs and by its reliance on literature and institutional sources rather than farm-level performance data. Future research should therefore examine user experiences and measurable post-adoption outcomes more directly.

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FINANCING DIGITAL INNOVATION IN AGRICULTURE: A STUDY OF BULGARIAN SMES

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Abstract

Digitalization is identified as a key factor for enhancing efficiency and competitiveness in the agricultural sector. The aim of the paper is to analyze and evaluate the financial aspects of digital transformation in the context of financing digital solutions through European/national programmes, and to assess the attitudes of SMEs toward the adoption of Industry 4.0 technologies. A survey was conducted between December 2025 and February 2026 using a structured interview and an online questionnaire. The research focuses on agricultural SMEs in Bulgaria. We evaluated the dependencies among the awareness of available funding opportunities, access to financial resources, the level of digitalization, attitudes toward the adoption of advanced technologies, among others. The direction and strength of the association are evaluated using Somers' d (Y|X), as a complement to Pearson's χ^2 and Spearman's ρ. The findings reveal that policies fostering digitalization should prioritize enterprises with limited capital, while simultaneously addressing the development of their internal capacity, the transfer of knowledge, the sharing of risk associated with slower investment returns, and the creation of targeted incentives.

Key words**:** *Industry 4.0 technologies, financial instruments, digitalization of agriculture, investment behavior*

INTRODUCTION

The contemporary agricultural sector in Europe, and Bulgaria in particular, is undergoing a period of profound transformation driven by the digital revolution and the reforms of the European Union's Common Agricultural Policy (CAP). European policies and national support strategies have positioned digitalization as a fundamental instrument for enhancing competitiveness and overcoming contemporary market challenges [16].

The achievement of such high economic efficiency is inextricably linked to the concept of Agriculture 4.0, which is identified as a key driver for economic growth and the establishment of a more sustainable, adaptive, and environmentally responsible agricultural sector [8]. It is widely acknowledged that the successful advancement of digital agriculture necessitates not only technological solutions, but also targeted state strategies and investments to bolster the sector's resource capacity [16] [11], primarily due to the substantial financial commitments required. Empirical evidence indicates that enterprises undertake digital transformation at varying paces. Large-scale enterprises typically assume a leading role in the digitalization process, whereas small and medium-sized enterprises (SMEs) frequently lag behind due to an acute deficit of financial resources [6], a lack of adequate awareness [9], among other constraints. It is important to note that a sluggish digital transformation entails a multitude of risks, primarily because SMEs play a pivotal role in ensuring production capacity and economic viability. They constitute an integral component of the agricultural sector in numerous developing and transitional economies, frequently accounting for a substantial proportion of all agricultural enterprises. A comprehensive understanding of these barriers necessitates a meticulous analysis of the agricultural technologies per se. The deployment of contemporary 'smart farming' solutions, such as IoT sensors, drones, and farm management software systems, requires a significant initial capital outlay. According to recent studies, the high investment costs associated with the acquisition, integration, and maintenance of such equipment create an almost

insurmountable economic barrier for small-scale farms [18].

Although small and family-owned farms are increasingly recognized as a fundamental pillar for the sustainable development of rural areas and the broader agricultural economy in Bulgaria [12], a highly disproportionate distribution of project and investment activity is currently evident. While large corporate structures possess the requisite administrative capacity to attract European funding, smaller farms frequently remain marginalized within the financial ecosystem. Contextualizing this issue at the national level, previous research [17] has established that digital transformation processes within Bulgarian enterprises generally continue to lag behind the European average, predominantly due to constrained financial capabilities and a shortage of skilled personnel.

In existing literature, digitalization is primarily examined from a technological or adoption perspective. However, there remains an insufficient understanding of how financial instruments and policies for digitalization interact with the organizational capacity of SMEs. Furthermore, it is under-researched whether awareness and positive attitudes toward digital transformation actually translate into real investments in digital technologies.

The primary objective of this paper is to analyze and evaluate the financial dimensions of SMEc digital transformation, specifically within the context of funding digital solutions through European and national programs. Furthermore, it aims to ascertain the attitudes of agricultural SMEs in Bulgaria regarding the challenges impeding the digital transformation of their holdings.

The present study contributes to literature by expanding the analytical framework of research on the digitalization of agricultural SMEs by integrating the applied financing instruments/policy and the firms' investment behavior as central elements of digital transformation. It contributes to clarifying the interaction between financial support policy and the organizational and human capacity of SMEs. The results of the study will facilitate better understanding of the conditions under which financial policies can effectively stimulate digitalization in this vulnerable segment of the agricultural sector.

Through a structured questionnaire survey, the current digital capacity of agricultural SMEs is assessed, alongside the extent to which they require external support for the future integration of Industry 4.0 technologies.

MATERIALS AND METHODS

The present study adopts an empirical approach to analyze the level of awareness and access to financial resources, compared with the current degree of digitalization and the actual utilization of advanced technologies. The research was conducted over the period from December 2025 to February 2026, applying both structured interviews and an online survey. The survey was developed based on a systematic literature review and strictly adheres to the established five-step framework proposed by [8] for the design of semi-structured questionnaires. This rigorous methodological process ensures the reliability of data collection by accurately identifying the research prerequisites, leveraging prior knowledge regarding the economic dimensions of digitalization, and formulating logically coherent questions. The object of this study are small and medium-sized agricultural enterprises (SMEs). The final analysis is based on valid questionnaire responses, yielding a target sample comprising N = 38 economic entities. A purposive sampling approach was adopted during the sample formation, focusing exclusively on strategic decision-makers. This methodological choice aligns with economic empirical studies of SMEs within emerging markets [1], where respondent competence is deemed a more critical factor than random selection. However, the relatively small sample size represents a notable limitation of this research. While the purposive sampling ensures the high competence of the respondents, the small number of observations implies that the findings should be interpreted

as exploratory. They highlight early trends and ordinal associations regarding the digitalization of Bulgarian SMEs, rather than providing highly generalizable conclusions for the entire agricultural sector. The non-probability sample was drawn from active economic entities, with its structure attempting to reflect the current landscape of Bulgarian agriculture. Specifically, it captures the enterprises' level of awareness regarding available financing opportunities, access to financial resources, the current degree of digitalization, attitudes toward the adoption of Industry 4.0 technologies, and the extent to which advanced technologies are utilized.

The survey instrument is structured into three logically interconnected sections. The first section, designated as "Enterprise Profile" encompasses general questions (e.g., enterprise category, respondent's position, and primary agricultural activity). The second section, "Level of Digitalization," aims to ascertain the technological maturity of the enterprises and the subjective perceptions of management regarding the impact of digitalization on business development. The third section, "Financial Instruments," seeks to investigate the relationship between access to capital and investment behavior/activity. It poses questions regarding the perceived benefits of implementing agricultural digitalization solutions, awareness with various funding sources, and the associated constraints. To quantify and compare the outcomes pertaining to the respondents' subjective perceptions of their readiness for digital transformation, a Likert-type scale was employed [10]. This methodological instrument facilitates the quantitative measurement of qualitative attitudes, providing respondents with a response continuum ranging from “Strongly disagree/Low level” to “Strongly agree/High level”.

For the analytical purposes of this study, the following variables were established.

- Categorical variables – delineate the demographic and structural profile (enterprise size, manager's age, production orientation) as well as the current level of digital maturity.

- Binary variables – directed to capture the investment behavior. The sources of financing (internal funds, bank loans, European funds) were dummy-coded, assigning a value of 1 for 'utilized' and 0 for 'not utilized'.

- Normalized continuous variables – the evaluation of the barriers to digitalization was transformed onto a scale from 0 to 1, where values approaching 1 indicate a critical severity of the corresponding barrier.

To ensure a consistent analytical structure, the study is organized around four conceptual dimensions that reflect the processes influencing digital transformation in agricultural SMEs. They capture the financial, organizational, behavioral, and perceptual aspects of digitalization and are examined through a set of hypotheses, as outlined below:

Dimension 1: Awareness and Financial. The dimension examines awareness and financial knowledge as prerequisites for digital transformation, covering both familiarity with financial instruments and specific knowledge of European and national funding opportunities. Four hypotheses examine whether higher levels of awareness are associated with greater digitalization and more active investment planning in agricultural SMEs.

H1: A higher level of awareness regarding financing opportunities is positively associated with a more advanced stage of planned investments in digital technologies.

H2: Greater awareness of European/national funding opportunities is positively associated with a higher self-assessed level of digitalization.

H3: A higher level of general awareness is positively associated with a greater degree of familiarity with financial instruments.

H4: A higher degree of familiarity with financial instruments is positively associated with a more advanced stage of investment planning.

Dimension 2: Organizational Capacity and Human Capital.

The focus is on internal organizational capacity and human capital as key conditions for digital technology implementation in this dimension. Three hypotheses assess whether

staff readiness and firms' internal capacity to adopt digital solutions influence investment behavior and the use of external financing.

H1: Greater staff readiness to adopt digital solutions is positively associated with a higher organizational capacity to implement digital technologies without external support.

H2: A higher organizational capacity for the implementation of technologies without external support is positively associated with a more advanced stage of planning digital investments.

H3: A higher organizational capacity to implement digital technologies without external support is negatively associated with the enterprise's experience in applying for European funding programs.

Dimension 3: Drivers, Barriers, and Investment Behavior.

The behavioral and structural factors are examined as influencing digital investment decisions in agricultural SMEs. It focuses on the role of current digitalization level, perceived barriers and accumulated driving factors related to investment planning and actual implementation. Three hypotheses are formulated to assess how positive incentives and constraining factors together shape SMEs digital investment behavior.

H1: A higher level of digitalization is positively associated with a more advanced stage of investment planning.

H2: A higher number of perceived barriers is negatively associated with the probability of an enterprise being at a more advanced stage of planning and executing digital investments.

*H3:*A higher number of driving (stimulating) factors for digitalization is positively associated with a more advanced stage of investment planning.

Dimension 4: Perceptions of Digital Transformation

Enterprises' perceptions of digital transformation in relation to sustainability and competitiveness are examined in this dimension. Two hypotheses assess whether these perceptions are associated with digitalization levels and prior experience with European funding programs.

H1: The perception of digital transformation as a key driver for sustainability and competitiveness is positively associated with a higher self-assessed level of digitalization.

H2: Greater enterprise experience with European funding programs is positively associated with the perception of digital transformation as a key driver for sustainability and competitiveness.

As a preliminary step in the analysis, cross-tabulations are applied to present the distribution of observations across the examined ordinal variables. To establish the presence of a statistically significant dependence between them, Pearson's χ^2 test is used, which provides an overall assessment of the independence of the distributions. Given the ordinal nature of the variables and the limited statistical power of the Pearson χ^2 test when dealing with small subgroups and numerous ties, Spearman (ρ) rank correlation coefficient is also incorporated into the analysis. This coefficient is highly recommended for ranked and non-normally distributed data [2] [4] [7]. For pairs characterized by a theoretically expected direction and a monotonic relationship, it is appropriate to apply the ordinal measure Somers' d (Y|X). The asymmetric specification of this measure facilitates the interpretation of the effect on the dependent variable (Y) given a systematic increase in the independent variable (X) [13]. Somers' d is a particularly valuable metric for small sample sizes and data featuring a multitude ties, as it is capable of revealing a statistically significant trend even where the Spearman correlation shows statistically non-significant results [14]. In this paper, the formulated hypotheses are set as ordinal pairs of variables with an anticipated monotonic relationship. Consequently, the evaluation of the direction and strength of the association between them is predominantly based on Somers' d (Y|X), serving as a robust complement to Pearson χ^2 (for general dependence) and Spearman ρ.

RESULTS AND DISCUSSIONS

The analysis of the primary data shows a sample predominantly composed of micro-enterprises (n = 28) within the Bulgarian agricultural sector, accounting for 73.68% of

the total, followed by small enterprises (23.68%). Regarding production orientation, crop farming prevails within the sample (68.4%), succeeded by mixed farming (23.7%) and livestock production (7.9%). The data analysis reveals substantial disparities related to farm size: the probability of small enterprises diversifying their operations (into mixed farming) is over six times higher (66.7%) compared to micro-enterprises (10.7%). Conversely, micro-enterprises exhibit a significantly stronger propensity to remain strictly specialized in crop production (78.6%) relative to small holdings (33.3%).

Concerning the cross-distribution of enterprises by size and type of economic activity, the findings indicate that the sampled micro-enterprises are characterized by a high degree of specialization in crop farming (78.57%). In contrast, small enterprises shift status to mixed farming (66.67%). This structural complexity inherent in micro-enterprises posts a critical determinant of specific digital requirements.

Furthermore, the empirical evidence suggests that micro-enterprises are equally adept at adopting new technologies compared to the small enterprises (Table 1). A total of 25% of the micro-enterprises identify themselves at an "Advanced" level, compared to 22% of the small enterprises given the same response. This evidence suggests that farm size is not the sole determinant to a more accelerated digital transformation. A plausible explanation is that exceptionally small teams facilitate faster and more streamlined decision-making, while the implementation of technology within a highly specialized activity is inherently less complex.

Table 1. Enterprise size by level of digitalization, 2026

Enterprise Category	Advanced	Basic	Planning Stage	Intermediate
Micro-enterprise	25.00% (n=7)	28.57% (n=8)	21.43% (n=6)	25.00% (n=7)
Small enterprise	22.22% (n=2)	11.11% (n=1)	44.44% (n=4)	22.22% (n=2)

Source: own contribution.

Concurrently, nearly half of the small enterprises remain situated strictly at the "Planning Stage". One probable cause for this delay is the broader diversification of their operations. For these entities, the digitalization process is inherently more challenging, as their holdings are typically larger and simultaneously engaged in multiple agricultural activities. Consequently, digitalization represents a more costly and risk-intensive endeavor for these owners, prompting them to exercise greater caution and defer tangible investments.

Regarding the cross-analysis of enterprise size and the sources of financing utilized over the past three years, the data reveal a substantial imbalance in the absorption of external capital. Micro-enterprises have used European/national funding at approximately half the rate of small enterprises. Specifically, the probability of accessing European subsidies for micro-enterprises is nearly twice as low as that observed for small enterprises. This disparity suggests the presence of market imperfections and a constrained utilization of financial instruments, likely stemming from institutional or other structural barriers.

Within *Dimension 1* (Awareness and Financial Knowledge), the results show that awareness is a necessary but not sufficient condition for digital investment. While internal consistency within the general awareness is confirmed (H3), and familiarity with financial instruments is positively related to investment planning (H4), awareness of funding opportunities does not systematically translate into higher digitalization levels or active investment behavior (H1, H2). This dimension therefore reveals a clear gap between information availability and actual investment decisions.

In contrast, *Dimension 2* (Organizational Capacity and Human Capital) highlights the central role of internal capabilities. Staff readiness is consistently associated with firms' capacity to implement digital technologies (H1), while enterprises with stronger internal capacity rely less on European funding programs (H3). At the same time, internal capacity alone does not automatically lead to more advanced

investment planning (H2), indicating that organizational capacity conditions, but does not independently drive, investment behavior.

The findings related to *Dimension 3* (Drivers, Barriers and Investment Behavior) show that digital investment decisions are primarily shaped by enabling factors rather than by perceived constraints. Higher levels of digitalization and a greater accumulation of driving factors are strongly associated with more advanced stages of investment planning (H1, H3), whereas perceived barriers do not significantly deter investment activity (H2). This suggests that positive incentives and prior digital experience outweigh the discouraging effects of reported obstacles.

Finally, Dimension 4 (Perceptions of Digital Transformation) confirms the existence of a discrepancy between perceptions and actions. Experience with European funding programs is associated with stronger recognition of digital transformation as a driver of sustainability and competitiveness (H2), yet positive perceptions alone are not linked to higher digitalization levels (H1).

All empirically supported hypotheses within the four conceptual dimensions are presented in Table 2.

The results indicate that SMEs with higher levels of digitalization demonstrate a stronger investment orientation, reflected in both ongoing and planned investments over the next three years (D3*H1*). These enterprises are more likely to plan or implement investments.

In contrast, SMEs with lower digitalization levels are more frequently characterized by low investment activity and an absence of planned investments. The findings suggest that digitalization is associated with a higher propensity for capital expenditure and more active investment planning, indicating a closer link between digital advancement and firms' investment behavior.

Analogously, the SMEs with higher levels of general awareness on the financial support mechanisms tend to show greater familiarity with financial instruments, including more advanced forms of knowledge related to their application. It can be assumed that general awareness plays an important role in shaping enterprises' capacity to identify, understand, and apply for support from available funding programs (D1*H3*).

Table 2. Research hypotheses with empirical support

Dimension	Hypotheses	Expected Sign	Statistical Evidence
D1: Awareness and Financial Knowledge	H3	+	Spearman ρ≈0.43, p≈0.022; Somers' d≈0.511, p=0.001; χ^2 p=0.001
	H4	+	Spearman ρ=0.314, p=0.055 (threshold); Somers' d≈0.26, p<0.029; χ^2 p=0.09
D2: Organizational Capacity and Human Capital	H1	+	Spearman ρ≈0.45, p≈0.0137 Somers' d≈0.377, p=0.019; χ^2 p=0.101
	H3	-	Spearman ρ=-0.48, p=0.0055 Somers' d≈0.39, p<0.000; χ^2 p=0.09
D3: Drivers, Barriers, and Investment Behavior	H1	+	Spearman ρ=0.618, p<0.001; Somers' d≈0.416, p<0.001; χ^2 p=0.046;
	H3	+	Spearman ρ=0.475, p=0.0029; Somers' d≈0.40, p<0.003; χ^2 p=0.11
D4: Perceptions of Digital Transformation	H2	+	Spearman ρ=-0.5226, p=0.0054 Somers' d≈0.39, p<0.01; χ^2 p=0.09

Source: own contribution, 2026.

The results indicate that staff readiness to work with digital tools is an important factor related to firms' capacity to implement digital technologies (D2*H1*). Enterprises with higher levels of staff readiness consistently demonstrate a greater ability to adopt digital solutions, suggesting that human capital plays a key role in the digital transformation process. Although the relationship is not fully captured by all statistical tests, a positive and systematic association is observed, indicating that higher staff preparedness is linked to stronger digital implementation capacity.

Next finding is that the presence of a larger number of driving factors is associated with more advanced stages of investment planning and execution *(D3H3*). Enterprises facing more motivating factors tend to progress more consistently toward active investment implementation rather than remaining at preliminary or non-investment stages. This suggests that the accumulation of complementary drivers plays an important role in translating intentions into actual digital investments. These findings highlight the importance of a systematic and coordinated

support policy in facilitating the actual implementation of digital investments.

The analysis examines whether the information policies implemented under various funding programs effectively stimulate investments in digital solutions (D1*H4*). The results indicate that higher awareness regarding financial instruments tend to reach more advanced stages of investment decision-making, where digital investments are either planned or already underway. This indicates that information availability and practical knowledge related to funding instruments are linked to a greater likelihood of moving from intention to actual investment activity. Overall, the findings point to the role of information policies in supporting more active decision-making regarding digital investments.

SMEs financial capacity appears to be inversely related to their experience with European funding programs (D2*H3*). Enterprises with limited ability to finance technological adoption through their own resources apply for European programs more frequently, whereas firms capable of self-financing digital investments tend to make less use of these opportunities. This suggests that EU programs function as a supportive mechanism to firms with limited self-financing capabilities.

The analysis highlights that greater experience with European programs over the past three years contributes to a better understanding of digital transformation as a key factor for sustainability and competitiveness (D4*H2*). Enterprises with more extensive participation in national and European funding programs tend to better recognize the economic and strategic benefits of digitalization. The results suggest that active participation in national/European funding programs for digital solutions enhances the perceived benefits of digitalization.

A total of five hypotheses within the four dimensions were not empirically supported (Table 3).

The analysis highlights a clear relationship between investment planning and the level of awareness regarding funding opportunities under European and national programs (D1H1).

Table 3. Research hypotheses not empirically supported

Dimension	Hypotheses	Expected Sign	Statistical Evidence
D1: Awareness and Financial Knowledge	H1	+	Spearman ρ≈0.26, p≈0.13 (ns); Somers' d=0.216, p=0.134 (ns); χ^2 p=0.010 – sig, but non-monotonic
	H2	+	Spearman ρ=0.378, p<0.044; χ^2 p≈0.45 (ns); Somers' d≈0.20, p≈0.27 (ns)
D2: Organizational Capacity and Human Capital	H2	+	Spearman ρ=0.219, p=0.245 (ns); χ^2 ns
D3: Drivers, Barriers, and Investment Behavior	H2	–	Spearman ρ=0.061, p=0.716 (ns)
D4: Perceptions of Digital Transformation	H1	+	Spearman ρ=0.195, p=0.240 (ns); (ceiling effect) Somers' d≈0.19, p<0.28; χ^2 p=0.45

Source: own contribution, 2026.

However, the results also reveal a distinct group of enterprises (nearly 24%) that, despite having sufficient information about available funding instruments, neither apply nor intend to apply for investment programs. This indicates that higher awareness does not translate uniformly into more active investment behavior. No consistent progression toward investment planning is observed among highly informed enterprises, as a part of them continues to refrain from investing in digital technologies. The findings suggest that awareness alone is not a sufficient condition to stimulate investment activity. Instead, the persistence of non-investment behavior among well-informed firms points to the presence of additional constraints, such as the scale of required investments, higher perceived risk, co-financing requirements, and administrative complexity, which may constrain the effective uptake of digital investment opportunities.

A similar pattern is observed when examining the role of awareness as a factor for achieving a higher level of digitalization (D1*H2*). The results indicate that, while awareness may be related to digitalization, this relationship is neither strong nor systematic. Higher levels of awareness do not consistently correspond to

more advanced stages of digitalization among enterprises.

The hypothesis that firms identifying digital transformation as a key factor for sustainability and competitiveness have already undertaken measures to increase their digitalization level (D4*H1*) is not supported. The results indicate that, although enterprises generally express a positive attitude toward digital transformation, this perception has not yet been translated into tangible actions aimed at implementing digital solutions. This discrepancy between recognition and actual implementation may be explained by the way firms assess digital transformation as uncertain and costly process, characterized by a slow return on investment, with its effects being inherently difficult to quantify [5].

An additional finding of this study is that the presence of more numerous barriers to obtaining European/national funding is not associated with a lower level of investment planning (D3*H2*). The data indicates that a substantial proportion of enterprises, despite reporting various obstacles, continue to invest in digital solutions when provided with appropriate incentives or driven by internal development needs. This indicates that perceived barriers do not necessarily prevent firms from engaging in digital investment activities. The results are aligned with prior research [3], which suggests that certain barriers do not function as statistically significant predictors of actual digital behavior. Indeed, many enterprises proceed with investments in advanced technologies regardless of perceived constraints [3], [15].

The hypothesis that a firm's higher capacity for independent technology implementation is positively associated with a more advanced stage of investment planning for digital solutions (D2*H2*) is not supported by empirical evidence. The results suggest that internal implementation capacity alone does not systematically translate into more active investment planning. Instead, investment decisions are driven by other factors, such as the current level of digitalization, available external incentives, and familiarity with European/national funding instruments. It can be assumed that technological capacity, while relevant, is not a decisive driver of investment planning.

These findings unequivocally demonstrate the need for a more in-depth study of the factors hindering digital transformation in agriculture, as well as the continuation of support and incentive policies targeted at enterprises at the micro-level in the coming years. The policy for financing the adoption of advanced technologies for SMEs logically follows a broader digitalization strategy that has already achieved measurable effects. A brief chronological overview of the evolution of European digitalization policies (Figure 1) is summarized in four consecutive phases.

It begins with the development of basic internet infrastructure (2000–2010), continues with the creation of the Digital single market and the promotion of growth (up to 2020), and subsequently shifts its focus toward digital sovereignty, regulations, and secure data exchange.

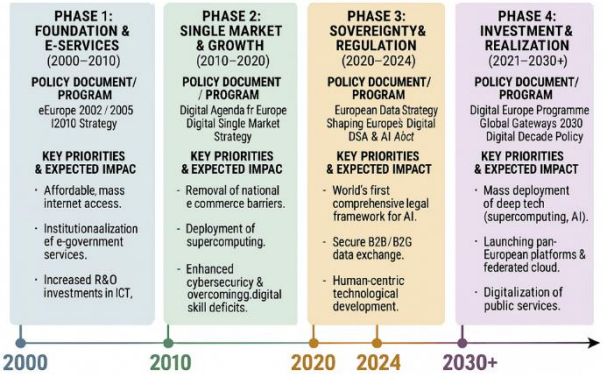

Fig. 1. Chronological and conceptual evolution of the strategic, regulatory, and financial frameworks for digital transformation

Source: own contribution, 2026.

Since 2021, the EU has entered a phase of significant investment in artificial intelligence, supercomputing power, data platforms, and digital services.

SMEs, and micro-enterprises in particular, are traditionally rationed by the credit and financial markets, financing their investments primarily through own capital and subsidies. At the same time, financial policy instruments evolve alongside the development of financial markets and the digitalization of economies (Figure 2).

Funding Source	Characteristics	Potential Impact
OWN FUNDS	• Retained earnings, depreciation allowances, personal savings.	• Ensure financial independence, low risk. • Often insufficient for large-scale growth.
GRANTS & SUBSIDIES	• Direct payments, EU grants, national subsidies.	• Reduce capital costs, stimulate eco-friendly agriculture.
DEBT FINANCING	• Working capital and long-term investment loans.	• Enable business scaling, *but* increase interest burden and financial risk.
MACHINERY LEASING	• Leasing of agricultural machinery and precision farming equipment.	• Facilitate rapid access to modern technologies *without* significant initial capital.
TRADE CREDIT	• Deferred payments to suppliers until crop realization.	• Ensure flexible cash flow management, cover seasonal financial needs.
INSTITUTIONAL FINANCIAL INSTRUMENTS	• Preferential loans and guarantee schemes.	• Improve access to external financing through lower collateral requirements and optimized credit costs.
VENTURE CAPITAL & BUSINESS ANGELS	• Equity investments targeting innovations and AgTech solutions.	• Catalyze digital transformation, bring "smart money" (know-how), *but* require equity relinquishment.

Fig. 2. Sources of financial support for the development of agricultural enterprises
Source: own contribution, 2026.

A significant proportion of the surveyed owners (over 70%) indicate that they are unwilling to share ownership of their enterprise in exchange for financing or technology transfer, which severely constrains their potential for growth and development. The benefits of modern financial instruments, such as venture capital and institutional guarantees, not only help overcome barriers to initial investment and the lack of collateral but also directly catalyze digital transformation through the transfer of technology and know-how. The observed high level of caution and uncertainty among owners regarding the use of venture capital signals a need for targeted policies to encourage digital transformation.
A structural shift is observed in the European funding model for small and medium-sized enterprises during the 2021-2027 programming period. The focus is shifting away from traditional subsidization toward market-oriented support mechanisms, with over 79% (Figure 3) of the total resources allocated to repayable instruments in the form of equity investments, guarantees, and loans
The share of grant-based financial assistance has been reduced to just under 21%, no longer functioning as a standalone source of capital. Instead, the grant component is applied exclusively within hybrid schemes (blended financing within a single operation).
The share of grant-based financial assistance has been reduced to just under 21%, no longer functioning as a standalone source of capital. Instead, the grant component is applied exclusively within hybrid schemes (blended financing within a single operation). This strategic transformation aims to share both technological and market risks associated with digital and innovative projects, turning limited grant aid into an effective catalyst for mobilizing additional private investment resources.

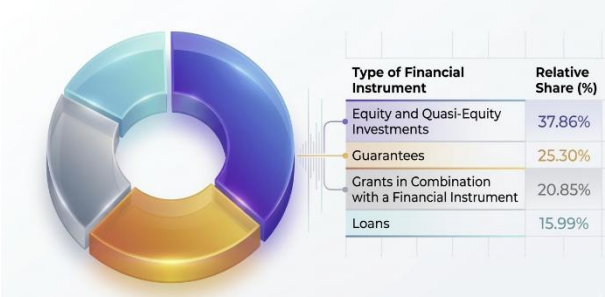

Fig. 3. National Framework for Digitalization Funding in Bulgaria: Distribution of Financial Instruments and Potential Application in Agriculture - 2021 - 2027,
Source: Own contribution, data from the Fund Manager of Financial Instruments in Bulgaria (FMFIB), 2026 [19].

It is essential that SMEs be directed (including through incentive policies) toward new forms of financing that offer benefits far exceeding those of traditional subsidies. Most important, innovative instruments facilitate the transfer of skills and technology, which is critical for the digital transformation process, especially for SMEs.

CONCLUSIONS

The main contribution of the study lies in advancing the analytical understanding of digital transformation in agricultural SMEs by integrating financing mechanisms and firms' investment behavior as central analytical elements. Rather than treating financial support as an external driver, the results demonstrate that the effectiveness of financial instruments dependent on SMEs internal organizational and human capacity, as well as on their level of digitalization.
The findings show that awareness of funding opportunities and positive attitudes toward digital transformation are necessary but not sufficient factors for initiating digital investments. Instead, digital investment behavior results from the interaction between

financial support, organizational capacity, human capital and accumulated digital experience. In this context, SMEs with limited own financial resources rely more intensively on external funding instruments, while enterprises with stronger internal capacity tend to finance digital investments independently and participate less in European programs.

Based on these findings, the study suggests that digital transformation support should move beyond traditional schemes and focus on targeted, risk-sharing financial instruments that address capital constraints, support internal capacity building and reduce the uncertainty related to slow investment returns, among others. Although the study is exploratory and based on a limited sample, the results provide focused insights into the interaction between financing mechanisms and investment behavior, contributing to the literature on financing digital innovation in agricultural SMEs.

ACKNOWLEDGEMENTS

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FUNCTIONAL FRAGMENTATION AND AGRICULTURAL COMPETITIVENESS: EVIDENCE FROM BULGARIA

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Abstract

Agricultural competitiveness in Bulgaria remains structurally constrained within the European Union despite long-term policy integration and technological modernization. This study examines whether functional fragmentation, understood as the cumulative simultaneity of biological, technological, managerial, and institutional–market functions, constitutes a structural determinant of agricultural competitiveness in Bulgaria relative to the European Union benchmark, and extends the analysis through stochastic scenario projections under the European Green Deal. Using a multidimensional competitiveness index, a multiplicative fragmentation index, and a structural modelling framework combined with scenario-based stochastic simulation, the study evaluates Bulgaria's historical competitiveness position, its comparative gap vis-à-vis the European Union, and its projected path to 2030. The results indicate a weak competitiveness position, with an average composite score of −0.61, low-income generation per hectare and labour unit, and negative factor-efficiency performance. Functional fragmentation is identified as a significant structural constraint. A 10% reduction in fragmentation is associated with a competitiveness gain of 0.157 index units, while a transition toward a less fragmented structural configuration implies an improvement of 0.411 index units. The scenario results indicate stagnation under structural persistence, deterioration under stronger policy pressure, and partial recovery under adaptive adjustment.

***Key words*:** *functional fragmentation, agricultural competitiveness, stochastic scenario modelling, European Green Deal, Bulgaria*

INTRODUCTION

Agricultural competitiveness represents a fundamental dimension of economic development and structural transformation within rural economies. Despite technological progress, increasing integration of agricultural markets, and long-standing policy support mechanisms, substantial disparities in competitive performance continue to characterize agricultural systems across Europe. Differences in structural organization, technological intensity, institutional conditions, and historical development paths contribute to persistent variation in productivity, income generation, and market positioning among national agricultural sectors. These structural characteristics influence the capacity of agricultural systems to convert available resources, technological inputs, and policy support into sustainable economic outcomes, thereby shaping long-term sectoral performance within the European agricultural economy (Ivanov, 2025; Bachev et al., 2025; Koteva et al., 2021; Bachev, 2011) [13, 4, 14, 3].

The institutional environment of European agriculture is characterized by a complex governance architecture that integrates supranational policies with national regulatory frameworks (Sweet and Sandholtz, 1997; Petrov, 2025) [19, 16]. The Common Agricultural Policy, the regulatory mechanisms of the single European market, and diverse national governance structures collectively shape investment incentives, technological modernization, and production strategies across Member States. Although these policy frameworks seek to promote convergence in agricultural development and competitiveness, structural differences between agricultural systems remain

pronounced (Therond et al., 2017) [21]. Variations in farm size distribution, capital intensity, technological adoption, and institutional capacity continue to influence the relative competitive position of national agricultural sectors within the integrated European market. These structural disparities indicate that agricultural competitiveness cannot be interpreted solely through isolated economic variables, as sectoral performance is embedded within broader systemic and institutional contexts (Boehlje, 1999; Coppola et al., 2018; Minh, 2019) [7, 9, 15].

In recent years, the strategic priorities of the European Green Deal have introduced an additional dimension to the transformation of European agriculture. Through initiatives such as the Farm to Fork Strategy and the EU Biodiversity Strategy, the European Union has articulated an ambitious agenda aimed at improving the environmental sustainability of food systems while strengthening climate resilience and resource efficiency. These policy objectives include reductions in pesticide and fertilizer use, expansion of organic farming practices, and stronger environmental compliance requirements within agricultural production. While these measures seek to address ecological challenges, they also modify the economic and institutional conditions under which agricultural producers operate. The resulting adjustments affect production structures, technological choices, and long-term investment strategies, thereby influencing the competitive dynamics of agricultural sectors across Europe (Sassenrath et al., 2008) [18].

The interaction between environmental policy, institutional frameworks, and agricultural competitiveness has increasingly attracted scholarly attention. Research addressing climate variability emphasizes the inherent exposure of agricultural production to stochastic environmental processes and the implications of climate-related uncertainty for productivity and economic performance (Teku, 2025) [20]. Other studies highlight the importance of institutional quality and governance structures in shaping competitiveness through regulatory stability, transaction costs, and policy incentives that influence production decisions and investment behaviour (Arianpoor, 2025; Alam et al., 2019) [2, 1]. Parallel strands of research identify technological modernization, digital transformation, and innovation in farm management as key drivers of productivity growth and structural adjustment within agricultural systems (Bocean, 2024; Benfica et al., 2023) [6, 5]. Although these approaches provide valuable insights into individual determinants of agricultural performance, they frequently analyse technological, institutional, and environmental factors independently, which limits the ability to capture the systemic interactions that characterize agricultural production systems.

Agricultural production differs from most economic activities in that it requires the simultaneous coordination of multiple functionally interdependent processes. Biological production cycles, technological operations, managerial decision-making, and compliance with institutional and market regulations must be aligned within constrained temporal and resource conditions. These domains interact continuously within agricultural production systems, and the efficiency with which they are coordinated affects the transformation of productive potential into realized economic outcomes. When inconsistencies arise in the interaction among these domains, production systems may experience structural inefficiencies that influence productivity, cost structures, and ultimately competitive performance.

Recent analyses of the intellectual structure of agricultural competitiveness research demonstrate that contemporary scholarship increasingly recognizes the importance of structural transformation, policy frameworks, and uncertainty in shaping agricultural development trajectories (García-Agüero et al., 2023; Thompson and Scoones, 2009) [11, 22]. Nevertheless, empirical analyses frequently focus on average relationships between productivity indicators and explanatory variables, while the dynamic evolution of competitiveness under conditions of policy change and structural adjustment receives less attention. This analytical limitation becomes particularly relevant in the

context of the European Green Deal, where the transformation of agricultural systems is likely to introduce new forms of uncertainty regarding the future development of agricultural competitiveness (Boix-Fayos and De Vente, 2023; Cuadros-Casanova et al., 2023) [8, 10].

In response to these challenges, the present study adopts a systemic perspective on agricultural competitiveness based on the concept of functional fragmentation (AFF/SIT Theory Agricultural Functional Fragmentation/Structural Incompatibility Theory) in agricultural systems. This theoretical framework conceptualizes competitiveness as an outcome of the structural interaction among multiple production-related domains embedded within agricultural systems. Functional fragmentation emerges when biological processes, technological operations, managerial coordination, and institutional–market requirements are weakly aligned within the production process. Under such conditions, the transmission of productive potential into realized economic performance becomes less efficient and more sensitive to structural constraints. The concept therefore provides an analytical lens for examining how the internal organization of agricultural systems influences the ability of the sector to maintain competitiveness in changing economic and policy environments (Petrov et al., 2026) [17].

Within this broader European context, Bulgaria represents a particularly relevant case for examining the structural dynamics of agricultural competitiveness. As a Member State integrated within the institutional architecture of the European Union while undergoing its own trajectory of agricultural transformation, Bulgaria combines the influence of common European policy frameworks with country-specific structural characteristics. The examination of Bulgarian agricultural competitiveness alongside the broader European benchmark makes it possible to evaluate both national development patterns and relative positioning within the integrated European agricultural system. This comparative perspective allows the analysis to capture how structural conditions shape competitiveness dynamics under shared policy frameworks. In this analytical setting, functional fragmentation is treated as a structural property of agricultural systems that influences the capacity of the sector to sustain competitiveness under evolving technological, institutional, and policy conditions. Agricultural production requires the concurrent execution of biologically conditioned processes, technological operations, managerial coordination, and compliance with institutional and market regulations. These processes interact within limited temporal windows and under resource constraints, making the coherence of their interaction critical for production efficiency and economic performance. When the interaction among these domains becomes more fragmented, the conversion of productive capacity into competitive outcomes becomes less stable and more vulnerable to policy adjustments and external shocks.

The objective of this study is to examine the relationship between functional fragmentation and agricultural competitiveness in Bulgaria in comparison with the European Union and to explore potential future trajectories of competitiveness through stochastic scenario modelling under the policy conditions associated with the European Green Deal. By integrating a systemic theoretical framework with stochastic scenario analysis, the study aims to contribute to the understanding of how structural organization, institutional pressures, and uncertainty jointly influence the evolution of agricultural competitiveness within the European agricultural system.

MATERIALS AND METHODS

The methodological design of the study follows the theoretical proposition advanced by Petrov et al. (2026) [17], according to which agricultural competitiveness is a realized outcome of technological potential filtered through institutional conditions and reduced by functional fragmentation across biological, technological, managerial, and institutional–market domains. In the present study, this structural perspective is retained as

the analytical core, but it is extended in two directions. First, the empirical focus is shifted from the general EU-wide historical relationship toward the position of Bulgaria relative to the EU benchmark. Second, the structural model is complemented by a stochastic scenario module derived from Ivanov (2024) [12], in order to assess the possible future trajectories of agricultural competitiveness under policy pressure associated with the European Green Deal. More specifically, the study investigates three objects. The first is the historical level and dynamics of Bulgarian agricultural competitiveness. The second is Bulgaria's relative competitiveness gap *vis-à-vis* the European Union. The third is the prospective path of competitiveness to 2030 under alternative Green Deal scenarios, simulated through a stochastic error structure. Thus, the analysis does not aim merely to estimate whether fragmentation affects competitiveness. It examines how structural fragmentation conditions the present position of Bulgaria and how that position may evolve under different policy-pressure regimes. As formulated by Petrov et al. (2026) [17], the structural AFF/SIT relationship is expressed as:

$$C = \tau T^* e^{-\alpha^{FF}} \quad \text{.....(1)}$$

where:
C denotes agricultural competitiveness, τ is the institutional–market transmission coefficient, T^*
is the feasible technological potential of the agricultural system, FF is the functional fragmentation index, and $\alpha > 0$ measures the negative structural effect of fragmentation on competitiveness.
In the present study, this relationship remains the theoretical basis of the empirical model. To incorporate policy pressure associated with the European Green Deal, the structural identity is extended as follows:

$$C_t^{(s)} = \tau_t T_t^* \exp(-\alpha FF_t - \theta GD_t^{(8)}) \quad \text{.....(2)}$$

where:
$GD_t^{(8)}$ denotes the Green Deal pressure term under scenario s, and θ measures the sensitivity of competitiveness to policy-induced structural pressure. In this specification, the Green Deal does not replace fragmentation as the principal structural mechanism. It acts as an additional force affecting the translation of productive potential into realized competitiveness.

Measurement of Agricultural Competitiveness

Following Petrov et al. (2026) [17], agricultural competitiveness is treated as a multidimensional construct combining income performance, land productivity, and factor efficiency. For this reason, competitiveness is not represented by a single indicator, but by a synthetic index derived from several standardized components.
The composite competitiveness index is defined as:

$$C_t^* = \sum_{j=1}^{m} w_j Z_{j,t} \quad \text{.....(3)}$$

where:
$Z_{j,t}$ denotes the standardized value of competitiveness component j and the time t, and w_j denotes its weight. The baseline specification uses equal weights, while principal-component weights may be used as a robustness alternative. The component set includes income per hectare, income per labour unit, gross margin per hectare, yield-based land productivity, and total factor productivity.
In order to preserve the comparative design of the study, the EU benchmark is defined as the contemporaneous average competitiveness level across the European Union:

$$C_{EU,t}^* = \frac{1}{Nt} \sum_{c=1}^{Nt} C_{c,t}^* \quad \text{.....(4)}$$

and Bulgaria's relative position is measured by:

$$\Delta C_t = C_{BG,t}^* - C_{EU,t}^* \quad \text{.....(5)}$$

where:

$C^*_{BG,t}$ is the Bulgarian competitiveness index and $C^*_{EU,t}$ is the EU benchmark.

Functional Fragmentation Index

The principal explanatory variable in the model is functional fragmentation. As defined by Petrov et al. (2026) [17], fragmentation is not equivalent to diversification or general complexity. It refers to the cumulative coordination burden generated by the concurrent execution of biological, technological, managerial, and institutional–market functions within agricultural systems. The present study retains this four-domain logic without altering its conceptual content. The fragmentation index is therefore specified as:

$$FF_t = B_t \cdot T_t \cdot M_t \cdot I_t \quad \text{.....(6)}$$

where:

B_t denotes the biological component, T_t the technological component, M_t the managerial component, and I_t the institutional–market component.

In order to evaluate Bulgaria's structural position relative to the European Union, the fragmentation gap is calculated as:

$$\Delta FF_t = FF_{BG,t} - FF_{EU,t} \quad \text{.....(7)}$$

where:

$FF_{BG,t}$ denotes the fragmentation level of Bulgaria and $FF_{EU,t}$ the EU benchmark. This measure allows the interpretation of Bulgaria's competitiveness not only in relation to its own historical trajectory, but also in relation to its structural distance from the European average.

Structural Estimation Model

The historical relationship between competitiveness and fragmentation is examined through an empirical specification derived from the estimating strategy of the Functional Fragmentation, but extended here by adding the Green Deal policy term. The baseline structural equation is written as:

$$C^*_{c,t} = \beta_0 + \beta_1 FF_{c,t} + \beta_2 Tech_{c,t} + \beta_3 GD_{c,t} + \beta_4 (FF_{c,t} \times GD_t) + \mu_c + \lambda_t + \varepsilon_{c,t} \quad \text{..... (8)}$$

where:

$C^*_{c,t}$ is the competitiveness index, $FF_{c,t}$ is the fragmentation index, $Tech_{c,t}$ denotes technological intensity, GD_t is the Green Deal policy-pressure term, μ_c captures country fixed effects, and λ_t captures time effects. The interaction term $FF_{c,t} \times GD_t$, is essential for the present article because it expresses the proposition that policy pressure is mediated by structural organization. In other words, the same policy burden is not expected to affect all agricultural systems symmetrically; its effect depends on the level of pre-existing fragmentation.

Stochastic Projection of Competitiveness

The principal methodological extension of the present study is the incorporation of stochastic scenario modelling. This component follows Ivanov (2024) [12], who develops a projection framework based on autoregressive adjustment, dynamic elasticities, trend variation, and calibrated stochastic error. In Ivanov's article, this apparatus is applied to production indicators in the oilseed sector. In the present study, the same projection logic is transferred to the competitiveness index itself. Thus, the object of simulation is not sectoral output or area, but the future path of Bulgarian agricultural competitiveness. Following this, the stochastic projection equation is expressed as:

$$C_{t+1} C_{AV} + (C_t \beta^2 - C_{AV}) E_t \quad \text{.....(9)}$$

where:

C_{AV} is the historical average competitiveness level, C_t is the observed level in period t, β is the autoregressive regression coefficient, and E_t is the dynamic elasticity coefficient. This specification allows the projected value of competitiveness to depend simultaneously on its lagged position, its historical average, and the elasticity-adjusted direction of movement. To account for stochastic dispersion around

the projected path, the future competitiveness level is represented in scenario form as:

$$C_{t+1}^{(s)} = \hat{C}_{t+1}^{det} \pm AJ\varepsilon_{t+1}^{(s)} \quad \text{.....(10)}$$

where:
$\hat{C}_{t+1}^{det}$ is the deterministic value derived from the structural model, and $AJ\varepsilon_{t+1}^{(s)}$ is the adjusted stochastic error under scenario s. On this basis, three scenarios are simulated: a baseline scenario preserving historical structural tendencies, a Green Deal pressure scenario with stronger policy burden, and an adaptive scenario in which technological and organizational adjustment reduces the effective competitiveness loss associated with fragmentation.
In this way, the present methodology combines the structural theory and measurement strategy with the stochastic simulation logic. The first provides the explanatory core of the model; the second provides the prospective scenario mechanism. Their combination makes it possible to examine not only where Bulgaria stands in relation to the European Union, but also how its agricultural competitiveness may evolve under different structural and policy conditions.

RESULTS AND DISCUSSIONS

The evaluation of agricultural competitiveness in Bulgaria begins with the structural indicators describing the performance of the sector over the observed period. Competitiveness is measured through a composite index integrating income performance, land productivity and factor efficiency. The resulting indicator captures the ability of the agricultural sector to transform productive resources and technological inputs into stable economic outcomes. The calculated competitiveness index for Bulgaria indicates a structurally weak position within the European agricultural system. The average value of the composite competitiveness indicator is −0.61, which reflects relatively low-income generation, modest labour productivity and limited factor efficiency. The decomposition of the index shows that farm net income per hectare reaches 266.15 EUR, while family farm income per labour unit amounts to 2863.73 EUR. The gross margin per hectare remains limited at 14.44 EUR, and the estimated residual total factor productivity component is negative (−0.30). These values reveal structural inefficiencies in the conversion of productive resources into economic output. The observed competitiveness structure indicates that the performance limitations of Bulgarian agriculture cannot be attributed to a single economic factor. The interaction between low-income generation, limited productivity growth and weak factor efficiency suggests the presence of systemic constraints affecting the sector. The competitiveness index therefore reflects broader structural characteristics related to the organization of agricultural production, technological capacity and institutional environment.

Table 1. Structural indicators of agricultural competitiveness in Bulgaria (average values)

Indicator	Value
Composite competitiveness index C^*	-0.61
Farm net income per hectare (EUR)	266.15
Family farm income per labour unit (EUR)	2863.73
Gross margin per hectare (EUR)	14.44
Yield-based productivity (EUR/ha)	1195.62
Total factor productivity residual	-0.30

Source: Authors' calculations based on the study dataset.

The historical competitiveness profile indicates that Bulgarian agriculture operates under persistent structural limitations. The sector demonstrates limited ability to convert productive inputs into competitive outcomes, which affects its long-term economic performance.

Bulgaria in Comparison with the European Union

The comparative analysis reveals substantial variation in agricultural competitiveness across European Union member states. Countries characterized by highly productive and technologically intensive agricultural systems demonstrate significantly higher competitiveness levels. The competitiveness

index reaches 0.85 in Belgium and 0.74 in the Netherlands, followed by Spain (0.66) and Denmark (0.48). These countries combine high productivity levels with strong technological intensity and efficient institutional frameworks supporting agricultural production. Italy (0.35), Germany (0.16) and Austria (0.11) occupy intermediate positions within the competitiveness distribution. In contrast, Bulgaria's competitiveness level of −0.61 places the country among the lower performing agricultural systems in the Union. The competitiveness gap reflects structural differences in production organization, technological capacity and income generation. The Bulgarian agricultural system demonstrates significantly lower economic returns relative to land and labour resources.

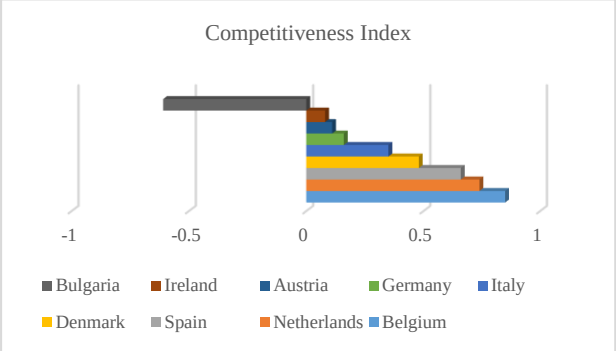

Fig. 1. Agricultural competitiveness levels in selected EU countries
Source: Authors' calculations based on the study dataset.

The comparative evidence demonstrates that Bulgaria occupies a structurally disadvantaged position within the European agricultural competitiveness distribution. The competitiveness gap reflects differences in production structures, technological intensity and institutional conditions affecting the agricultural sector.

Functional Fragmentation as a Structural Constraint

The structural model identifies functional fragmentation as a significant determinant of agricultural competitiveness. Functional fragmentation represents the cumulative coordination burden generated by the simultaneous interaction of biological, technological, managerial and institutional production domains.

The estimated structural coefficient associated with fragmentation is negative ($\beta = -3.734$), indicating that higher levels of fragmentation reduce the competitiveness of agricultural systems. The magnitude of the coefficient suggests that fragmentation affects the baseline level of competitiveness rather than merely influencing marginal productivity effects.

The structural sensitivity of competitiveness to fragmentation can be illustrated through counterfactual simulations. A structural reduction in fragmentation of approximately 10 percent corresponds to an increase in competitiveness of about 0.157 index units. A larger structural adjustment moving the system from the upper quartile of fragmentation toward the median level increases competitiveness by approximately 0.411 index units.

Table 2. Structural impact of functional fragmentation on agricultural competitiveness

Structural change	Change in fragmentation index	Competitiveness effect
Reduction of fragmentation by 10%	-0.042	+0.157
Transition from upper quartile to median fragmentation	-0.110	+0.411
High vs. low fragmentation systems	+0.180	-0.672

Source: Authors' calculations based on model simulations.

The Bulgarian agricultural system demonstrates a relatively high degree of structural fragmentation. The interaction of biological diversity, technological requirements, managerial coordination and institutional obligations generates coordination costs that limit the efficiency of production processes. The estimated effects indicate that structural improvements in system coherence could significantly increase agricultural competitiveness.

Stochastic Scenario Projections under the European Green Deal

The scenario analysis evaluates the possible evolution of Bulgarian agricultural

competitiveness under different structural and policy conditions. The projections extend the historical competitiveness level through stochastic scenario modelling, which incorporates structural adjustments and policy-related pressures. Three scenarios are constructed. The baseline scenario assumes continuation of the existing structural configuration of the agricultural system. The policy pressure scenario reflects the potential impact of stricter environmental regulations and production constraints associated with the European Green Deal. The adaptive scenario assumes technological and organizational adjustments that reduce structural fragmentation and improve production efficiency.

The baseline scenario maintains the current competitiveness level. The policy pressure scenario introduces a negative structural adjustment equivalent to a 0.157 decline in the competitiveness index. The adaptive scenario incorporates a positive structural adjustment corresponding to a competitiveness increase of 0.411 index units by 2030.

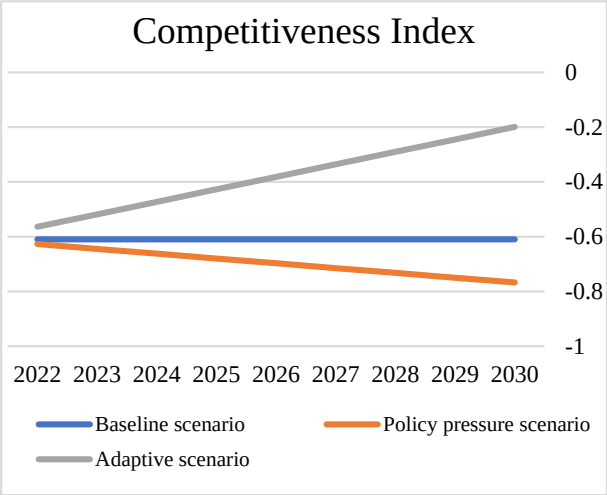

Fig. 2. Scenario projections for agricultural competitiveness in Bulgaria (2022–2030)
Source: Authors' projections based on the estimated structural model and stochastic scenario simulation.

The scenario results demonstrate that the future trajectory of Bulgarian agricultural competitiveness depends strongly on structural adaptation within the agricultural system. The baseline scenario indicates stagnation at a relatively low competitiveness level. The policy pressure scenario shows a gradual decline in competitiveness due to increased regulatory constraints and production adjustments. The adaptive scenario produces a noticeable improvement in competitiveness as a result of reduced structural fragmentation and improved coordination between production domains.

The divergence between scenarios highlights the importance of structural coherence in agricultural systems. Competitiveness outcomes are determined not only by technological inputs and market conditions but also by the degree of coordination between biological, technological, managerial and institutional production functions. Structural improvements in system organization therefore represent a key mechanism through which the Bulgarian agricultural sector can strengthen its competitiveness under evolving policy environments.

CONCLUSIONS

This study examined the relationship between functional fragmentation and agricultural competitiveness in Bulgaria in comparison with the European Union and extended the analysis through stochastic scenario projections under the policy conditions associated with the European Green Deal. The analytical framework combined a structural interpretation of competitiveness with a scenario-oriented modelling approach, allowing the study to connect historical performance, comparative positioning, and prospective development within a single empirical structure.

The results indicate that Bulgarian agricultural competitiveness remains structurally weak in comparative European perspective. The composite competitiveness profile is characterized by limited income generation, weak labour returns, low gross margin per hectare, and negative factor-efficiency performance. This configuration places Bulgaria in the lower segment of the competitiveness distribution within the European Union and confirms the relevance of a structural interpretation of sectoral performance. The observed weakness is

associated with the internal organization of the agricultural system and with the reduced capacity to transform productive resources into stable competitive outcomes. The analysis identifies functional fragmentation as a significant structural constraint on competitiveness. The estimated negative relationship between fragmentation and competitiveness confirms that the simultaneous burden generated by biological, technological, managerial, and institutional–market functions affects the general level of agricultural performance. The reported counterfactual effects show that changes in structural coherence are economically meaningful. A moderate reduction in fragmentation is associated with a measurable competitiveness gain, while movement toward a less fragmented structural configuration produces a substantially stronger improvement. These findings support the proposition that competitiveness depends on the coherence of the agricultural production system and not only on conventional indicators of productivity or technological intensity.

The scenario analysis extends this result into a prospective dimension. The baseline scenario points to persistence of the current structural position, with competitiveness remaining at a low level over the projection horizon. The policy pressure scenario indicates a gradual deterioration of competitiveness under stronger environmental and regulatory constraints associated with the European Green Deal. The adaptive scenario produces a more favourable trajectory, reflecting the effect of organizational and technological adjustment on the reduction of structural fragmentation. The divergence between the three paths demonstrates that the future of Bulgarian agricultural competitiveness depends on the interaction between policy pressure and structural adaptation capacity.

The contribution of the study is methodological as well as substantive. At the methodological level, the paper connects the structural logic of functional fragmentation with scenario-based stochastic modelling, thereby extending the analysis of competitiveness beyond static historical estimation. At the substantive level, the paper shows that the competitiveness problem in Bulgarian agriculture should be interpreted through the structural organization of the production system. The policy significance of this result is direct. Measures aimed at improving competitiveness require greater attention to the internal coherence of agricultural systems, the coordination burden faced by producers, and the capacity of the sector to adapt under conditions of regulatory transition. Several limitations should be acknowledged. The stochastic projections are conditional on the structural assumptions embedded in the model and on the quality of the available competitiveness indicators. The Green Deal pressure term is introduced in scenario form and therefore reflects analytically defined policy intensity rather than a fully observed long-run historical process. In addition, the empirical analysis is conducted at an aggregated country level, which limits the ability to capture intra-sector heterogeneity across farm types and production systems. These limitations do not weaken the central result of the paper, but they define the scope within which the findings should be interpreted.

Future research may extend the present approach in several directions. A first step would involve the reconstruction of longer annual competitiveness series at sectoral and sub-sectoral level for Bulgaria. A second step would examine farm-type heterogeneity in functional fragmentation and competitive performance. A third step would involve the incorporation of additional policy variables allowing a more differentiated modelling of Green Deal transmission channels. Such developments would strengthen the empirical precision of the framework while preserving its structural logic.

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MANAGEMENT PRACTICES AND MANAGEMENT DECISIONS IN COOPERATIVE ORGANIZATIONS - A STUDY CASE-BULGARIA

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Abstract

Cooperative organizations hold a significant place in the contemporary economy, combining economic goals with the principles of democratic governance and member participation. In the context of a dynamic economic environment, increasing competition, and changing regulatory frameworks, these organizations face the necessity of implementing effective management practices to ensure sustainable development and competitiveness. Management decisions must consider both economic efficiency and social responsibility, as well as the interests of the members, which further complicates the management process. The aim of the present article is to investigate management practices and the processes of making management decisions in cooperative organizations, with the emphasis placed on their institutional and functional specificity. The article analyzes the fundamental principles of cooperative governance, the management bodies and their role in the management process, as well as the applicability of established management theories within the cooperative context.

Key words**:** *cooperative governance, management decisions, sustainable development*

INTRODUCTION

Cooperative organizations constitute a distinctive form of socio-economic arrangement grounded in the voluntary association of individuals who seek to achieve shared economic, social, and cultural objectives through collective action. Within this framework, cooperatives are characterized by organizational flexibility with regard to both capital formation and membership structure. Their functioning is based on principles of mutual support, cooperation, and the active involvement of members in organizational processes.

The governance framework of cooperative organizations is shaped by a coherent system of values and principles that set the cooperative model apart from conventional economic structures (Miteva A., 2014) [7]. These principles, principles are formulated in the Statement on the Cooperative Identity of the International Co-operative Alliance, derive from the historical legacy of the Rochdale cooperative movement. Historically, the cooperative movement emerged as a socio-economic alternative to capitalist enterprises in the mid-19th century in Rochdale, England. Cooperative principles and values have evolved and adapted over time in accordance with contemporary economic and social conditions while simultaneously preserving their original philosophy; however, three of them are accepted as fundamental to the cooperative model – common ownership, democratic control, and the equitable distribution of benefits among members.

In this context, the paper aimed to present the fundamental principles of cooperative management and their role in the managerial process of this type of organization in the agriculture of in Bulgaria.

MATERIALS AND METHODS

This research is grounded in empirical evidence obtained through a questionnaire-based survey of cooperative organizations in Bulgaria. The data collection was undertaken within the scope of a research project № КР-06-N65/1 "Cooperative Models for Doing Business in Bulgaria and Their Potential for the Implementation of Innovative Management Solutions", funded by the National Science Fund [8].

The sample includes 107 cooperatives operating in different economic sectors across the country. The information was collected through a standardized questionnaire completed by representatives of the respective cooperatives. The survey covers questions related to the main characteristics of the cooperatives, the number of cooperative members, the procedures for electing management bodies (chairperson and management board), as well as the practices for admitting new members.

The collected data were processed using descriptive statistical methods, including grouping, calculation of relative shares, and graphical presentation of the results. They are compared with the legislative framework governing cooperatives to identify consistencies and discrepancies between legal provisions and actual management practices.

RESULTS AND DISCUSSIONS

Cooperative principles function as a management framework that defines the relationships between members, management bodies, and the external environment (Sarov, 2014) [9].

One of the key features of the cooperative model is the democratic principle of governance, whereby each member has an equal vote, regardless of the amount of capital contributed. This significantly distinguishes them from capital-based companies, where voting rights are typically proportional to the capital owned (Birchall, 2011) [4]. This principle ensures broader member participation in decision-making processes and limits the concentration of power in the hands of large investors (Stoyanova, D., 2024) [11].

Cooperatives are also characterized by their **dual nature** – they are simultaneously economic enterprises and social organizations. This characteristic is manifested in their pursuit not only of economic efficiency but also of the sustainable development of the community in which they operate. This leads to a specific management mechanism where economic decisions are balanced with both operational efficiency and the social goals of the cooperative. In this sense, the cooperative model is often viewed as an intermediate form between purely market-driven structures and non-profit organizations (Battilani & Schröter, 2012) [3].

An important characteristic of the cooperative model is its **orientation toward long-term sustainability** rather than short-term financial returns. Due to the fact that cooperatives are owned by their members – who are often simultaneously consumers, producers, or workers – decisions are made with a view toward the long-term interest of the community, rather than solely for investor profit (Birchall & Ketilson, 2009) [5]. The cooperative, through its values such as democracy, volunteerism, and mutual assistance, possesses genuine potential to contribute to the sustainable development of economic sectors globally (Aleksiev, 2024) [1].

According to cooperative legislation and customary practice, **the management of a cooperative** is executed through multiple primary bodies, foremost among them being the General Meeting of Members – the supreme governing body, which adopts the statutes, elects the management bodies, and makes decisions on key issues concerning the cooperative's functioning.

Managing Board – entrusted with the day-to-day administration of the cooperative, as well as with the formulation and execution of its strategic objectives and the allocation of resources.

Supervisory Board – performs an oversight function by monitoring the activities of the governing bodies and ensuring adherence to applicable legislation and the cooperative's internal regulations.

Chairperson of the Cooperative – elected from among the members for a four-year term, the chairperson also presides over the managing board and takes part in its decision-making process with equal voting rights [6]. The interaction between these bodies forms the management structure of the cooperative by distributing responsibilities, powers, and control mechanisms. The effective functioning of this structure is a key condition for the sustainable development of

cooperative organizations with a view to integrating their economic and social objectives (Todorova, S., 2023) [12].

The agricultural focus of the Bulgarian economy during the late 19th century created the conditions for the formation of the country's initial cooperative organizations. This historical foundation has exerted a persistent influence on the cooperative sector, with a notable proportion of cooperatives continuing to operate chiefly within the agricultural sphere (Atanasova, 2024) [2], (Sarov, A., 2025) [10]. This is also confirmed by the present study. Most of the respondents provided detailed descriptions of the activities of the cooperatives they represent. (Figure 1). Exceptions include two survey forms: in one, the activity was not mentioned, while in the other, a general response was provided, indicating that they operate within the agricultural sector.

Fig. 1. Distribution of cooperatives by type of activity
Source: own results.

At the time of the study, only one cooperative was declared liquidated, while the remaining 106 are active (Figure 2).

Some of the respondents did not fully complete the provided survey forms; consequently, the number of member-cooperators for 22 cooperatives cannot be discussed or analyzed. **To determine the size of the studied cooperatives**, they are grouped based on the number of member-cooperators as follows: the first group includes representatives with up to 50 members, followed by groups defined at intervals of 100, while the final groups have larger intervals due to the smaller number of cooperatives. As shown in Figure 2, cooperatives with 51 to 200 members predominate, followed by those with up to 50 members and those with between 201 and 300 members. In this study, the smallest active cooperative has 7 member-cooperators, while the largest has 1,720 members, followed by a cooperative with 1,100 members.

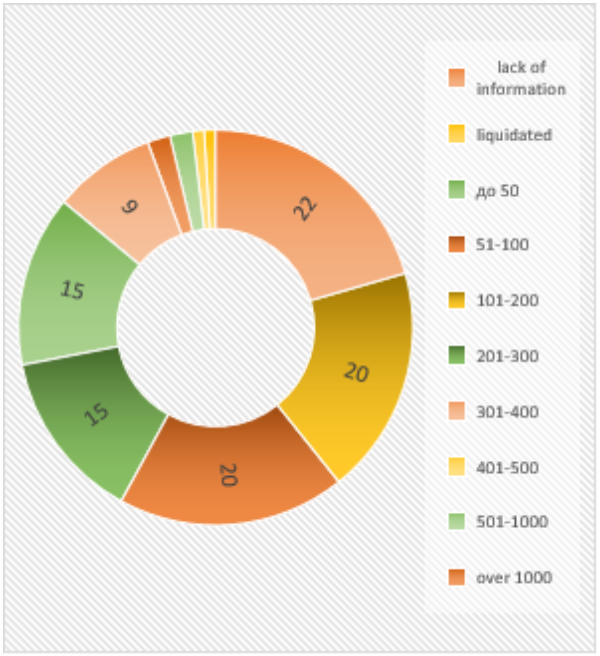
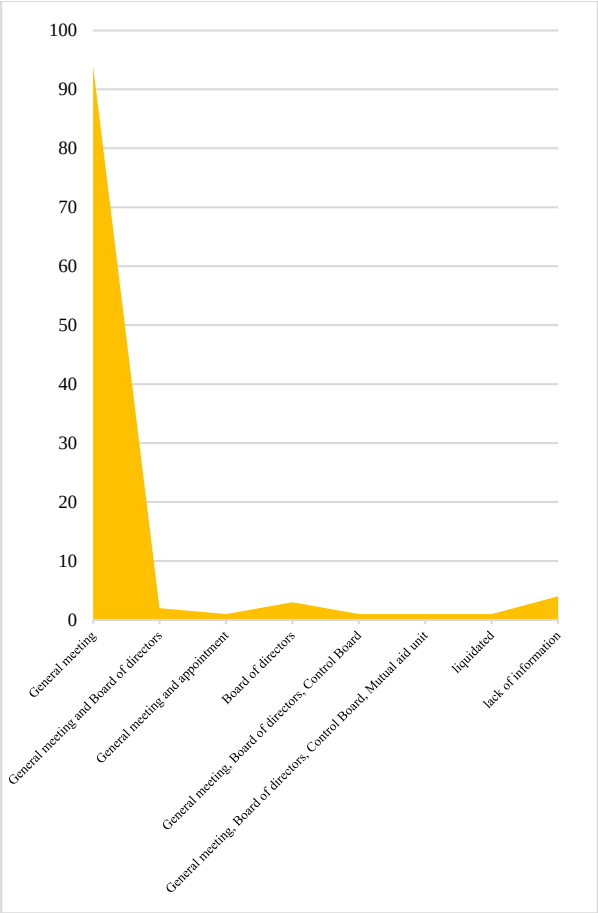


Fig. 2. Distribution of cooperatives by size
Source: own results.

Election of the chairman of the cooperative

Under the Cooperatives Act, the general meeting holds the authority to elect the chairman of a cooperative. However, survey results indicate that in practice, not all cooperatives strictly follow this statutory procedure. Among the respondents, 88% reported that their chairman is indeed elected by the general meeting (Figure 3). In contrast, three cooperatives indicated that their chairman is chosen by the managing board, while in two cases, the decision is made jointly by the managing board and the general meeting.



Fig, 3. Methods for electing the chairperson of the cooperative
Source: own results.

The surveyed representatives of two cooperatives noted that, in their cases, the election is conducted at three levels – general meeting, managing board, and supervisory board – and in one of these instances, the decision-making process even involves their established internal mutual assistance unit.

Election of the Cooperative's Managing Board

According to the Cooperatives Act, the managing board is elected by the general meeting. Survey responses indicate that this procedure is generally followed; however, there are two approaches to the election: either by a simple majority or by a two-thirds majority. Among the cooperatives surveyed, 66 reported that their managing board is chosen through a simple majority vote, or 50% of the members of the general meeting +1, while approximately 32% do so by a 2/3 majority.

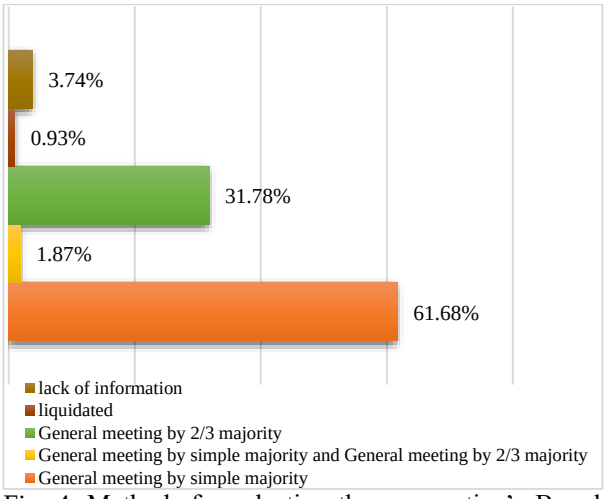


Fig. 4. Methods for selecting the cooperative's Board of directors
Source: own results.

Admission of member-cooperators

Regarding the admission of new member-cooperators, the respondents' answers are diverse. This is due to the fact that, in addition to the requirements described in the Cooperatives act, each cooperative has the opportunity to set additional guidelines for admitting new members, provided these are explicitly detailed in its statutes. Eight of the respondents did not provide an answer to this question in their completed questionnaires. This is most likely because their practice overlaps with the regulations stipulated by law. According to the law, candidate members must first submit a written application, which is reviewed by the managing board at its first meeting following its submission. Consideration may be postponed to a subsequent (second) meeting only if the first meeting took place before 14 days had passed since the application's receipt. Membership in the cooperative becomes effective from the moment the managing board's decision is pronounced. The application for membership is submitted to the general meeting and is placed as the first item on the agenda of the following session. Newly admitted members are not entitled to vote during that particular meeting. If the candidate's membership is not approved that is, if the general meeting does not ratify the managing board's recommendation - the membership is terminated on the date of the meeting. Alternatively, the managing board may decide

to reject the membership application prior to submission to the general meeting. In such a case, the candidate has the right to appeal to the general meeting within 14 days of receiving the written notice of rejection. If the general meeting overturns the refusal, the candidate's membership is deemed effective from the date of the meeting's decision. Conversely, if the general meeting upholds the refusal, or if the candidate has missed the 14-day deadline, they then have the opportunity/right to reapply for membership six months after receiving the notice of refusal.

According to the Cooperatives Act, once candidates are admitted, they are recorded in the register of cooperators. The register includes the member's name and address, the date of admission, the conditions under which membership may be terminated, details on the type and amount of contributions, as well as the dates on which these contributions are made.

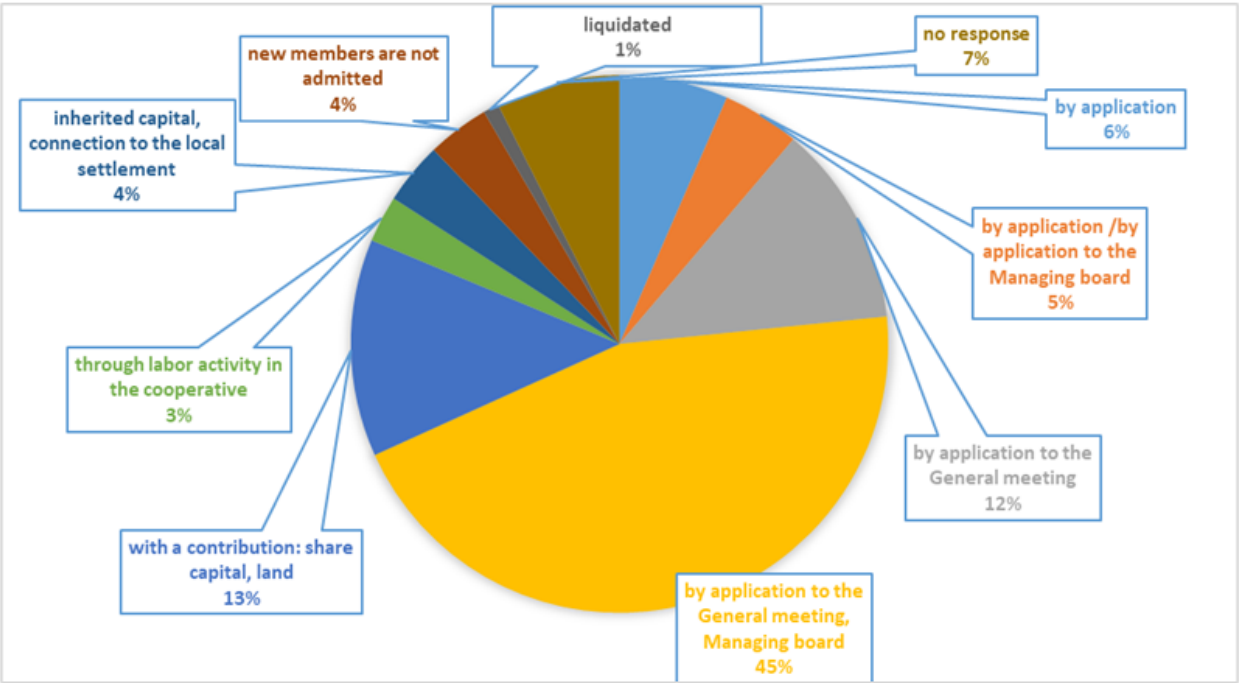


Fig.5. Methods for admitting cooperative members
Source: own results.

In the current sample, the methods for admitting member-cooperators are heterogeneous among the representatives of the surveyed cooperatives. An attempt has been made to summarize them into 10 primary groups (Figure 5).

All groups are examined in descending order. Firstly, 45% of the respondents shared that they admit new member-cooperators in accordance with the guidelines set forth in the Cooperatives Act. In the next largest group, representatives indicated that in order to admit a new member, it is necessary for them to possess/contribute land and share capital. For some, the requirement for both elements is mandatory, while others require only one of them. However, for all of them, it is mentioned that an application must be submitted to the managing board, which is subsequently to be approved by the general meeting. In two of the questionnaires, respondents provided specific amounts required from their candidates, namely: 1) a contribution of 20 BGN in share capital, and 2) a share capital contribution ranging from 300 BGN to 1,000 BGN and ownership of a minimum of 10 decares of land. The next three largest groups provided identical answers that are close to the legal requirements; however, as some basic elements were missing from the responses, they have been categorized based on the specific information provided. In 12% of the questionnaires, the answer to how new

members are admitted was recorded as "by application to the general meeting," while 6.5% noted that only an application is necessary, and 4.7% specified an "application/statement to the managing board." It is possible that in recording this information, respondents did not account for the entire procedure the candidate's application must undergo; however, it is also possible that, based on their statutes, they have adopted a procedure whereby the application of candidate member-cooperators is presented directly to the general meeting, where the decision for admission or refusal is made by a simple or 2/3 majority vote. The following two groups have an equal number of respondents, each accounting for 3.7% of the total sample. Four of the surveyed cooperatives claim that to admit new members, they must be connected to the local settlement or possess inherited capital. In three of these, both principles must be observed. In one cooperative, it is also necessary to pay a membership fee, the amount of which was not mentioned. In four of the questionnaires, it is explicitly stated that new members are not admitted. Finally, 2.8% of the respondents state that the admission of member-cooperators is linked to their labor activity. For two of the cooperatives, a period of 1 or 2 years of work experience is required, while for the third, no such experience is necessary – an application for membership can be submitted upon commencement of employment.

CONCLUSIONS

The findings of the study provide a basis for outlining several key observations regarding the practical application of cooperative management principles in Bulgarian cooperatives. The results indicate that, to a considerable extent, the organizational structures and procedures for establishing governing bodies are aligned with the regulatory framework set out in the Law on Cooperatives. In most of the surveyed organizations, both the chairperson and the managing board are elected by the general assembly, reinforcing the role of the democratic principle of “one member – one vote” as a central governance mechanism.

At the same time, the empirical evidence reveals certain variations in the implementation of these procedures across individual cooperatives. Differences are observed in both the election of leadership and the admission of new members, largely reflecting the specific provisions of internal statutes and organizational rules. This suggests a degree of institutional flexibility within the cooperative model, enabling adaptation to diverse economic and social contexts.

The analysis further shows that a substantial share of the surveyed cooperatives operate with a relatively small or medium-sized membership base, which is indicative of broader structural characteristics of the cooperative sector in Bulgaria. In addition, a pronounced concentration of cooperatives in the agricultural sector persists, reflecting the historical trajectory of cooperative development in the country.

Overall, cooperatives in Bulgaria continue to represent a distinct organizational form that integrates economic activity with principles of democratic governance and mutual support. The preservation of these features supports the view that the cooperative model remains a viable and socially oriented approach to economic organization, with capacity for further development and adaptation under contemporary conditions.

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THE BENEFITS OF ESTABLISHING A LAVENDER CULTURE USING AIRTIFICIAL INTELLIGENCE

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Abstract

Romania is experiencing interest among young people in agricultural entrepreneurship, supported by the access to European funds. Gorj County has a significant agricultural potential and it stands out through a high percentage of young participants in subsidy-granting processes. Artificial intelligence is an essential tool for a farmer or entrepreneur who wants to start a modern agricultural business, transforming traditional agriculture into precision agriculture, which is more efficient and more profitable. This paper presents the important role that artificial intelligence (AI) plays in choosing the most suitable business in the field of agriculture, depending on the area, the pedoclimatic conditions, and the terrain, as well as its ability to provide intelligent tools for making good, fast, and profitable decisions, considering the possibility of analyzing large amounts of data to identify the best investment or agricultural activity options. The case study for Gorj County, in South-West Romania, is based on the method of using artificial intelligence, to simultaneously analyze economic, climatic and market factors and indicate the type of business that contributes to obtaining a qualitative and quantitative culture in the area. It has been demonstrated that lavender cultivation assisted by artificial intelligence tools is a sustainable, accessible, adaptable and profitable choice in the rural environment of Gorj County, and the use of this method in the decision-making process aims to reduce risks, optimize resources and maximize profit. The advantages of using artificial intelligence in smart agriculture include cost reduction (inputs, labor), faster and better decision-making, increased productivity/yields, reduced waste of water, fertilizers, and pesticides, and better adaptation to the climate change.

Key words**:** *entrepreneurship, agriculture, artificial intelligence, business, suitable establishment*

INTRODUCTION

The structure of agricultural entrepreneurship represents the set of elements that form and support economic activity in agriculture, carried out with the aim of making a profit. Considering that Romania has high agricultural potential due to its large areas of arable land, diverse relief, and favorable climate conditions, the components of agricultural entrepreneurship at the national level are:

- the agricultural entrepreneur (the person or group of people who initiates, organizes, and manages the agricultural business, assumes risks, makes decisions, and pursues profit)

-production resources: natural (extensive agricultural land, fertile soil, favorable climate), human (large rural population, traditional experience in agriculture, growing interest in European funds), financial (own capital, bank loans, subsidies through the Agency for Payments and Intervention for Agriculture, European funds through the Common Agricultural Policy), machinery, buildings, irrigation systems, labor force (permanent or seasonal workers), and technology (modern equipment, digitalization, smart farming systems)

-economic activities: crop production, animal husbandry, processing of agricultural products, marketing and distribution of products

-agricultural services (transport, consultancy, mechanization)

-business organization (legal forms such as: Authorized Natural Persons (PFA), Individual Enterprise, Limited Liability Agricultural Companies (oriented toward profit and

modern investments), Agricultural Cooperatives (bringing together multiple producers for joint purchasing, processing, and more efficient product valorization) and Family Farms.

The specific characteristics of agricultural entrepreneurship are: dependence on climate and season, high risk (drought, diseases, price fluctuations), large long-term investments, the need for subsidies and European funds, and the importance of innovation and mechanization.

The agricultural potential of Gorj County is based on an area of 250,000 hectares of arable agricultural land, which represents 44% of the county's total surface, the rest of the territory being occupied by forests, urban areas, waters, and non-productive land (Amarfii-Railean, 2020) [2]. In terms of agricultural activities, livestock farming, forestry, fruit growing, viticulture, and beekeeping predominate in the northern part of the county, while the central and southern areas are oriented toward cereal crops (maize, wheat, rye), forage crops, barley, oats, and potatoes. (Ilie, M., 2023) [5].

After 1989, agriculture in Gorj County was affected due to:

-the destruction of agricultural infrastructure (irrigation networks, machinery, agricultural buildings)

-slow land restitution and land fragmentation, which hindered the efficient use of modern agricultural machinery

-outdated equipment, lack of investment, and soil infertility

-surface lignite mining and the fact that significant areas of land were not returned to the agricultural circuit

During the period 2008–2012, crop agricultural productivity reached its peak in 2011, after which it declined (EU Digitalization of the Agricultural Sector) [4].

Cultivation was dominated by maize, covering areas of up to 62,000 hectares, while wheat accounted for approximately 10%, and vegetables and potatoes each having a smaller share (Ionescu, 2022, Agricloud) [7].

The modernization of agriculture can be achieved through:

-smart irrigation systems (to automatically adjust the amount of water according to soil moisture) (Ahamed, 2025) [1].

-drones and sensors (for crop monitoring and for detecting diseases and pests)

-AI-based local weather forecasting (to help farmers plan agricultural activities)

-data analysis (to select the most suitable crops based on soil, climate, and market conditions)

-the implementation of agro-fruit trees culture.

Agro-fruit trees culture is an ideal solution for Gorj County as a sustainable agricultural practice that combines agriculture (crop cultivation) and fruit growing (fruit trees) on the same land area in order to achieve ecological, economic, and social benefits, based on:

-diversity of the relief (hills, plains, sub-mountain areas)

-tradition in fruit growing (apple, plum, pear, walnut trees)

-land fragmentation (ideal for mixed systems)

-need for sustainable solutions for degraded or non-productive land

In Gorj County, the ideal areas for agro-pomiculture are:

-Târgu Jiu – Rovinari Depression (fertile soils, mild climate)

-sub-mountain areas in the north (Polovragi, Baia de Fier) (apple, plum, walnut)

-southern hills (Motru, Țânțăreni) (suitable for mixed farming and small farms)

The advantages of agro-pomiculture in Gorj County are as follows:

-increased land productivity (efficient use of space through intercropping among fruit trees)

-protection against erosion (tree roots stabilize the soil)

-greater biodiversity (attracts pollinators, reduces pests, improves the agricultural ecosystem)

-multiple sources of income (annual crops/cereals or vegetables + fruit production + beekeeping)

-climate adaptability (trees provide shade, reduce water evaporation, and protect understory crops)

The fruit tree culture combinations of fruit trees + crops that can be applied are the following:

-plum + cereals (barley, oats), shade-tolerant vegetables (lettuce, spinach), alfalfa
-apple + potatoes, onions, clover, medicinal plants
-walnut + alfalfa, grasses, fodder maize
-cherry + wheat, aromatic plants (mint, basil), strawberries

The stages followed in the implementation of an agro-pomiculture system are the following:
-planning (soil analysis, water availability, sun exposure; selection of species compatible with each other)
-land design (spacing between tree rows; leaving space between rows for crops or grazing)
-initial investments (tree planting, irrigation system, hedgerows, forest shelterbelts for protection)
-financial support (European funds through the National Rural Development Programme – PNDR/Agency for Financing Rural Investments – AFIR, for mixed or agro-ecological farms, programs for conversion to fruit growing or rural regeneration) [9].

According to surveys conducted in 2023 (USAMV, World Vision), over 60% of young people with higher education in agriculture or engineering are interested in applying digital technologies on farms, following courses and specializations in precision agriculture, agricultural robotics, and data science applied to agronomy (Ozdogan et al, 2017) [10].

In 2023, Romania had over 70 active AgriTech and FoodTech startups (e.g., AgroCity, Agxecutive, Nofence, Iris Robotics) in areas such as smart irrigation, food traceability, sustainable agriculture, and digital farmer networks. Support for digitalization in agriculture is provided through the National Rural Development Program (PNDR 2023–2027) and the National Strategic Plan (PNS), which allocate specific funds for investments in smart equipment, automation systems, and digital transformation of farms. Additionally, the Ministry of Agriculture and Rural Development's Smart Agriculture Program, piloted in 2024–2025, offered grants of up to €200,000 for the implementation of technology in small and medium-sized farms. Romanian entrepreneurs using sensors and automated systems represent less than 10%, which is below the European Union average (Bălăceanu et al., 2025) [3].

Current statistics regarding the involvement of young people, especially university graduates, in developing agricultural businesses in Romania and in Gorj County are as follows:

a. financial support and young farmer initiatives (National Rural Development Program – PNDR/Agency for Financing Rural Investments – AFIR) [9].

-2015–2022: The Agency for Financing Rural Investments (AFIR) received 77,721 applications for funding agricultural businesses, of which 66,709 investments were contracted, totalling €2.6 billion, with €1.86 billion paid to farmers. A total of 20,124 young farmers benefited from funds, including 13,924 under Sub-measure 6.1 – Young Farmer Installation, 4,718 under Sub-measure 6.3, and 785 young farmers and 68 young fruit growers under Sub-measure 4.1, of which 4,132 are from mountainous areas:
-at the level of Gorj County, during 2014–2020, under Sub-measure 6.1 of the PNDR – Young Farmer Installation, young people under 40 accessed non-reimbursable funds of €40,000–€50,000 per farm, as professionally trained owners or managers, provided they submitted a business plan, demonstrated professional competence, had domicile or farm headquarters in the area, and implemented the plan within six months
-through the Gorj County Agricultural Chamber, advisory support was offered, facilitating access to Measure 112, with projects ranging from €10,000–€25,000, with total projects exceeding €4 million
-in 2022, 2,089 agricultural businesses were initiated with a budget of €98 million (excluding Sub-measure 6.1). For 2023–2027, €420.3 million is allocated for measures dedicated to young farmers, including €250.7 million for installation (€70,000 per beneficiary) and €169.6 million for farm consolidation (€200,000 per project)
-entrepreneurs under 40 years old hold only 12% of agricultural holdings in the EU, of which only 3% are women. Romania ranks among the top five EU countries in the number of young farmers under 25, with

approximately 155,740 young active farmers in 2020

-regarding producers registered in the TOMATA Program of the Ministry of Agriculture and Rural Development, nationally, young people under 40 represent 32% (7,154 registered). In Gorj County, 16 applications were submitted, of which 7 belong to young people under 40 (43.75%)

-through PD-03 Complementary Income Support, young farmers up to 40 years old can receive annual payments for the first 50 ha for five years, provided they are the managers of the farm.

b. economic Context and Digitalization

-Romania accounts for 23% of the European Union's agricultural workforce (1.77 million jobs), but 44.3% of farmers are over 65 years old. In 2023, the number of AgriTech/ FoodTech startups was 73. Between 2018 and 2023, funding amounted to €14 million for FoodTech and €1.6 million for AgriTech.

-agriculture represented 3.9% of GDP in 2023, decreasing to 3.2% in 2024, with a 0.4% reduction in GDP contribution and a 10.5% decrease in production volume.

c. higher education and entrepreneurial potential in rural areas

-only 23% of young Romanians (ages 25–34) have higher education, well below the EU average of 43%.

-31% of graduates with secondary agricultural education intend to continue their studies, while approximately 33% plan to start or develop a business.

-the participation rate in higher education is low (due to a lack of essential entrepreneurial skills: communication, economic and social knowledge), but the interest of young people in rural areas is higher than that of their urban counterparts.

The current situation in Romania regarding agricultural entrepreneurship is dominated by experienced individuals aged between 45–60 years, but for the application of AI in agricultural business development, the participation of young people is necessary and beneficial. The use of AI in agriculture is based on: crop monitoring through drones and satellite images, intelligent irrigation systems, weather and plant disease predictions, farm management through software, GPS/auto guided machinery, and data analysis. Romania has over 2.8 million agricultural holdings (most of them very small), of which only about 1–3% of commercial farms use real forms of AI or advanced intelligent analysis, meaning approximately 5,000–15,000 agricultural entrepreneurs use AI in a concrete way. At the level of Gorj County, around 10–50 active farmers use simple AI tools or smart farming applications (GPS, sensors, drones, or modern software) in a recognizable way, while most entrepreneurs use smartphones, weather apps, and online communication.

Artificial intelligence can become a driver of rural development in Gorj County if it is strategically integrated into agriculture. The link between smart agriculture and artificial intelligence lies in the fact that AI is the technological engine that enables agriculture to become intelligent, predictive, and automated. Smart agriculture involves the use of advanced technologies (sensors, drones, GPS, software), while AI transforms data into automated or assisted decisions. (Schouten, M.A., 2011) [12].

Types of artificial intelligence used in agriculture:

-Machine Learning (ML): AI learns from historical data to make microclimate weather forecasts, yield estimates, and disease recognition.

-Computer Vision: analysis of images from drones or cameras to identify weeds, estimate plant density, and control crop quality.

-Natural Language Processing (NLP): Used in voice assistants for farmers, translating pesticide labels, and training farmers through interactive applications.

-Smart agriculture (Smart Farming or AgriTech) is of interest globally and in Romania, particularly among young entrepreneurs and university graduates, as it offers opportunities to optimize resources, produce sustainably, reduce manual labour, and make farming more profitable in the long term (Plesa et al, 2024) [11].

It involves using modern technologies to improve agricultural processes:

-IoT sensors (for soil, moisture, temperature).

-drones (for crop monitoring and treatment application).
-Big Data and AI (for yield predictions and pest control).
-autonomous tractors.
-digital farm management platforms (agricultural ERP, GIS software, mobile applications).
Artificial intelligence can help rural entrepreneurs (farmers, local producers) optimize their businesses through:
-automated e-commerce platforms (for selling local products)
-virtual assistants (providing advice on business, accounting, or marketing)
-predictive market analyses (to anticipate demand and consumption trends)
In this context, the purpose of the paper is to demonstrate that artificial intelligence tools can be used in the practice of smart agriculture in the South-West Romania region, to simultaneously analyze economic, climatic and market factors, identify the type of sustainable, accessible, adaptable and profitable crop, reduce costs and optimize resources (inputs, water waste, fertilizers, pesticides, labor), make faster and better decisions and maximize profit.
The development prospects of agricultural entrepreneurship include: agricultural digitalization, modern irrigation, farmer association in cooperatives, development of organic agriculture, and increased agricultural exports.

MATERIALS AND METHODS

The To indicate which type of business has the greatest potential for success in a particular area. (case study for Gorj County, in South - West Romania), artificial intelligence was used, which simultaneously analysed economic, climatic and market factors.
a. Analysis of soil and climatic conditions has as purpose the identification of crops or types of agriculture (wheat, lavender, fruits, vegetables, viticulture, which are most suitable for a particular area)
-soil type and quality (with the help of sensors and satellite maps)
-precipitation, temperatures, humidity levels
-drought or flood risks (using satellite imagery and weather data; for example: Google Earth Engine, precision agriculture platforms such as Climate FieldView, CropIn)
-artificial intelligence can suggest which crops are suitable or which irrigation technologies will be needed
b. Profitability forecasts (artificial intelligence combines data and recommends the agricultural business with the best profit potential; for example: sea buckthorn cultivation versus greenhouse tomato production)
-production costs
-local and regional market prices
-consumer demand
-subsidies or government support
c. Studying competition and market supply and demand (artificial intelligence analyses and selects a market niche with high demand and low competition; for example: organic beekeeping or organic mushroom farming)
-competition for a specific crop in the area
-products that are missing from the market
-forecasts for trending products (organic, aromatic plants, exotic crops, eco, local)
-data from agricultural markets, consumption trends, and historical prices
-the result is the selection of a profitable niche (for example: lavender, berries, microgreens cultivation)
d. Business plan optimization (with the help of AI, the business becomes better structured and more prepared for financing)
-creation of a personalized business plan
-estimation of initial expenses and profit
-identification of available funding (European funds, grants)
e. financial simulations, risk assessment, and scenarios (choosing a safer business with lower risks and steady returns)
-building predictive models for costs, estimated profit, and investment payback period
-business performance in the event of drought
-effects of market price decreases
-profit generated by investing in irrigation systems or greenhouses

-integration of climate risks and price volatility (resulting in the selection of a business with an optimal risk–profit ratio)
f. Virtual assistants for agricultural consultancy (quick access to expert information and personalized answers, without relying on an agricultural consultant)
-crops to be planted according to the season
-obtaining organic certification
-required equipment
-personalization of recommendations (based on location, available capital, and level of experience, AI can suggest a traditional farm or a modern solution such as hydroponics, aquaculture, or vertical farming; for example: farm-planning systems used in Australia and the Netherlands)
g. Continuous monitoring and strategy adaptation
-since business selection is not a static process, AI can monitor market fluctuations and weather conditions in order to recommend crop changes, production diversification, or adjustments to marketing strategies
Table 1 presents examples of the role of artificial intelligence depending on the technology or system used in smart agriculture.

Table 1. Examples of the role of artificial intelligence according to the technology or system used in smart agriculture

Technology or system used	Role of artificial intelligence (AI)	Example
soil, moisture, and light sensors	analyses data to optimize irrigation	the system automatically decides when and how much to irrigate crops
drones and satellite imagery	image recognition for identifying diseases and pests	detects affected areas in corn fields
autonomous tractors and robots	assist with navigation, obstacle avoidance, harvesting	robots that harvest without human intervention
farm management applications	provide predictions on yield, prices, and required inputs	recommend the optimal sowing date
climate and weather models	integrate historical as well as real-time data for accurate forecasts	prevent losses caused by hail or drought

Source: Authors' synthesis.

Artificial intelligence was used to determine the most suitable agricultural business for Gorj County.

RESULTS AND DISCUSSIONS

With the help of AI technologies for analysis, planning, and sales, investment for young entrepreneurs in rural areas becomes safe and efficient. (Ministry of Agriculture and Food Industry of the Republic of Moldova, 2022) [8]
Case study: Lavender cultivation business in Gorj County, selected with the help of artificial intelligence (Photo 1).

Photo 1. Lavender cultivation – a sustainable business for Gorj County
Source: [13].

Artificial intelligence has shown that a lavender business is a sustainable, accessible, adaptable, and profitable choice in the rural areas of Gorj County, and its use in the decision-making process aims to reduce risks, optimize resources, and maximize profit (Ingvar, 2024) [6].
1. Business Selection
With the help of an AI system (platforms such as AgroSmart, FarmAI, or CropX), the following data were analysed for a rural locality in Gorj County, with lavender cultivation being recommended by AI as the most profitable and sustainable choice for this land:
-soil type (sandy, well-drained – ideal for lavender)
-climate (hot, dry summers; mild winters – good conditions for Mediterranean plants)
-precipitation (moderate – lavender requires little water)
-market (growing demand for natural, organic, and cosmetic products)
-competition (low in the county – niche opportunity)

-available funding (PNDR and Start-Up Nation cover 80% of costs)

2. Business Plan

Business Description – The business involves establishing a lavender crop on an agricultural plot of 1 ha (10,000 m²) for the purpose of processing the flowers into essential oils, phyto therapeutic, decorative, and cosmetic products, considering that lavender is a resilient plant with high demand in the organic and cosmetic markets.

Motivation for AI-assisted selection – An AI-based agricultural analysis platform is used to:

-verify the compatibility of the soil and climate with lavender

-estimate long-term profitability

-compare with other crops (corn, wheat, raspberries)

AI recommends lavender as the most profitable choice for the area, offering high yield and low maintenance.

Business Objectives

-establish the crop in Year 1

-obtain the first harvests of dried flowers and oil in Year 2

-create a private brand for lavender-based products in Year 3

-expand vertically (processing) and horizontally (rural tourism or beekeeping products)

Market Analysis

-growing demand for natural products (essential oils, dried flowers, phyto-therapeutic products, cosmetics, decorations, bouquets)

-target customers (pharmacies, health food stores, beauty salons, online customers via Etsy and Facebook, guesthouses, export markets)

-low competition in Gorj County (market opportunity)

Initial Investment

-€8,000 – €12,000 (mechanization, planting, maintenance, harvesting)

(Table 2 shows the initial investment cost for a 1 ha lavender crop)

Sources of funding can be:

-own contribution = €2,000 non-reimbursable funds (PNDR, Start-up Nation, GAL) = €7,000

Table 2. Initial investment cost for a 1 ha lavender crop (euros)

Expense Type	Estimated cost (euro)
land preparation and ploughing	800
lavender cuttings (10,000 units)	3,000
planting and labour	1,000
drip irrigation system	1,200
mini essential oil distiller	1,500
packaging, labels	500
other expenses (transport, consultancy)	1,000
Total	**9,000**

Source: Authors' synthesis.

The revenues obtained after Year 2 of lavender cultivation are presented in Table 3.

Table 3. Revenues obtained after Year 2 of lavender cultivation (euros)

Product	Estimated Production/ M.U.	Selling Price	Estimated Revenue (euros/year)
Dried flowers	300 kg	10 euro / kg	3.000
Lavender essential oil	10 l	80 euro / l	800
Packaged products (sachets, oil)	300 pieces	5 euro / pieces	1,500
Total			**5,300**

Source: Authors' synthesis.

Profit (after Year 3) is as follows:

-annual expenses (maintenance, packaging, harvesting) = €1,000

-estimated profit/year = €4,000 per year (€3,000 – €6,000 after Year 2, depending on processing and sales)

-crop duration = 10 – 15 years

3.The Role of AI in Planning and Decision-Making

-soil analysis (checks compatibility with lavender using maps and sensors)

-crop selection (compares lavender with other crops such as corn, wheat, and raspberries)

-cost estimation (generates a budget based on local data and historical price trends)

-weather forecasting (provides alerts and recommendations for agricultural tasks)

-marketing and sales (suggest online promotion strategies via Google, Instagram, Etsy) (The roadmap for Digital Transformation in Agriculture, 2022).

-implementation schedule (Table 4):

Table 4. Implementation schedule

Period	Activity
October – December 2025	soil analysis, purchase of cuttings, land preparation
March 2026	lavender planting
Summer 2027	first harvest of dried flowers
Autumn 2027	oil processing and market launch

Source: Authors' synthesis.

4. Advantages of a Lavender Business

-high demand in the organic, wellness, and cosmetic industries

-low maintenance compared to other crops

-can be fully utilized (flowers, oil, lavender honey)

-ideal for families or small farms

5. Risks and AI Management

-drought (smart irrigation system with moisture sensors)

-pests (early detection through monitoring with drones or mobile applications)

-market oversaturation (AI tracks trends and recommends diversification: cosmetic products, sachets, creams, tourism)

-unforeseen costs (financial simulations with AI and monthly updates) (Clusters Agriculture, 2011).

CONCLUSIONS

-The structure of agricultural entrepreneurship in Romania is diverse, including small family farms, medium and large holdings, and agricultural companies, and it encompasses the resources, organization, and activities necessary for developing an agricultural business, with profit depending on efficient management, market adaptation, and the use of modern technologies.

- Statistical data are presented regarding the involvement of young people and higher education graduates in developing agricultural businesses in Romania and in Gorj County.

-The agricultural potential of Gorj County is based on arable land, which accounts for 44% of the county's total area, primarily used for fruit growing, viticulture, and crop farming (cereals such as corn, wheat, rye; fodder crops; barley, oats, and potatoes).

-The agro-pomiculture is an ideal solution for Gorj County as a sustainable farming practice that combines crop cultivation and fruit tree cultivation on the same land to achieve ecological, economic, and social benefits.

-Entrepreneurs are interested in applying digital technologies in farms, precision agriculture, agricultural robotics, and data science applied to agronomy.

Smart agriculture (Smart Farming or AgriTech) is an opportunity to optimize resources, produce sustainably, reduce manual labor, and make agriculture more profitable in the long term, involving the use of modern technologies to improve agricultural processes: IoT sensors, drones, Big Data and AI, autonomous tractors, and digital farm management platforms (agricultural ERP, GIS software, mobile applications).

-Artificial intelligence is at the core of smart agriculture, making farming an exact science (predictive, adaptive, and sustainable) and a major opportunity for young agricultural entrepreneurs who understand technology.

-Smart agriculture involves using advanced technologies (sensors, drones, GPS, software), but artificial intelligence transforms the data into automated or assisted decisions.

-Artificial intelligence has shown that a lavender business is a sustainable, accessible, adaptable, and profitable choice in the rural areas of Gorj County, and its use in the decision-making process aims to reduce risks, optimize resources, and maximize profit.

-The problems of agricultural entrepreneurship in Romania include: fragmentation of agricultural land, low levels of mechanization in some areas, dependence on climate conditions, lack of young labor force, and difficult access to financing for small farms. The development of this sector depends on modernization, investments, and the effective use of European funds.

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INTERNATIONAL TRENDS IN SUNFLOWER PRODUCTION AS A FEEDBACK TO FOOD AND ENERGY CRISIS, ENVIRONMENT PROTECTION, BIODIVERSITY PRESERVATION, CLIMATE CHANGE AND CONFLICTS IMPACT

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Abstract

The purpose of the paper is to study the dynamics of sunflower cultivated area, production and yield performance at the global level and in the EU in the in last five years 2021-2025 in order to identify the main tendencies in the context of food and energy crisis, environment protection and biodiversity preservation, climate change and conflicts impact. The data from USDA and Eurostat served as primary data which have been processed using trend analysis, regression equations, descriptive statistics, structural indices and comparison method. The results pointed out that in 2025, sunflower was cultivated on 33 million ha, (+1.46% than in 2021). Russia, Ukraine, the EU, Argentina and China totalized 22.9 million ha, meaning 77.6% of the global acreage with sunflower in 2021, while in 2025, they summed 24.18 Million ha, that is by 5.58% more. Despite this, seed production increased by 1.37% reaching 59 Million MT in 2025, the contribution of the major producers being: Russia 29.6%, Ukraine 18.6%, the EU 14.5%, Argentina 11.8% and China 3.5%. While in Argentina and Russia, production increased (+118.7%: + 12.9%), in the other countries it declined. The global average yield attained 1.78 MT/ha in 2025, by 10.2% less than in 2021. A peak of 2.15 MT/ha was recorded in 2024. In the EU-27, sunflower covered 4.9 Million ha, by 9.1% more. The largest surfaces are in Romania (26.4%), Bulgaria (20.4%), Hungary (14.7%), France (14.2%), Spain (13.7%) and summing 71.4% of the EU area with this crop. The climate change impacted mainly in the Eastern and Southern Europe, so that seed production accounted for 8.6 Million MT in 2025, by 7.31% less than in 2021. Production declined in Romania, Bulgaria, France, but increased in Spain and Hungary. The EU-27 average yield was 1.79 MT/ha. The changes in cultivated area and production are a response to actual economic, social, environmental and geopolitical problems proving that sunflower will continue to be a key climate resilient crop, a high value food and feed, a sustainable resource of bioenergy, an environment protector and a promoter of agribusiness efficiency in the future.

Key words**:** *sunflower, cultivated area, production, yield, trends, globally, EU*

INTRODUCTION

Sunflower (*Helianthus annuus* L.) has been and continue to be an important crop in the world taking into account its multiple features as a source of high value food and feed, a climate resilient plant, a renewable energy resource, a soil protector against pollution, a support for biodiversity, an income source for producers and promoter of a high efficient agribusiness.

Photo 1. Sunflower
Source: Original.

Sunflower has a high nutritional value grace to the rich content of the seeds in fats, protein, fiber, minerals and vitamins and other important components playing a vital role for immunity system, heart and skin protection and antioxidant effect. That is why it is considered a medicinal plant as well.

The whole plant could be successfully used. Seeds could be eaten as such or roasted with salt, or transformed in sunflower butter and high quality edible oil destined for cooking. The young buds before their opening could be grilled and steamed. Petals are colorful and sweet suitable to decorate salads or desserts. The leaves could be chopped in salads or boiled and then transformed into a mashed meal like spinach. The peeled and chopped stalks could be a delicious snack [2].

Oil is extracted by pressing seeds and is edible, having a low content in saturated acids protecting heart and lowering cholesterol, and also key important vitamins mainly A, D, E which protect skin and hair. It is agreed in the kitchen being used in salads and various sorts of meals [1].

Sunflower is an excellent feed because of its nutritional value (fats, protein, fibers etc) for many farm species such as: cattle, swine, poultry, sheep. It could be used as raw seeds, flower heads with seeds, fresh or dried leaves and stalks, pellets, and sunflower meal (cake) resulting after oil extraction [37].

Grace to its deep root system, which could reach water far below the ground and its resistance to drought and heat, sunflower is considered a climate resilient crop. More than this, the plant has a low carbon footprint as it requires small amounts of nitrogen fertilizers and pesticides. It is also adaptable to valorize the degraded soils by salinity.

However, in case of extreme climate phenomena like heat waves, long and severe droughts during the vegetation period, sunflower yield could be affected by seed losses, oil content decline and alteration of the fatty acids. Farmers are obliged to take measures to sustain their business using early and tolerant-to-stress varieties and hybrids, changing in advance the sowing period and moving the area of cultivation [12, 32, 33, 26].

Sunflower is a renewable energy resource, as from seeds processing results biodiesel, which lowers gas emissions. Seed husks are a good biofuel. Processed under an anaerobic digestion, the crop residues could be transformed in biogas (methane) [19].

Depending on the oil content, from one tone of sunflower seeds could be obtained between 18,300 and 25,100 MJ dietary/fuel energy.

This amount is structured in:

- 350-500 kg oil, which contains the most of energy (13,000 to 19,500 MJ) and by-products like:

-340-400 kg sunflower meal (3,500 to 4,500 MJ energy content)

-200-250 kg hulls and residues (1,800-2, 200 MJ energy content) [23].

As a soil protector, sunflower has the capacity to capture CO_2 from the atmosphere and store it into the ground. Also, it protects soil against contaminants (toxins, radioactive isotopes, heavy metals).

It sustains biodiversity being an attractive plant for pollinators and mainly for bees which transform the collected nectar into delicious sunflower honey and also store the pollen. Grace to its beautiful yellow flowers, the plant creates magnificent sceneries of the landscapes [5].

Due to the high demand for seeds for producing food, oil, and feed, sunflower has a long perspective in the future to be cultivated, processed and traded. It is a profitable crop because it need lower inputs (water and

fertilizers) than other crops, sales are assured both on the domestic and international marked, the profit margin is high in case of oil, it is useful in crop rotation with cereals increasing soil fertility. Therefore, farmers love sunflower cultivation and will continue to do this. It also plays an important role assuring jobs and income in the rural areas [14].

The new technologies sustained by precision agriculture tools enhance yield and sustain producers' efforts for a sustainable development of the culture of this crop.

Guided automatic tractor steering is used to strengthen sowing precision at a low cost [25].

Precision planters assure a higher plant density, a uniform growth and finally better yields [61].

Drones are useful to controlling planting density and irrigation patterns, the plant growth across the vegetation period and to assess the optimum seed per plant [17].

Remote sensing allows the evaluate the vegetation indices [11].

Using satellite imagery, farmers could study plant development, set up models characterizing the crop temporal variation and forecast production based on NDVI and NBR indices [15].

More than this, satellite imagery could evaluate plant health, detect and monitor weeding degree, flowering stage, optimize fertilization and estimate yield [3].

The most important sunflower seed producers and exporters in the world ar**e** Russia, Ukraine, EU (Romania, Bulgaria), Argentina and China.

The top exporters of sunflower oil are Ukraine and Russia with a market share of 33%, and respectively 30% in the global export. Ukraine's main beneficiaries are India, Spain, and the Netherlands. In case of Russia, its exports are destined to the Middle Est and Asia.

Then, Argentina assures 12-14% of the global seed exports, Turkey 4-5% and Romania and Bulgaria are important seeds exporters, coming on next positions. The top importers of sunflower seeds are China, India, Turkey, Spain, and Italy [53].

The top producers of biodiesel from sunflower seeds are in the EU: France, Germany, Spain and Italy, followed by Russia and Ukraine [18].

During the last five years, sunflower was facing various challenges and disruptions in cultivation, production and trade such as: difficulties across the food chain during the Covid-19 pandemic, decline in yields caused by climate change impact in certain countries and areas, bottlenecks in commercialization due to the conflict between Russia and Ukraine and geopolitical shocks.

All these aspects have weakened the relationships between producers, traders and beneficiaries, reflecting the sensitivity of seeds and oil supply chains and also of the agricultural systems in front of the natural disturbing factors, increasing the food security risk [9].

In this context, the paper aimed to examine the dynamics of the sunflower cultivated area, production and yield in the main producing countries at the global level and in the EU in order to identify the new tendencies and challenges, using the data from USDA and Eurostat. Graphical illustration of the trend line, as well as the regression equations and R square, coefficient of variation, descriptive statistics, structural indices and comparisons have formed the methodological background.

MATERIALS AND METHODS

This research was based on a large documentation from the literature in field collected mainly from WoS and Google Scholar. The empirical data were provided by FAOSTAT and Eurostat Databases for the period 2021-2025, especially selected because of the large variability of factors impacting sunflower cultivation, production and yield at the global and in the EU.

It is about the food and energy crisis, climate change, environment problems related to the pollution caused by agricultural technologies, biodiversity preservation, and military conflict between Russia and Ukraine.

The studied indicators have been: cultivated area, seed production and yield, analyzed both at the global level and in the EU, pointing out

the main trends also in the top five countries cultivating sunflower at each level.
For this purpose, there were made suggestive graphics illustrating the dynamics, the trend line, regression equations and R squares.
Descriptive statistics characterized the results for each country in terms of mean, standard deviation, R square, kurtosis, skewness, minimum and maximum value. Also, the variability of each indicator was appreciated based on the coefficients of variations.
CAGR was calculated to express the positive or negative growth along the analyzed period.
Fixed and structural indices were also determined and comparison method allowed to show the differences among the selected countries, either at the global level and in the EU.
The results were accompanied by pertinent comments and at the end, the conclusions summarized the main ideas in brief.

RESULTS AND DISCUSSIONS

Sunflower at the global level

Sunflower cultivated area

Among the oil crops, sunflower is a major productive plant, an important supplier of raw materials for various processing industries like food, feed, energy, pharmaceutical, cosmetics sectors. Also, it is a more drought resistant plant, a useful item in crop rotation, a good protector of soil quality and fertility, and a high efficient crop, assuring enough income for farmers to cover the production cost and achieve profit. Because of the high market demand of sunflower as food, feed and bioenergy resource, and its high profitability, farmers increased the cultivated area year by year. In the analyzed interval, it was achieved a gain of 11.86% from 29.5 Million ha in 2021 to 33 Million ha in 2025 (Fig. 1) [38].

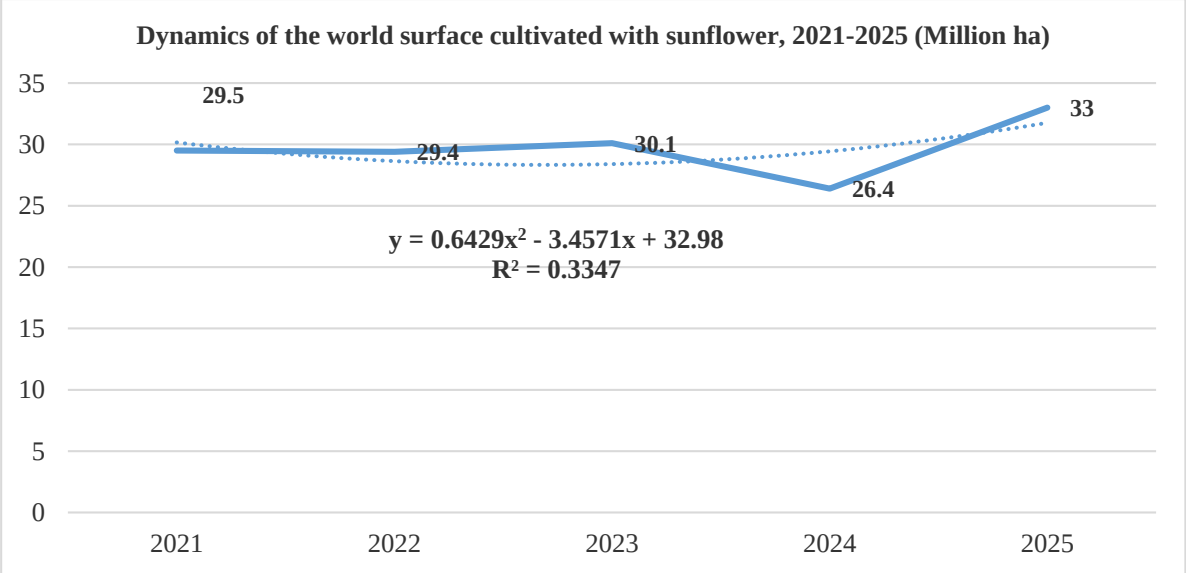

Fig. 1. Dynamics of the global area cultivated with sunflower, 2021-2025 (Million ha)
Source: Own design based on the data from [20].

The cultivated area varies from a year to another in accordance with the changes in climate conditions, technological modernization and market requirements, from a continent to another and from a country to another.
The geographical distribution of the acreage reflects that about 70% of the global cultivated area with this crop is in Europe and accounts for about 22-23 Million ha [56].
Asia comes on the 2nd position with 3.5 million ha, accounting for about 12%, being followed by the Americas 9%, Africa 8% and Oceania 1% [20, 28].
In the year 2025, it was achieved 33 Million ha, the largest cultivated area with sunflower in the world during the last five years (Fig. 1).
A slight inflexion was noticed in the year 2022, but the deepest one was carried out in 2024, when the area decreased to 26.4 Million

ha versus 2021 (-10.5%). The CAGR was 2.27%.

The major cultivators of sunflower in the world are Russia, Ukraine, the EU, Argentina and China, in 2021, all these five countries together accounting for 22.91 Million ha, meaning 77.6% of the global acreage with this crop, but in 2025 they kept 24.18 Million ha representing 73.27% (Fig. 2).

In the decreasing order after China in 2025, there were: Kazakhstan 1.8 Million, Romania 1.2 Million ha, Bulgaria 0.98 Million ha, Turkey 0.76 Million ha, Hungary 0.71 Million ha, France 0.68 Million ha, Spain 0.66 and USA 0.52.

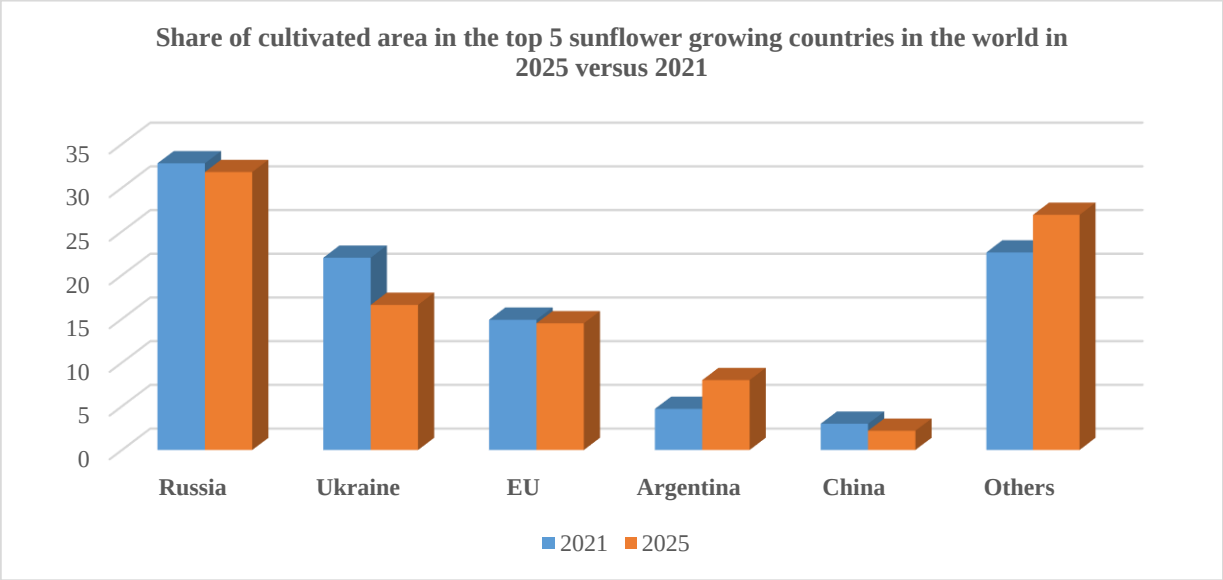

Fig. 2. Share of the top five countries growing sunflower in the world in the global cultivated area (%)
Source: Own design and calculation based on the data from [20].

In Russia, sunflower is the main crop producing edible oil, but also it is used for many other purposes. Besides the fact that this plant is an important income source for producers, it also sustains various processing industries such as: oil, food, chemical, pharmaceutical and cosmetics, supplying them its entire biomass above the ground as raw material.

Its edible oil is a high value food, but also sunflower cakes are an important feed. The plant is pollinated by bees and others pollinators, and the honey achieved from its nectar account for about 20-30 kg per ha.

That is why this plant it is one of the most profitable crops in Russia.

The suitable regions for cultivating sunflower are Southern Federal District and Middle and Lower Volga Federal District, where the soils are rich in nutrients, light, warmth and moisture are abundant, exactly what sunflower needs for growing in good conditions and performing in production.

Grace to the implementation of the technologies based on high production potential, early herbicide-resistant varieties and hybrids, resulting from the progress achieved in genetics and breeding, integrated weed management and precisions agriculture, sunflower cultivation is expanding to Non-Chernozem regions and also in Eastern Siberia and the Far East.

In Russia, production performance varies between 1.5-2.5 tons/ha depending on the soil and climate conditions, but in the favorable years it could be obtained even 3 tons/ha [8].

In the interval 2021-2025, the cultivated area increased by 8.2% reaching 10.5 Million ha in 2025 (Fig. 3). Russia makes efforts to continue its leading position in the world sunflower cultivation and production.

Ukraine

Ukraine is a strong competitor for Russia regarding sunflower cultivation and production. A few years ago, before starting the conflict between the two countries,

Ukraine occupied the top position in the world for sunflower seeds and oil output [31].

The most fertile regions are Steppe and Forest-Steppe areas where sunflower is successfully grown. However, the increased temperatures are expanding the cultivation area to Northern Ukraine (Pollisya) [51].

Yields are higher and higher due to the adoption of the use of high oleic hybrids, precision agriculture and new tillage methods, especially no-till or minimum tillage which allow the storage of more moisture into the soil [48, 58].

Yield could range between 2.2-2.8 tons/ha, usually 2.6 tons/ha, assuring a high profitability rate.

Since 2022, when the hostilities begun, the Eastern and Southern regions have been impacted by disruptions in cultivation, soil degradation which obliged producers to move their business to the less affected regions.

In consequence, the surface cultivated with sunflower decreased from 6.5 Million ha in 2021 to 4.7 Million ha in 2022 (- 1.8 million ha, that is -17.7%). In 2025, Ukraine succeeded to grow sunflower on 5.5 Million ha, accounting for 84.6% of the area sown in 2021 (Fig. 3).

The EU is an important player in the sunflower cropping and especially in the geographical areas where the plant could find favorable soil and climate conditions, such as the South East and also South West part Europe. The main producing countries are Romania, Bulgaria, France, Hungary and Spain.

Sunflower is successfully integrated into crop rotation grace to its drought-resistant capacity.

Romania is the top producer of sunflower seeds, cultivation being characteristic in the Eastern and Southern part of the country. In the Bulgarian plains, sunflower is a common crop, in France it is cropped in the West and South areas and in Spain in the Central and South parts.

Because of the intensified frequency of extreme climate phenomena, producers have adapted their technologies using high drought-tolerant hybrids and drones to manage precise inputs and plant protection.

Genetics and hybridization are a useful option to produce hybrids adapted to the EU soil and climate conditions, to increase oil content, early vigor and drought-tolerance.

Crop rotation with cereals is frequently applied to capture soil nutrients and preserve moisture into the ground.

Sunflower cultivated in organic system is increasing, Romania being the leader in this respect.

In this field, in the West Plain of Romania, AI and robotics are helpful for weeding management and monitoring and the use of tractor autonomous alternatives [16].

In the analyzed interval, in the EU, it was registered a slight upward trend from 4.4 Million ha in 2021 to 4.8 Million ha in 2025 (+0.4 Million, meaning +9.09%) (Fig. 3).

Argentina is another important player in producing sunflower seeds and oil. However, at the moment, in some regions, the country is facing with low yields, caused by tillage system (No tillage and conventional tillage). No tillage cultivation is applied on a large scale for preserving moisture, reducing soil erosion and keeping costs at a low level.

However, the use of Phosphorus fertilizers and high herbicide-resistant and high oleic cultivars favor production.

Weeding control is based on the use of herbicide-tolerant hybrids, soil fertility is monitored using phosphorus and nitrogen fertilizers timely during the crop vegetation period to increase protein and oil content.

Crop management is assured along the supply chain using precision agriculture and traceability.

The cultivation areas are Buenos Aires and La Pampa, and also in the North Chaco and Santa Fe.

The surface continues to be expanded year by year because of the low input of fertilizers and the attractive sale price which favor profitability.

About 90% of production is processed for oil and meals, which are successfully exported.

In 2025, Argentina cultivated 2.65 Million ha with this crop, by +87.9% more than in 2021, when it harvested 1.41 Million ha (Fig. 3).

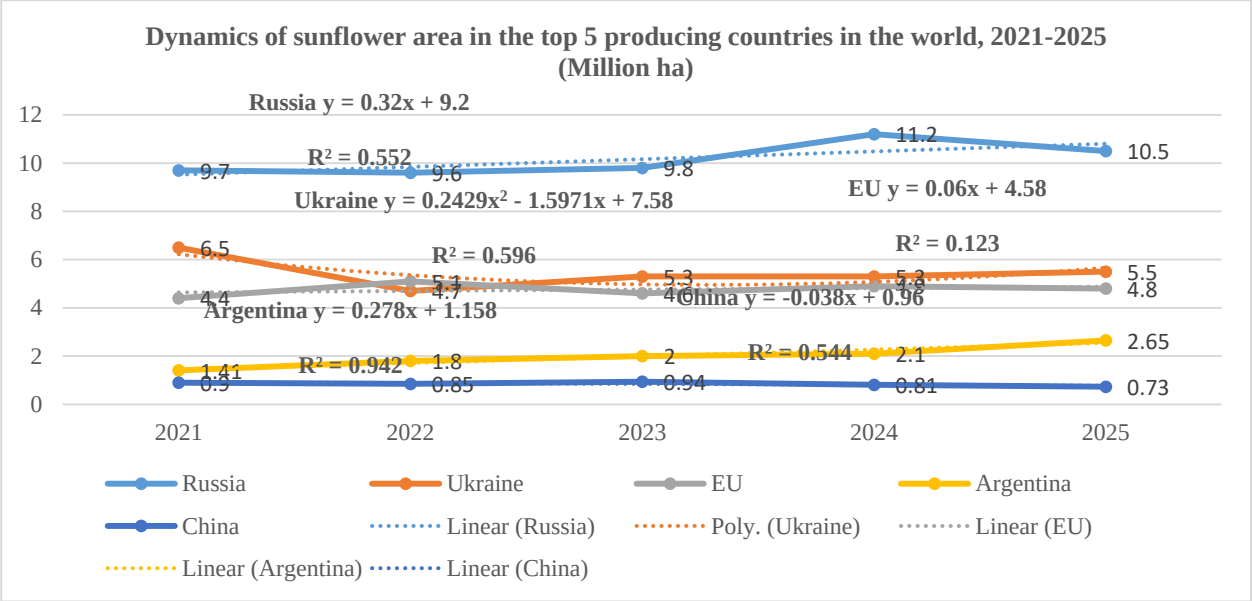

Fig. 3. Dynamics of sunflower area cultivated by the top five countries in the world (Million ha)
Source: Own design and calculation based on the data from [20].

China is the major producer of sunflower seeds in Asia, but also among the top five countries at the global level.

The cultivation of this crop is in the North West part of the country more exactly in Inner Mongolia, where 75% of production is carried out and Xinjiang, where crop technologies are well adapted to temperature variation and low rainfall.

Seed cultivars are oriented for roasting market. To assure water requirements, two systems are applied: wasteful flood irrigation and the modern system – drip irrigation and fertigation in the large companies.

In this way, water soluble fertilizers are directly injected into the drip or sprinkler irrigation system.

These methods have contributed to the expansion of modern farming, greenhouses and hydroponics in China.

However, in some regions, the low quality of the soils still maintains a reduced yield. To improve this situation, biochar and fulvic acid are applied.

Pollination is both naturally and artificially applied for increasing nectar and honey yield.

Seed yield level varies depending of the technology applied. In the traditional system, it could be obtained 1.6- 2.4 tons/ha, while in the hybrid farms it could be achieved 2.6 tons/ha. In the high tech farms, it could be achieved 3.7-4.5 tons/ha.

Having in mind that demand and consumption are high, sunflower cultivation will remain an important activity for many farmers [21, 30].

Despite that it is a large Asian country, China cultivated only 0.9 Million ha with sunflower in 2021, and in the last years the areas decreased up to 0.73 Million ha in 2025 (-0.17 Million ha, - 20.9%) (Fig. 3).

The evolution of the acreage with sunflower by the major cultivators is graphically illustrated in Fig. 3.

The share of each country in the global sunflower cultivated area is shown in Table 1.

The data from Table 1 shows that these five countries cultivate the largest part of the global area with sunflower, the percentage ranging between 71.9%, the minimum share in 2023 and 91.9 %, the highest share in 2024. This high share is explained by the fact that the year 2024 was an unfavorable year at the global level for sunflower and the harvested area was smaller than in the previous years.

Descriptive statistics for sunflower cultivated area at the global level and in the top 5 countries growing this plant is presented in Table 2.

The coefficients of variations regarding cultivated areas have small values in case of global situation, Russia, Ukraine EU and China, reflecting that the distribution of the variables is around the mean, therefore the mean is representative.

Table 1. The weight of the cultivated area with sunflower in Russia, Ukraine, EU, Argentina and China in the global surface covered by this crop (2021-2025) (%)

	2021	**2022**	**2023**	**2024**	**2025**
Russia	32.8	32.6	32.5	42.4	31.8
Ukraine	22.0	15.9	17.6	20.0	16.6
EU	14.9	17.3	15.2	18.5	24.5
Argentina	4.7	6.1	6.6	7.9	8.0
China	3.0	2.8	3.1	3.1	2.2
Total 5 countries	**77.4**	**74.7**	**71.9**	**91.9**	**73.1**

Source: Own calculations based on the data from [20].

Table 2. Descriptive statistics for sunflower cultivated area at the global level and in the top 5 countries growing this plant (2021-2025)

	Global	**Russia**	**Ukraine**	**EU**	**Argentina**	**China**
Mean	29.68	10.16	5.46	4.76	1.99	0.84
St. Dev.	2.34	0.68	0.65	0.27	0.45	0.08
R square	0.33	0.55	0.59	0.12	0.94	0.54
Kurtosis	1.744	-0.168	2.26	-0.68	1.02	-0.34
Skewness	0.043	1.116	1.008	-0.18	0.36	-0.47
Min	26.4	9.6	4.7	4.4	1.41	0.73
Max	33	11.2	6.5	5.1	2.65	0.94
CV%	7.88	6.68	11.9	5.67	22.6	9.52
CAGR %	2.34	1.6	-3.29	1.76	13.45	-4.1

Source: Own calculations.

A high variation was found for this parameter in case of Argentina, 22.6%, reflecting that the standard deviation is 22% of the average. This means a moderate to a high variability of the data.

The CAGR in the analyzed interval was for Russia 1.6%, Ukraine -3.29, UE 1.76%, Argentina 13.45% and China -4.1% (Table 2).

Sunflower seed production at the global level

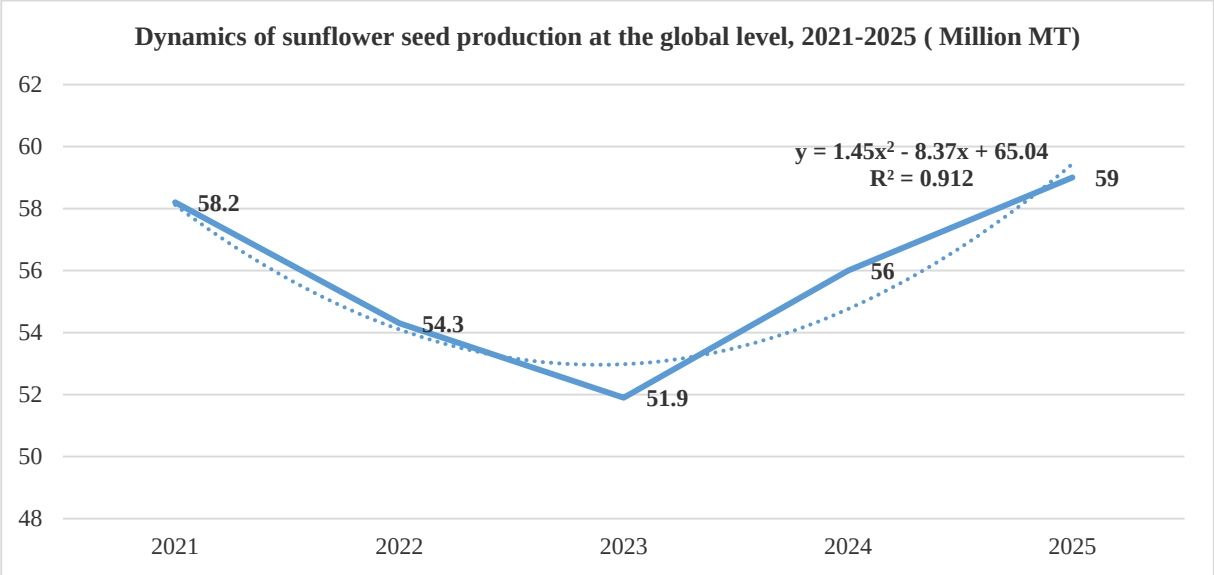

Fig. 4. Dynamics of the global sunflower seed production, 2021-2025 (Million ha)
Source: Own design based on the data from [20].

Taking into consideration the increased acreage, the variability of the applied technologies and climate conditions worldwide, sunflower seed production registered differences from a region to another and from a country to another [39].

Globally judging this aspect, seed production registered an upward trend from 58.2 Million MT in 2021 to 59 Million MT in 2025,

meaning a surplus of 1.37%. An important reduction was achieved in the year 2023, when at the global level seed output was only 51.9 Million MT. But in the coming years, it was noticed a recovery and production increased year by year up to 59 Million MT (Fig. 4).

In Russia production increased by 12.9% attaining 11 Million MT in 2025 (Fig. 5).

In Ukraine, the situation was good only in the year 2021, when Ukraine was ranked the 1st in the world for its performance of 16.9 Million MT. After starting the war in 2022, both the cultivated land and production were deeply affected. Production was only 11 Million MT in this year, meaning by 43.88% less versus 2021, and in consequence Ukraine passed on the 2nd position after Russia at the global level (Fig. 5)

The EU achieved a good seed production in 2021, accounting for 10.40 Million MT, but in the coming years it varied because the key member states producing sunflower seeds: Romania, Bulgaria in the South Eastern part and France, Hungary in the Central part and Spain in the South Western part of Europe have been affected by extreme high temperatures and droughts and low rainfalls, which diminished production to 8.6 Million MT in 2025, the minimum level achieved in the analyzed interval (Fig. 5).

Argentina attained its goal to become a strong seed producer in the Americas, and benefiting of good soil and climate conditions and modern technologies its production jumped from 3.2 Million MT in 2021 to 7 Million MT in 2025, reflecting an increase of 118.75%, a high performance which transformed this country in the major producer and exporter of sunflower to the EU market (Fig. 5).

China registered a reduction in sunflower seed production by 27.15, producing just 2.1 Million MT in 2025.

All these five countries together carried out in 2021 an amount of 48.88 Million MT seeds, meaning 83.9% of the global production.

The dynamics of seed production in the major five countries growing sunflower is shown in Fig. 5.

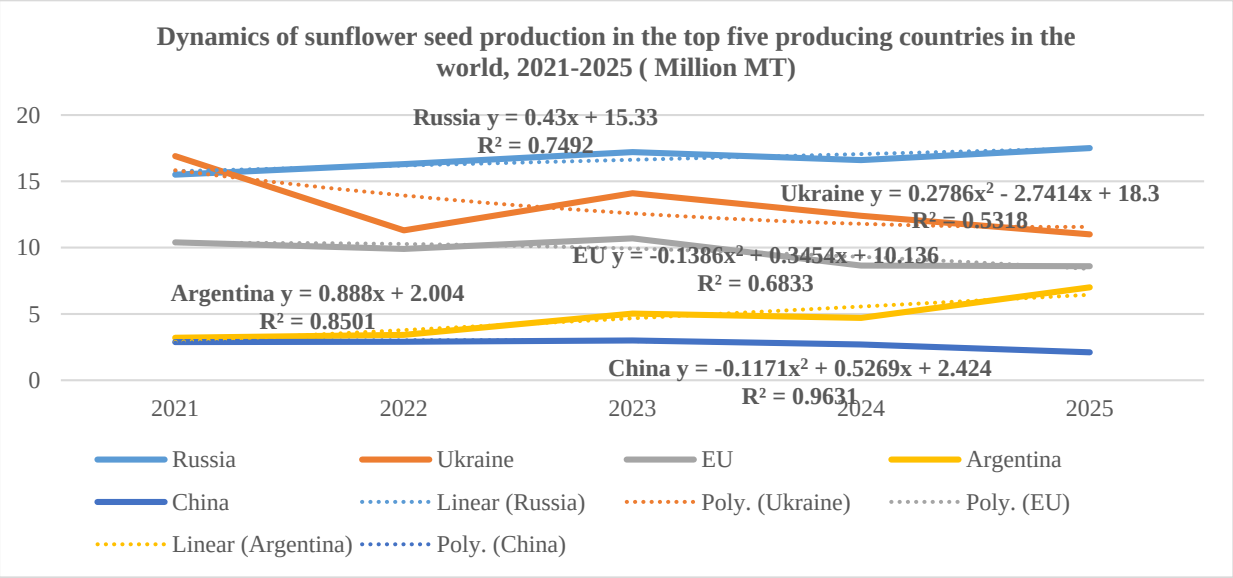

Fig. 5. Dynamics of seed production in the major five counties growing sunflower in the world (Million MT)
Source: Own design based on the data from [20].

The share of each country in the global sunflower production is described in Table 3.

In the decreasing order, it is obviously that Russia is ranked first, followed by Ukraine, EU, Argentina and China. The highest share was registered by Russia in the year 2023, by Ukraine in 2021, by EU in 2023, by Argentina in 2023 and by China also in 2023.

All these five countries together had the highest weight, accounting for 96.1% in the global sunflower seed production in the year 2023. In 2025, they summed only 78%.

Table 3. The weight of the seed sunflower production in Russia, Ukraine, EU, Argentina and China in the global output (2021-2025) (%)

	2021	**2022**	**2023**	**2024**	**2025**
Russia	26.6	30.0	33.1	29.6	29.6
Ukraine	29.0	20.8	27.1	22.1	18.6
EU	17.8	18.2	20.6	15.4	14.5
Argentina	5.5	6.3	9.6	8.4	11.8
China	4.9	5.3	5.7	4.8	3.5
Total 5 countries	**83.8**	**80.6**	**96.1**	**80.3**	**78.0**

Source: Own calculations based on the data from [20].

Descriptive statistics for sunflower seed production at the global level and in the top 5 countries growing this plant is presented in Table 4.

The coefficients of variations regarding seed production have small values below 10% in case of global situation, Russia and EU, showing that the mean is representative.

The highest variation was found in Argentina, CV% = 32.61% reflecting that standard deviation is about 33 % of the mean. This figure suggests a moderate to high variability of seed production in this country.

Also, in Urkaine was found a CV= 18.41%, meaning a moderate variability.

In the analyzed period, CAGR accounted for 0.27% at the global level, small and positive 2.46% for Russia, high and positive 16.95% for Argentina, and negative in case of EU -3.73%, Ukraine -8.23 and China -6.12 (Table 4).

Table 4. Descriptive statistics for sunflower seed production at the global level and in the top 5 countries growing this plant (2021-2025)

	Global	**Russia**	**Ukraine**	**EU**	**Argentina**	**China**
Mean	55.8	16.62	13.14	9.64	4.66	2.71
St. Dev.	2.89	0.78	2.42	0.98	1.52	0.36
R square	0.91	0.74	0.53	0.68	0.85	0.96
Kurtosis	-1.19	-0.45	0.40	-2.89	0.52	3.22
Skewness	-0.41	-0.48	1.09	-0.25	0.89	-1.77
Min	51.9	15.5	11.0	8.6	3.2	2.1
Max	59	17.5	16.9	10.7	7.0	3.0
CV%	5.17	4.69	18.41	10.16	32.61	13.28
CAGR %	0.27	2.46	-8.23	-3.73	16.95	-6.12

Source: Own calculations.

Sunflower seed yield at the global level

The amount of seeds obtained per surface unit decreased at the global level from 1.98 MT/ha in 2021 to 1.78 MT/ha in 2025, reflecting a reduction by 10.2%. This is the result of the climate impact change in the main producing countries, on one side, and of the conflictual situation in Ukraine, on the other side. However, the year 2024 was favorable for this crop, as average yield registered the top performance of 2.15 MT/ha (Fig. 6).

Yield varied from a country to another depending on the favorable or unfavorable soil fertility, temperature and rainfall levels.

In Russia, in 2025, it was obtained 1.66 MT/ha, but smaller than in the year 2022. In 2024, yield declined to 1.48 MT/ha, the lowest level in the analyzed interval. However, comparing the figures, it was noticed a slight growth by 2.4% in the whole period (Fig. 7).

In Ukraine, seed yield decreased by 23.2% from 2.6 MT/ha in 2021 to 2 MT/ha in 2025, the loss of 0.6 MT being determined by the hostilities in the region and also climate changes (Fig. 7).

In the EU, yield registered a downward trend from 2.36 MT/ha in 2021 to 1.79 MT/ha in 2025, which means a loss by 24.2% (Fig. 7). In this case, the cause was represented by the extreme meteorological phenomena like heat waves, droughts, low rainfalls in the

vegetation period in the Eastern and Southern part of Europe in Romania and Bulgaria which are the main producers, followed by Hungary and also in the Southern part of Europe in France and Spain.

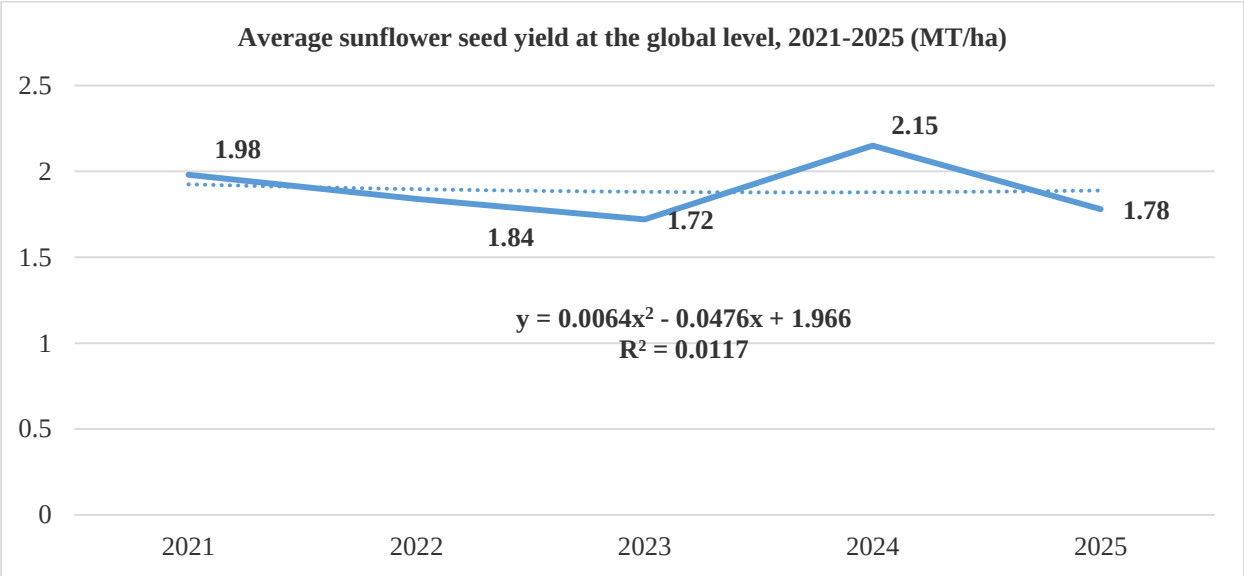

Fig. 6. Dynamic of sunflower seed yield at the global level in the period 2021-2025 (MT/ha)
Source: Own design based on the data from [20].

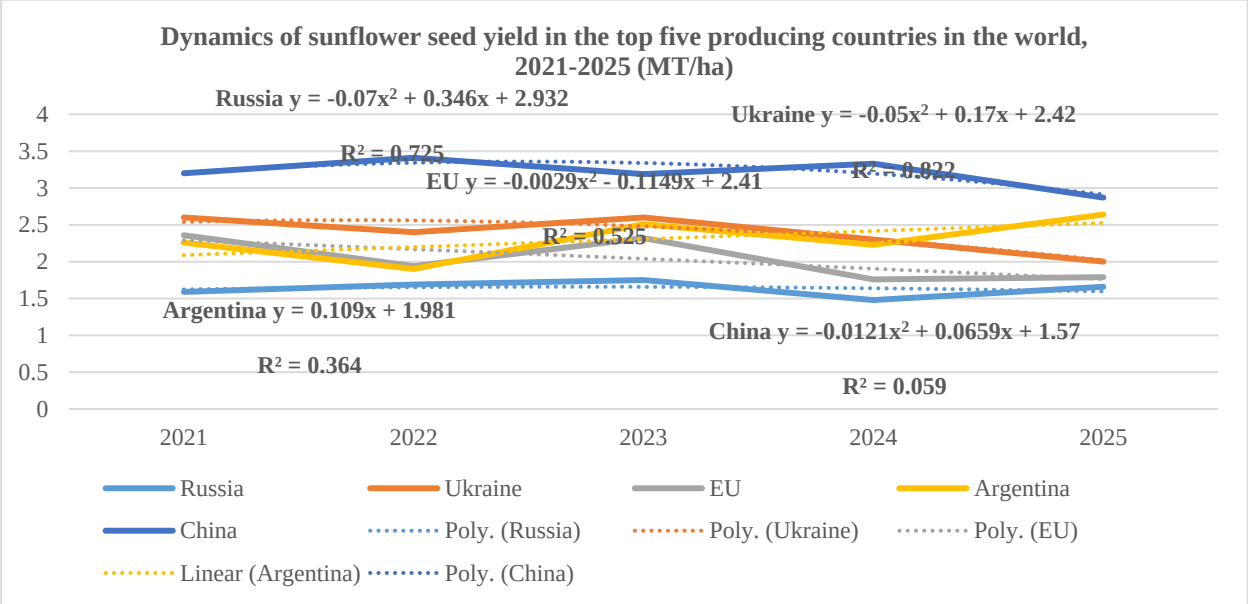

Fig. 7. Dynamics of sunflower seed yield in the top five producing countries at the global level, 2021-2025 (MT/ha)
Source: Own design based on the data from [20].

Argentina had a raising trend in the seed yield up to 2.87 MT/ha in 2025, the top level in the analyzed interval. Compared to 2.26 MT/ha in 2021, this means a surplus by 16.81% (Fig. 7).

China ended the year 2025 with 2.87 MT seeds per ha in average, meaning by 10.32% less than in 2021 (Fig. 7).

Descriptive statistics for sunflower seed yield the global level and in the top 5 countries growing this crop is displayed in Table 5.

The coefficients of variations regarding seed yield have small values below 10% reflecting good representation of the mean at the global level, in Russia, Ukraine and China. Also, in the EU and Argentina, the variability was low to moderate exceeding a little 10%, which

means a good distribution of the values around the mean.

Taking into account the trends at the global level and in each country, CAGR had a negative percentage for the world seed yield (-2.11%) and also in Ukraine (-5.11%), EU (-5.38%) and China (-2.15%). The only positive CAGR was found in Russia (0.87%) (Table 5).

Table 5. Descriptive statistics for sunflower seed yield at the global level and in the top 5 countries growing this plant, 2021-2025

	Global	Russia	Ukraine	EU	Argentina	China
Mean	1.89	1.63	2.38	2.03	2.30	3.20
St. Dev.	0.17	0.10	0.24	0.28	0.28	0.20
R square	0.01	0.72	0.82	0.52	0.36	0.05
Kurtosis	-0.32	0.22	0.31	-3.04	-0.17	1.75
Skewness	0.85	-0.74	-0.91	0.38	-0.42	-1.16
Min	1.72	1.48	2	1.76	1.9	2.87
Max	2.15	1.75	2.26	2.36	2.64	3.41
CV%	8.99	6.13	10.08	13.79	12.17	6.25
CAGR %	-2.11	0.87	-5.11	-5.38	3.16	-2.15

Source: Own calculations.

Sunflower in the European Union

Sunflower cultivated area

As it was mentioned before, the EU is a key player in the world in sunflower growing and production. In 2025, it cultivated 4.8 Million ha with this crop, a larger surface by 9.1% versus 4.4 Million ha in 2021. This is a consequence of its policy to produce more seeds for supporting the growth of energy from renewable resources. And sunflower is a plant which is called to help the EU to attain its goal of Green EU [45, 55, 59].

The main countries cultivating sunflower on the largest surfaces are Romania, Bulgaria, France, Hungary and Spain, which all together in the year 2025 kept 4.23 Million ha representing 88.15% of the EU area sown with this plant. Versus the cultivated area in 2021, that is 3.93 Million ha, this means an increase by 7.6%.

In 2025, the distribution of the cultivated area with sunflower among the top five producers in the E-27 was: 26.4% Romania, 20.4% Bulgaria, 14.7% Hungary, 14.2% France and 13.7% Spain.

The evolution of the cultivated area with sunflower in these countries is presented in Table 6.

Table 6. Sunflower cultivated area in the EU and in the top five growing countries in the period 2021-2025 (Million ha)

	2021	2022	2023	2024	2025	2025/2021 %
EU-27	4.4	5.1	4.6	4.9	4.8	109.1
Romania	1.11	1.2	1.07	1.55	1.27	108.1
Bulgaria	0.83	0.98	0.90	0.92	0.98	118.0
France	0.68	0.80	0.82	0.68	0.68	100.0
Spain	0.66	0.75	0.66	0.76	0.66	100.0
Hungary	0.65	0.70	0.67	0.69	0.71	109.2

Source: Own calculations based on [19].

Figure 8 present the evolution of the cultivated areas in these EU top five countries producing sunflower.

Romania has good agro-climatic conditions for growing sunflower, a reason why farmers love this crop very much and allocate a large surface for its cultivation, which totalize 1.2 Million ha, making Romania one of the major producers and suppliers of seeds in the EU [42, 43, 44].

The plant is cultivated mainly in the Southern-Eastern and East Romania, and especially in South Moldova plain and in Dobrogea region, including the counties: Constanta, Braila, Tulcea and Galati, and also in the Western plains in Timis, Arad and Bihor counties.

Sunflower needs fertile soils like chernozem and high summer heat to rich a good production of seeds. Special requirements such as: high genetic potential of the hybrids, climate resistant varieties and hybrids [40, 41], water reserve into the soil and a proper temperature suitable for sowing, a good plant density, sufficient rains during the vegetation period, agricultural works made at the proper time etc. are factors which could result into a good production of seeds in the flower head and also per surface unit.

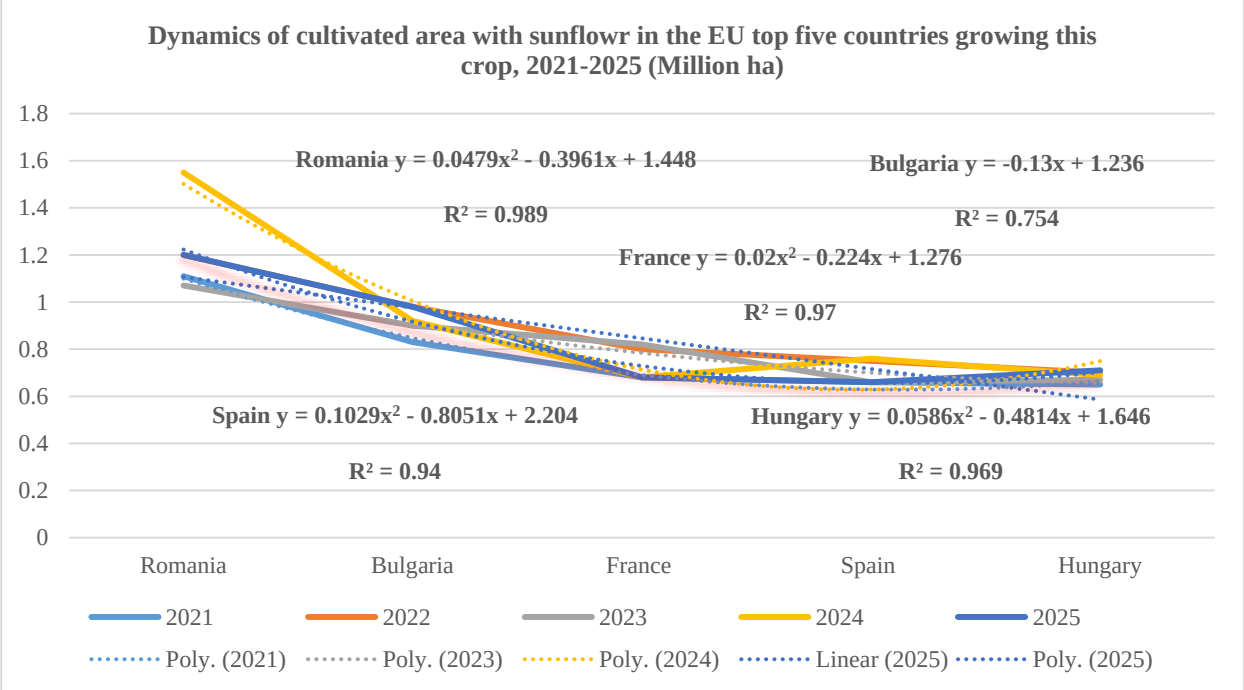

Fig. 8. Dynamics of sunflower cultivated area in the EU top five countries dealing with this crop, 2021-2025 (Million ha)
Source: Own design based on [19].

Also, crop rotation and fertilization with phospohorus and nitrogen are very important. Not to forget plant protection especially against the parasitic weeds *Orobanche Cumana*. To assure crop management, new high-tech crop systems like Clearfield, together with AI –precision agriculture, IoT and robotics are applied by the largest commercial farms [16].

The change in climate conditions during the last decade in Romania, in the regions where sunflower is cultivated, determined producers to adapt the old technologies to the new conditions. For example, the sowing date was established earlier in March instead of April so that, when the plant is growing, the heat waves of June not to affect its development [34, 35, 36, 46, 47, 60].

The frequent drought, the higher and higher diesel price for machinery, soil degradation in certain areas and the EU pressure for environment protection have determined a part of the farmers owning large farms to adopt conservative agricultural system (No till, Min till, Strip-till). But this system has a small share among the agricultural practices and covers only about 10% of arable land regarding all the crops. This practice also involves to assure soil cover (residues, mulches and cover crops) and different alternatives of crop rotation to assure weed, pest and disease management. In case of sunflower, No-till, Strip-till and cover cropping are adopted by the producers with large farms in the Dobrogea region and South East of Romania. Crop rotation sunflower with winter wheat and maize is an efficient solution against weeds and for improving organic matter in the soil [52].

Romania has the largest area cultivated with sunflower in the EU, accounting for 1.2 Million ha in 2025, meaning an expand by 8.1% versus 2021 (Fig. 8). In the regions with good soil climate conditions, farmers are

tempted to increase the cultivated area as long as the crop is a high profitable one.

Bulgaria is also another important grower of sunflower in the EU, both for seeds and biomass for oil, and it is a key exporter of seeds in the world [28].

After the country access into the EU, Bulgaria benefited of competitive advantages to continue developing sunflower industry [24].

Bulgaria has suitable agro-climatic condition to grow sunflower, similar to Romania and Serbia. The plant is cultivated in the North, on the fertile continental plains and also in the South of Bulgaria in the Upper Thracian Plain.

However, Bulgaria, like its neighbour countries, was facing during the last decade with terrible changes in the climate conditions like high temperatures, heat waves, long and severe droughts, lack of or low precipitations which affected yields [22].

The use of drought resistant hybrids, shifting to conservative farming technologies (zero tillage and minimum tillage), the use of Clearfied Plus technology to fight against parasitic weeds, using cover crops are solutions which have started to be largely applied.

Also, compensation financial aids offered by the EU and Government were helpful for the farmers facing with losses due to climate negative impact.

In Bulgaria, the cultivated area with sunflower increased by 18% in the analyzed period from 0.83 Million ha in 2021 to 0.98 Million ha in 2025 (Fig. 8).

In France, the largest surfaces cultivated with sunflower are situated in the South-West and Central part of the country. About 66% of the area with sunflower belongs to two regions: Nouvelle-Aquitaine and Occitanie, where cereals and protein crops like soybean are also grown.

The Provence region tries to contribute to the growth of the cultivated area. In the central France and the Loire Valley, where temperatures are high, farmers prefer to cultivate sunflower early and middle- early hybrids.

The cultivated area with sunflower in France is 453,000 ha, of which two-thirds are in the two South West regions mentioned above. About 30,000 farmers cultivate sunflower [4].

A special accent is put on the breeding programmes which produce high drought resistant and also resistant to mildew, verticillium and sclerotinia varieties and hybrids, high oleic varieties, dual-tolerance hibrids (Clearfield, Clearfield Plus, Express SX etc).

The new technologies like precision seeding, robotic cultivation, weeding and disease management, crop rotation, bio-solutions against abiotic stress and climate impact, specialized headers for harvesting to avoid seed losses are preferred by most of farmers [13].

Sunflower is also cultivated in organic farming in the same two important regions of the South and West France. Taking into account the soil and climate conditions, the technology applied is based on crop rotation, delayed sowing (often later than in conventional system), mechanical weed control, pest and disease management, no synthetic fertilizers and pesticides. Organic cultivation is permanently optimized to resist to climate factors [10, 29].

In the analyzed period, 2021- 2025, the cultivated area in France remained relatively stable at 0.68 Million ha (Fig. 8). Larger areas like 0.80 and 0.82 Million ha were sown in the years 2022 and 2023.

Spain is another important sunflower producer in the UE and in the world, the cultivated area being around 700,000 ha annually. High oleic and linoleic varieties are successfully used to produce sunflower oil, which is the main product for which this crop is cultivated in this country. Castilla y Leon, Andalusia and Castilla - La Mancha are the main regions where this crop is grown [54, 6].

Spain is facing with the competition of cheap seeds coming from import, high drought risk and the parasitic weed *Orobanche Cumana*.

For this reason, technologies have shifted to the use of early sowing varieties and genetic resilient varieties to pest and disease varieties (broomrape and mildew).

In the study period, the cultivated area with sunflower remained relatively constant to 0.66 Million ha in the analysed period (Fig.8). The

largest surfaces of 0.75 and 0.76 Million ha were sown in 2022, and, respectively in 2024.

In **Hungary,** sunflower is favoured by rich soils in the plains and alluvial basins existing in the East and Central parts of the country. The largest surfaces with this crop are in Great, Northern and Southern plains.

Hungarian farmers prefer to grow oilseeds and confectionary varieties. Annually, about 700,000 ha are cultivated with sunflower.

The most utilized technologies in sunflower cultivation are: precision agriculture, innovative tolerant to herbicide technologies, and loss free headers like machinery for harvesting. Also, modern weed control technologies (Clearfield, Express) are largely common among farmers [7, 57].

In the studied period, 2021-2025, the cultivated area increased by 9.2% from 0.65 Million ha in 2021 to 0.71 Million ha in 2025 (Fig. 8).

Descriptive statistics for sunflower cultivated area at the EU-27 and in the top 5 member states growing this plant is presented in Table 7.

Table 7. Descriptive statistics for sunflower cultivated area in the EU and top 5 member states growing this plant (2021-2025)

	EU-27	Romania	Bulgaria	France	Hungary	Spain
Mean	4.76	1.22	0.92	0.73	0.68	0.69
St. Dev.	0.27	0.18	0.06	0.07	0.02	0.05
R square	0.12	0.98	0.75	0.97	0.96	0.94
Kurtosis	-0.68	3.35	-0.31	-3.07	-0.94	-3.21
Skewness	-0.18	1.74	-0.67	0.65	-0.60	0.62
Min	4.4	1.07	0.83	0.68	0.65	0.66
Max	5.1	1.55	0.98	0.82	0.71	0.76
CV%	5.6	14.75	6.52	9.58	2.91	7.24
CAGR %	1.76	1.57	3.38	0.0	1.78	0.0

Source: Own calculations.

The coefficients of variations regarding cultivated areas have small values below 10% both at the EU level and in Bulgaria, France, Hungary and Spain.

In Romania, the CV% = 14.75% reflected a slight moderate variation.

CAGR was very small both at the EU level and in Romania, Bulgaria and Hungary.

In case of France and Spain, where the cultivated area was the same in 2025 with the one in 2021, CAGR was equal to zero (Table 7).

Sunflower seed production

In the EU, despite of the enlarged cultivated area, seed production decreased to 8.6 Million MT in the year 2025 versus 10.40 Million MT in 2021 (-11.31%) as a reflection of the impact of climate change in South East and South West of Europe, where the main producing member states are located (Fig. 9).

The evolution of the major EU producing member states is shown in Fig. 9.

In Romania, production registered a decline since 2021 when it was registered the peak of the interval accounting for 2.81 Million MT. The minimum level of 0.99 Million MT was achieved in the year 2024.

In 2025, production grew, but up to 2.06 Million MT, being by 26.7% smaller than in 2021 (Fig. 10).

The negative impact of the hot waves, high temperature and low rainfalls affected production in many farms. Even though, this performance situated Romania on the top position in the EU.

In Bulgaria, which was also disturbed by the impact of climate change, seed production was 1.98 Million MT in 2021, then raised a little to 2.12 Million MT in 2022, and in the next period it declined year by year, so that in 2025, the country harvested only 1.66 Million MT, by 16.2% less than in 2021 (Fig. 10).

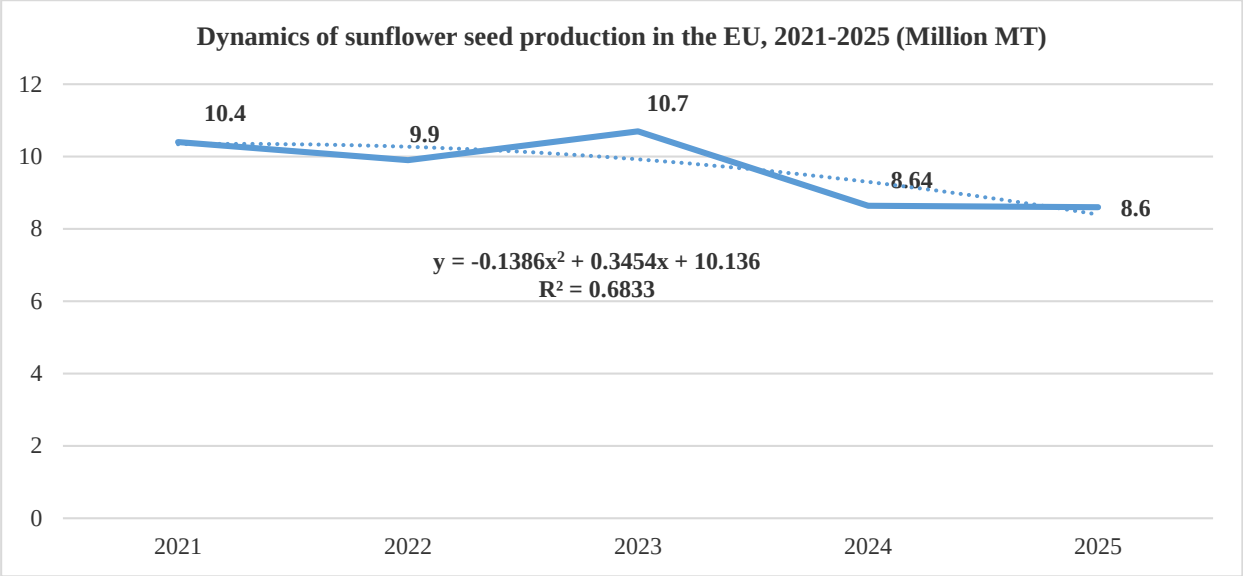

Fig. 9. Evolution of sunflower seed production in the EU, 2021-2025 (Million MT)
Source: Own design based on the data from [19].

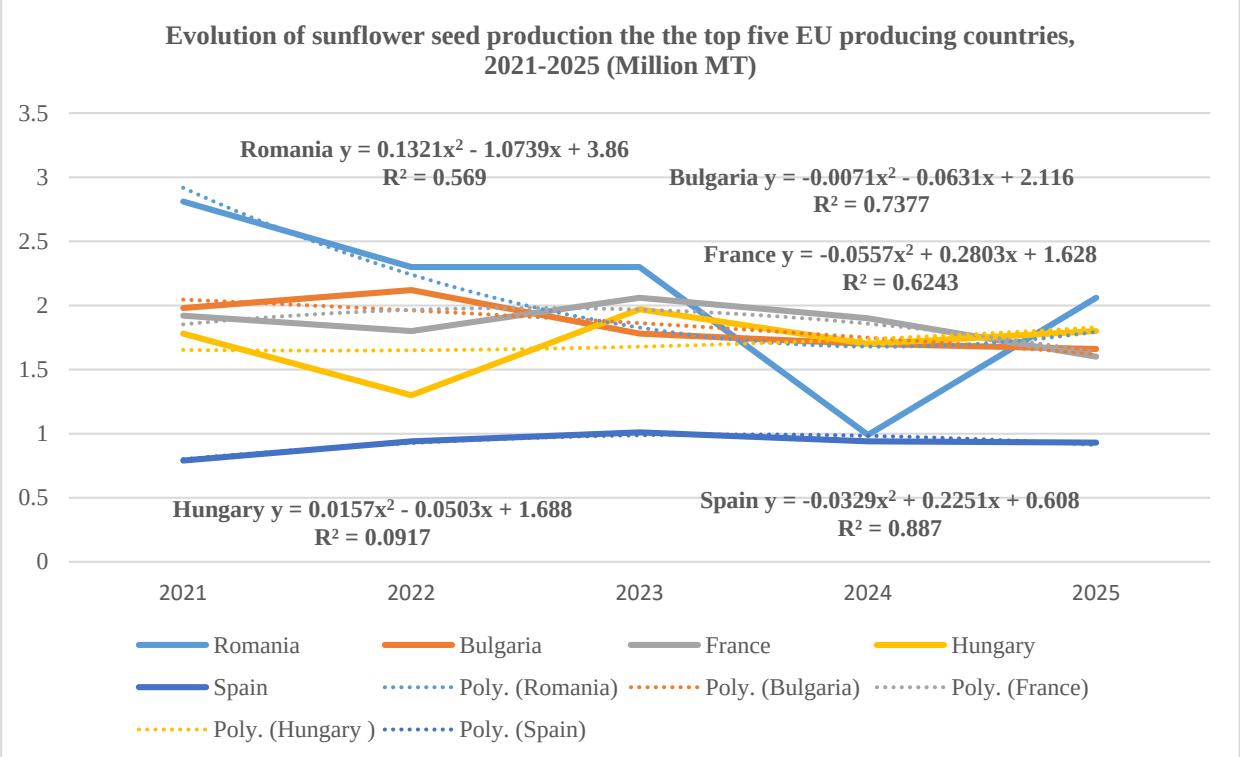

Fig. 10. Evolution of sunflower seed production in the top five EU producing countries, 2021-2025 (Million MT)
Source: Own design based on the data from [19].

France produced 1.92 Million MT seeds in 2021, the production decreased to 1.80 Million MT, and in 2023, it registered the top performance, 2.06 Million MT. Since this year, production continued to decrease up to 1.6 Million MT, meaning that in the year 2025, it was by 16.7% smaller than in 2021 (Fig. 10).

Hungary also recorded an up and down variation of seed production. After 1.87 Million MT in 2021, it registered a down ward to 1.30 Million MT, followed by the top performance of 1.97 Million MT in 2023. In 2025, Hungary produced 1.8 Million MT seeds, by 1.1% more than in 2021, buy by 8.7% less than the peak achieved in 2023 (Fig. 10).

Spain succeeded an upward trend between 0.79 Million MT in 2021 to 1.01 Million MT in 2023. But then, production declined up to 0.93 Million MT in 2025. However, the level recorded in 22025 was by 17.2% higher than in 2021 (Fig. 10).

Eastern Europe is the major source of sunflower seeds and oil for the EU and not only. Sunflower has perspectives to remain an important crop grace its important in food security, animal feeding, energy resource, biodiversity and environment protection [27].

The contribution of each top producing country to the EU seed production changed in the analyzed interval and the differences and shown in Table 8.

Table 8. Share of sunflower seed production in each top five producing countries into the EU seed output in 2025 versus 2021 (%)

	2021	2025	2025-2021 % points
Romania	27.01	23.95	-3.15
Bulgaria	19.03	19.30	+0.27
France	18.46	18.60	+0.14
Hungary	17.10	20.93	+3.83
Spain	7.59	10.81	+3.22

Source: Own calculations.

Descriptive statistics for sunflower seed production at the EU-27 level and in the top 5 member states growing this plant is presented in Table 9.

The coefficients of variations regarding seed production have small values below 10% only in France and Spain.

At the EU-27 level, in Bulgaria and Hungary, CV% ranged between 10% and 15%, meaning just a little change around the mean, which could be considered representative. In Romania, CV= 32.05 % reflects a high variations and that the mean is not representative.

Seed production registered a negative CAGR at the EU level, and also in Romania, Bulgaria, France, where output level was smaller in 2025 versus 2021. In Hungary and Spain, where production was higher in 2025 versus 2021, CAGR had positive values (Table 9).

Table 9. Descriptive statistics for sunflower production in the EU and top 5 member states growing this plant (2021-2025)

	EU-27	Romania	Bulgaria	France	Hungary	Spain
Mean	9.64	2.09	1.84	1.85	1.71	0.92
St. Dev.	0.98	0.67	0.19	0.17	0.24	0.08
R square	0.68	0.56	0.73	0.62	0.09	0.88
Kurtosis	-2.89	2.56	-1.59	0.95	2.63	2.86
Skewness	-0.25	-1.29	0.67	-0.68	-1.35	-1.28
Min	8.6	0.99	1.66	1.60	1.30	0.79
Max	10.7	2.81	2.12	2.06	1.97	1.01
CV%	10.16	32.05	10.32	9.18	14.03	8.69
CAGR %	-3.73	-6.02	-3.46	-3.68	0.22	3.32

Source: Own calculations.

Sunflower seed yield

At the EU level, average production per surface unit registered a decline from 2.36 MT/ha in 2021 to 1.79 MT/ha in 2025, meaning -24.2% (Fig. 11).

Romania carried out a large variation of seed yield from year to another caused by the changeable climate.

The year 2021 was the best for sunflower, average yield accounting for 2.53 MT/ha. The minimum level was 0.63 MT/ha, registered in 2024. However, in 2025, it was noticed a recovery, the average yield being 1.72 MT/ha, but by 32.02% smaller than in 2021 (Fig. 12).

Bulgaria registered a similar descending trend from 2.38 MT/ha in 2021 to 1.80 MT/ha in 2025, meaning a loss of 24.4% (Fig. 12).

France carried out a large variation also as a climate effect, from 2.82 MT/ha in 2021 to 2.35 MT/ha in 2025, which means a reduction by 16.67% (Fig. 12).

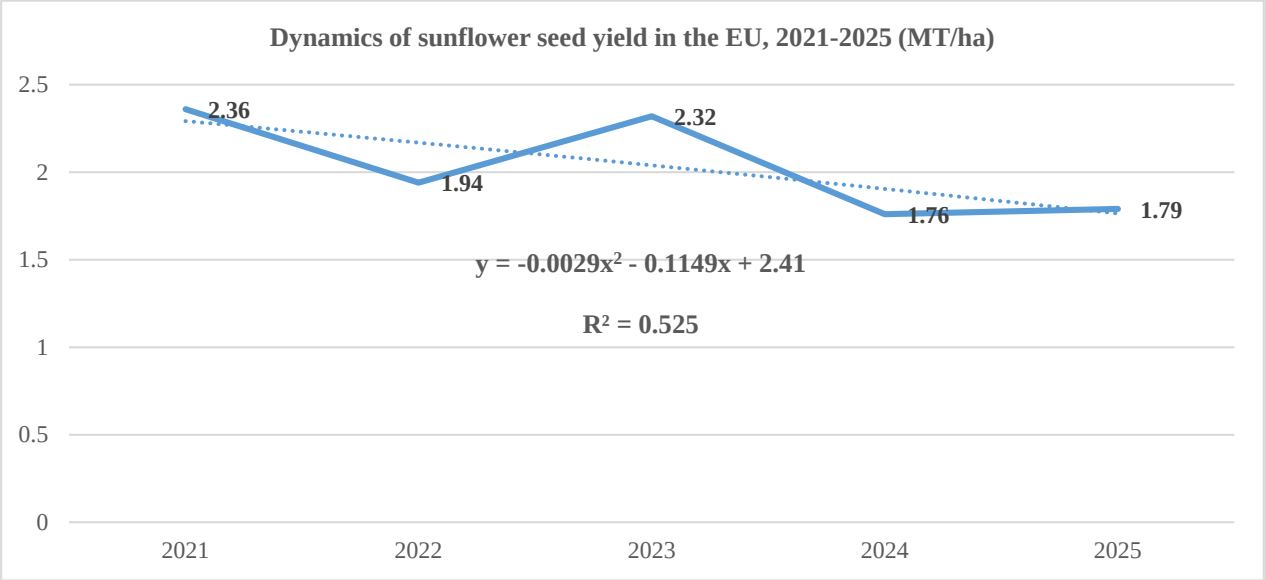

Fig. 11. Evolution of sunflower seed yield in the EU, 2021-2025 (MT/ha)
Source: Own design based on the data from [19].

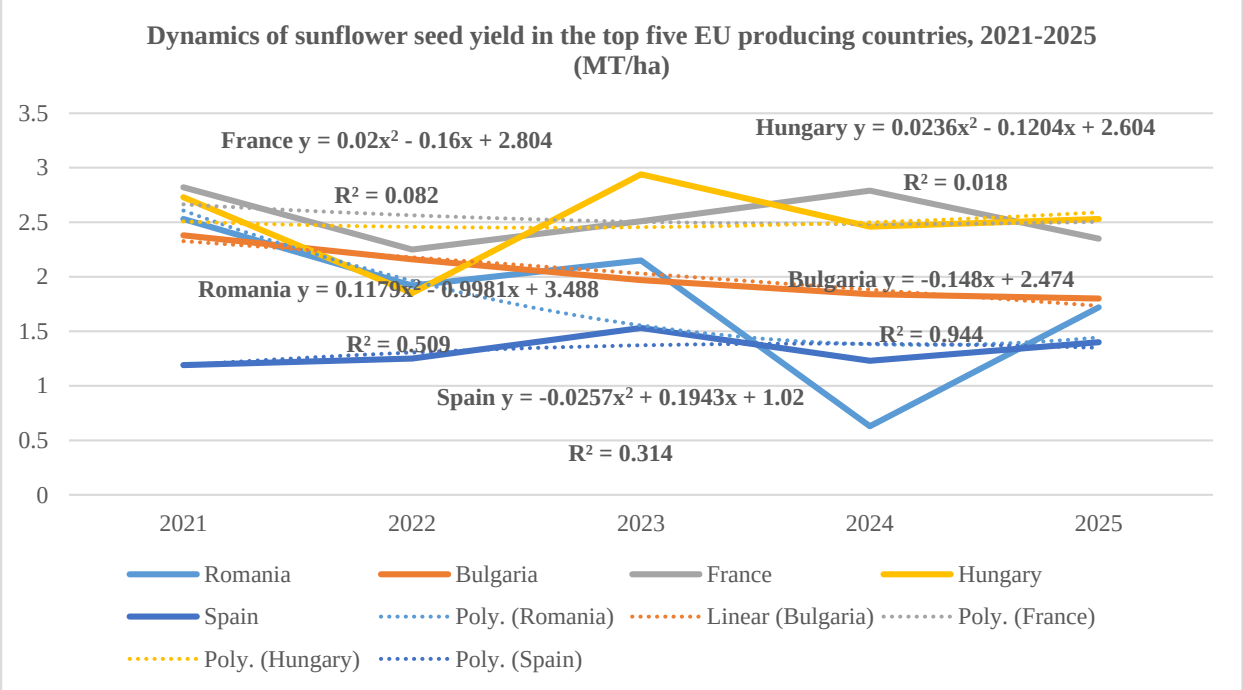

Fig. 12. Evolution of sunflower seed yield in the top five EU producing member states, 2021-2025 (MT/ha)
Source: Own design based on the data from [19].

Hungary reached 2.53 MT/ha in the year 2025, by 7.33% less than in 2021, but, in 2023, it performed a record of 2.94 MT/ha, the top yield level compared to all the other four EU competitors (Fig. 12).

Spain performed the smallest yields among these five top producing countries, but with a slight positive ascending tendency from 1.19 MT/ha in 2021 to 1.40 MT/ha in 2025, reflecting a surplus by 17.64% (Fig. 12).

Looking at Figure 12, we may notice that France and Hungary achieved higher yields than Romania and Bulgaria, while Spain comes the last.

Descriptive statistics for sunflower seed yield at the EU-27 level and in the top 5 member

states growing this crop is presented in Table 10.

The mean level points out the hierarchy of the top five countries producing sunflower seeds in the EU in the interval as follows: France, Hungary, Bulgaria, Romania and Spain. Only the last three countries exceeded the EU-27 mean of 2.03.

Table 10. Descriptive statistics for sunflower yield in the EU and top 5 member states growing this plant (2021-2025)

	EU-27	Romania	Bulgaria	France	Hungary	Spain
Mean	2.03	1.79	2.03	2.54	2.52	1.32
St. Dev.	0.28	0.71	0.24	0.25	0.41	0.14
R square	0.52	0.50	0.94	0.08	0.01	0.31
Kurtosis	-3.04	2.17	-0.78	-2.64	2.07	-0.69
Skewness	0.38	-1.26	0.77	0.07	-1.29	0.95
Min	1.76	0.63	1.8	2.25	1.85	1.19
Max	2.36	2.53	2.38	2.82	2.94	1.53
CV%	13.79	39.66	11.82	9.8	16.26	10.60
CAGR %	-5.38	-7.43	-5.43	-3.58	-1.51	3.3

Source: Own calculations.

The coefficient of variation regarding seed yield was below 10% only in France. At the EU level, in Spain and Bulgaria, the variation coefficient was a little higher than 10%, but also reflecting a representative mean. In Hungary, CV=16.26% shows a small to moderate variability.

In Romania, the CV= 39.66% is very high, reflecting that the standard deviation accounts for 39.66% of the mean. It is a matter of high relative variability and dispersion of the data around the average.

Like seed production, seed yield registered a negative CAGR at the EU level and also in Romania, Bulgaria, France, Hungary where the average production was smaller in 2025 compared to it level in 2021. The only country with a positive CAGR is Spain (Table 10).

CONCLUSIONS

This study has continued the research works started a few years ago on oil crops, this time emphasizing the present and future role of sunflower among the agricultural plants called to give their contribution to the sustainable economic, social and environment development at the global and EU level.

Three important economic indicators have been studied: cultivated area with sunflower, seed production and yield, at the global level and in the top five producing countries and also at the EU-27 level and in the top five member states growing this plant in the period 2021-2025.

The need for more food to nourish the global population, for more feed for nourishing animals, for resources producing renewable energy, for sustaining soil fertility, for reducing pollution, for mitigating the negative impact of climate change, for maintaining biodiversity and the beauty of the landscapes, for sustaining profitability in agriculture has lead to a more intense orientation to sunflower crop which is estimated to play a more important role in the world agriculture.

The analysis which covered only the last five years, 2021-2025, pointed out that in the year 2025, the cultivated area with sunflower reached 33 million ha in 2025, being by 1.46% higher than in 2021.

Five countries Russia, Ukraine, the EU-27, Argentina and China grow sunflower on 77.6% of the global acreage covered by this crop.

In 2025, these five countries together summed 24.18 Million ha, by 5.58% more than in 2021.

Sunflower seed global production attained 59 Million MT in 2025, of which 78% was carried out in the five countries mentioned above. The highest production increase was achieved in Argentina (+118.7%) and in Russia (+12.9%), but in the other three countries, production decreased. In Ukraine, production was affected by the war, while in the EU by the negative impact of climate

change in the top producing countries and in China as well.

The most favourable year for sunflower growing was 2024, when yield attained a peak of 2.15 MT/ha at the world level.

In the EU-27, sunflower covers 4.9 Million ha, by + 9.1% more in 2025 versus 2021. Romania, Bulgaria, Hungary, France and Spain are the main producing countries of sunflower seeds.

In 2025, seed output was by 7.31% smaller accounting for 8.6 Million MT, due to the damages caused by the climate change in the Eastern and Southern part of Europe, mainly in Romania, Bulgaria and France, and in a smaller proportion in Spain and Hungary.

The EU-27 yield is 1.79 MT/ha, a little bit higher than the world average yield of 1.78.

The challenges that the cultivation of sunflower is facing are:

- *Climate change* is one of the restraining factors, despite that sunflower is a climate resilient crop. But, the higher and higher temperatures and prolonged droughts which affect the specific geographical zones where sunflower is cultivated will shift its growing to other suitable regions.

More than this, the heat waves could affect nectare amount and quality leading to yield losses.

The warmer weather increases the risk of expanding the parasitic weeds like broomrape (*Orobanche cumana*) and also the incidence of diseases mainly caused by Sclerotinia and Verticilium which will diminish seed yield and its quality.

More than this the attack of predators will be intensified.

Nowadays, more and more farmers are aware that technologies applied in sunflower cropping should be adapted to climate change to mitigate the negative effects.

-*Agronomical and ecological challenges* regarding soil degradation, vulnerable biodiversity will impose the implementation of an integrated agricultural system of this crop, where sunflower to be included in crop rotation and to benefit of an integrated weed and plant protection management. New early maturing, heat tolerant and also salt tolerant hybrids should be used on larger surfaces and even in the coastal zones.

Precision agriculture could offer an alternative for more and more farmers to keep under control sowing quality, plant density, weed, pest and disease management and to enhance yield and production.

New cropping systems like: low-input alternatives, organic farming, intercropping will contribute to soil protection and water use optimization.

The use of lower amounts of chemicals could assure the obtaining of sunflower healthier seeds and edible oil for consumers at the same time diminishing environment pollution.

-*Supply chain disruptions* caused by geopolitical conflicts like the one between Russia and Ukraine, which are the main producers of sunflower seed and oil. These will continue to interrupt trade transactions, to prolong the time and to change the transport routes between exporters and beneficiaries increasing the price volatility.

-*Sustaining farmers' agribusiness* by cultivating sunflower is another challenge. Despite that, sunflower is recognized as a crop with a high economic efficiency and profitability, assuring an important income for farmer and his family, this business is permanently under the pressure of market volatility.

The price variability for farm inputs, the changes in the supply chain, the actual fuel crisis could have an unforeseeable evolution which could increase the business risk.

- *Energy crisis* requests the use of more productive oil varieties, which will modify the the production structure among seeds, oil and cakes. In this respect, the right decisions could be taken to harmonize the ratio between the sunflower utilizations so that both producers and consumers to be satisfied.

-*Biodiversity and landscapes beauty preservation* should continue to be a part of the strategic development of sunflower cultivation.

As a decorative item, sunflower remains one of the plants which sustains the splendour of the fields and beautiful sceneries during its blooming and which supports life not only for

humans, but also for a large variety of pollinators and other wild species.
Ornamental varieties are also a part of the sunflower offer for enchanting our eyes in nice floral arrangements.

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INTERNATIONAL TRENDS IN WHEAT MAJOR GROWING AREAS, PRODUCTION, YIELDS, CONSUMPTION, EXPORT AND IMPORT - A STATISTICAL APPROACH

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Abstract

The paper aimed to examine wheat acreage, production, consumption, trade flows and price in the world and the EU in the period 2020-2025, exploring the trends and challenges in the context of climate changes and disruptions in the food chains caused by geopolitics and policies which determine changes in the hierarchy of the main "players" in the wheat market. The data from USDA, FAOSTAT and Eurostat have been processed using trend line analysis, regression equations, R square, structural indices, comparison method, graphical illustrations. The results showed a decline by 1.4% in cultivated area which reached 215 million ha in 2025. India, Russia, China, EU and USA keep 53.4 % of the world cultivated area. Of the 24 million ha covered with wheat in the EU, 60.4% are in France, Germany, Poland, Romania and Spain. Wheat production increased by 8% from 781 Million MT in 2022 to 834.84 expected in 2026. The main producers are China, India, Russia, USA, Australia, France and Canada. Compared to the production peak of 136.1 million MT in the EU in 2025, in 2026 it is expected a decline by 5.8%. France, Germany, Romania and Poland together contribute by 81.1% to the EU output. Keeping pace with the global population growth, consumption reached 819.93 Million MT in 2026, by 4% more than in 2022. China, India, EU, Russian Federation and USA absorb 441 Million MT, meaning 53.8% of the total consumption. Germany, France, Spain and Poland are the top consumers in the EU. Wheat export increased to 214.1 Million MT, the suppliers being mainly Russia, EU, Canada, Australia and USA, while the imports reached 207.5 Million MT, the key beneficiaries being Indonesia, Egypt, Algeria, Bangladesh, Philippines, Vietnam, Nigeria and EU summing 75%. Wheat price is at a low level, varying between USD 250-280/MT, due to the conflict in Ukraine started in 2022. In 2025, the EU exported 26.25Million tons, by 33.3% less than in 2020, while the imported amounts reached 10.10 Million tons, a double figure than in 2020. The export value attained Euro 2.68 Billion, reflecting a surplus of +127.1% versus 2020, while the import value had similar values. The main EU exporters are France, Romania, Germany, Poland and Lithuania and the major importers are Italy, Spain, Slovenia, Ireland and Greece. New changes are visible in wheat market caused by the extreme climate phenomena impacting yields, the high input costs mainly for fertilizers and fuel, the disruptions noticed in the major exporting regions mainly from the Black Sea, affecting supply chains and routes, trade flows and food security.

***Key words*:** wheat acreage, production, consumption, price, trade flows**,** globally, EU

INTRODUCTION

The population growth determines a higher and higher food demand**.** Wheat is a key component in the global food supply, being called to contribute to food security [27].
Wheat is the most used cereal, grace to its high nutritional and energetic value.
The nutritional value of 100 g whole wheat grain flour includes: 72 g carbohydrates (starch), 13.2 g protein, more than maize and rice, 10.7 dietary fiber, 2.5 g fat, 0.4 g sugar, B vitamins (B1, B3, B6, B9), minerals (phosphorus, magnesium, zinc, manganese, iron), water 13.1 g and 340 kcal energy [2].
Wheat is destined for human consumption in

various foods, as feed for animals, for processing industries (starch to produce bioethanol for renewable energy), cosmetics (hair and skin care products), pharmaceutics (pills, tablets) etc.

Utilizations depend on the wheat grain composition and protein level. Wheat flour resulting after milling the grains is used to make bread, which is prepared and consumed on a large scale all over the world, rolls, pasta, noodles, cookies, biscuits, pancakes, breakfast cereals, crackers, muffins, pies, pizza, pretzels, cakes and drinks (beer and vodka) [5, 38, 54].

Lower grade wheat and byproducts are used as feed in poultry and pig farming, and also in cattle diets.

The demand for wheat far exceeds the supply and that is why it is needed that more wheat grains to be produced and more intensively commercialized in the international market.

World wheat production is increasing and is concentrated in specific zones of the globe. After the production record of 792 Million MT wheat grains in 2024, it was expected a higher performance of about 800 Million MT in 2025 and in 2026 even more [11].

Wheat production depends on the cultivated area, a reason to expand the acreage in the limits imposed by arable land existing at the global level and also in each country cropping wheat. Therefore, this alternative could be applied in the countries where it is possible to increase the cultivated area [25].

The limited land use imposes to pay more attention to yields whose performance depend of the genetic production potential of the varieties and hybrids and also of their resistance to high temperature and droughts, and to the attack of pests and diseases.

It is estimated that without climate change, wheat yields would be by 10% higher [4].

In this context, global wheat cultivation is supposed to changes regarding its growing mapping moving it to the North in more suitable regions from a climate point of view [15].

Soil degradation determined by conventional technologies has imposed a new approach destined to find conservation agriculture solutions (no-tillage, low-tillage etc), which could contribute to the maintenance of soil fertility and wheat yields [12, 13, 14].

During the last decades, climate change produced more damages to farmers in terms of lower yields and productions, and impossibility to maintain incomes to cover production costs [18, 31, 34, 44].

Under this situation, farmers passed to the use of more drought resistant varieties and hybrids [22, 40].

More than this, farmers proceed to the adaptation of the growing technologies so that to mitigate the negative impact of climate change on yields [23].

To avoid weeding, pest attack and diseases, integrated weed management, combined with crop rotation, biological control, and targeted chemical applications are viable solutions [1, 20, 24].

The increase of farm input price (fertilizer, energy, fuel, seeds, machinery etc) produced the growth of the production costs, a diminished farmers' income and raised the risk in wheat agribusiness [16].

Also, price volatility could influence risk management decision making and oblige farmers to prospect realistic pricing targets to maintain their business [55].

Geopolitical risks and conflicts have a deep impact on wheat production and trade increasing the price for inputs, transportation costs and routes, bottlenecks in the traditional wheat supply chain, increased price volatility. For example the conflict in the Black Sea region which accounts for 30% of the global wheat exports has led to a high risk volatility, damaged infrastructure, changes in supply chains, higher inflation and price volatility, higher freight and insurance costs, disruptions in supplying the North Africa and the Middle East countries [26, 8].

Global wheat production and trade was studied by various researchers who presented the tendencies and main producing countries on a specific interval [19, 41, 42, 45, 61].

In this context, it is justified to analyze the actual situation on wheat acreage, production, yield, consumption, price, export and import at the global level and at the EU level in the

period 2020-2025 in order to highlight the new trends and changes for updating the image of wheat importance.

MATERIALS AND METHODS

To set up this paper, a large range of literature in the field was studied and many data were necessary to proceed to the statistical picture which characterizes wheat market in its complexity.
The panel of specific indicators included: harvested acreage, production, and yields which have been analyzed at the global and at the EU level, and in the most representative countries for wheat growing.
Then, wheat consumption in absolute figures and also per inhabitant was studied at the global level, as well as wheat price, as a key indicator reflecting the changes in the wheat international market caused by various factors. The analysis of wheat international trade included both quantitative aspects and value aspects regarding export and import, and also emphasizing the performance in the top exporting and importing countries in the world and also in the EU. To solve such a complex approach concerning wheat production and trade, it was needed to benefit of official empirical data from the well-known authorized data sources like: USDA Reports, FAOSTAT, Eurostat and European Commission Agridata for production and trade. The data have been organized and structured in connection with the purpose of this research and then they have been processed using the dynamics analysis based on trend line and regression equations, R square, illustrative graphics, descriptive analysis, fixed basis and structural indices, and comparison method. The results have been synthesized in tables and displayed in suggestive graphics, accompanied by comprehensive comments. The conclusions presented the main results in brief creating the global and EU image of wheat emphasizing its role in assuring food security.

RESULTS AND DISCUSSIONS

Wheat at the global level

Global wheat acreage

The population growth has increased demand and consumption justifying the expansion of the cultivated surface with wheat. In the studied period 2020-2024 the cultivated area with this crop increased by 1.46% from 219 Million at the beginning of the interval to 222.2 Million ha at the end (Fig. 1).

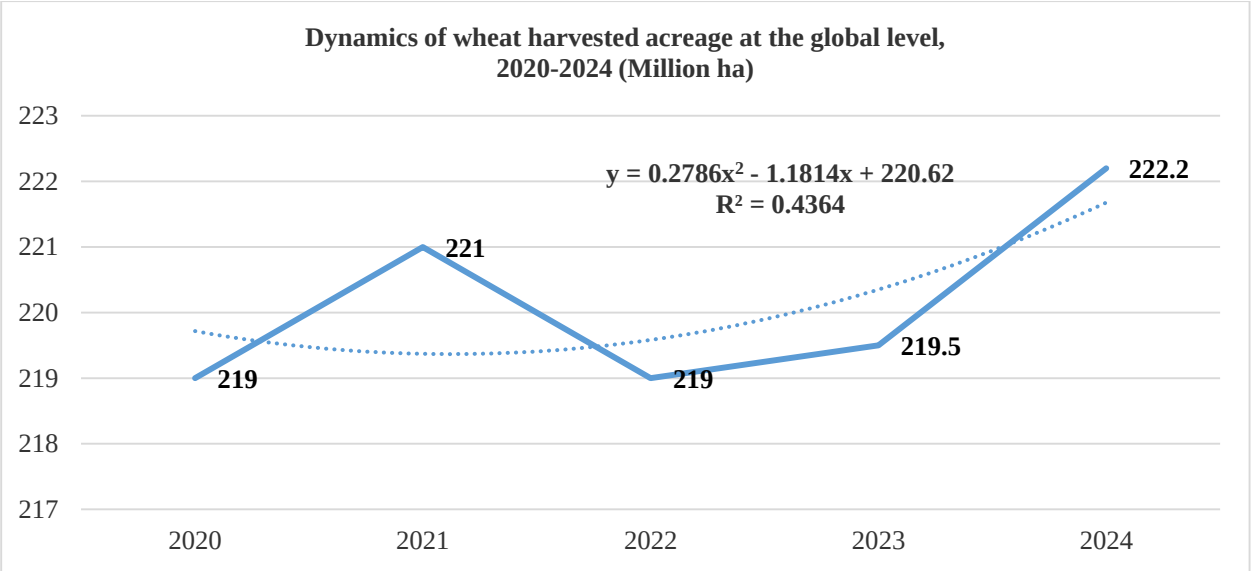

Fig.1. Dynamics of the cultivated area with wheat at the world level, 2020-2024 (Million ha)
Source: Own design based on the data [9].

In the decreasing order of the surface, the main countries cultivating wheat are: India, Russian Federation, China, EU-27 and USA, which together in 2024 harvested 120.53

Million ha, accounting for 54.24% of the world area covered by this crop.
In the analyzed interval, an increased area was noticed in India (+1.53%), USA (+4.5%), China (+0.8%), while in the EU-27 and Russian Federation the acreage declined by -1.1%, and, respectively -6.62%.
The evolution of the wheat harvested area in the major five global wheat producers is shown in Fig. 2.

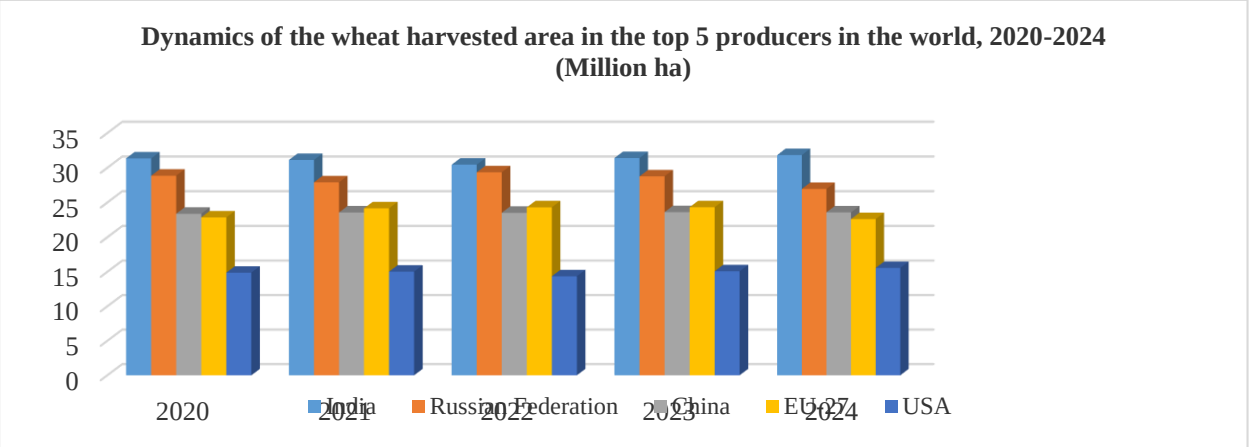

Fig. 2. Dynamics of the cultivated area with wheat in the top 5 producing countries at the world level, 2020-2024 (Million ha)
Source: Own design based on the data from [9].

Also, other 5 countries, following the ones mentioned above, in the descending order are: Australia, Kazakhstan, Canada, Pakistan and Turkiye.
In 2024, all these 10 states together summed 173.95 Million ha, representing 78.28% of the global wheat area, meaning a surplus of 1.27% versus 2020.
The share of these 10 countries in the global wheat area in 2024 is displayed in Fig. 3.

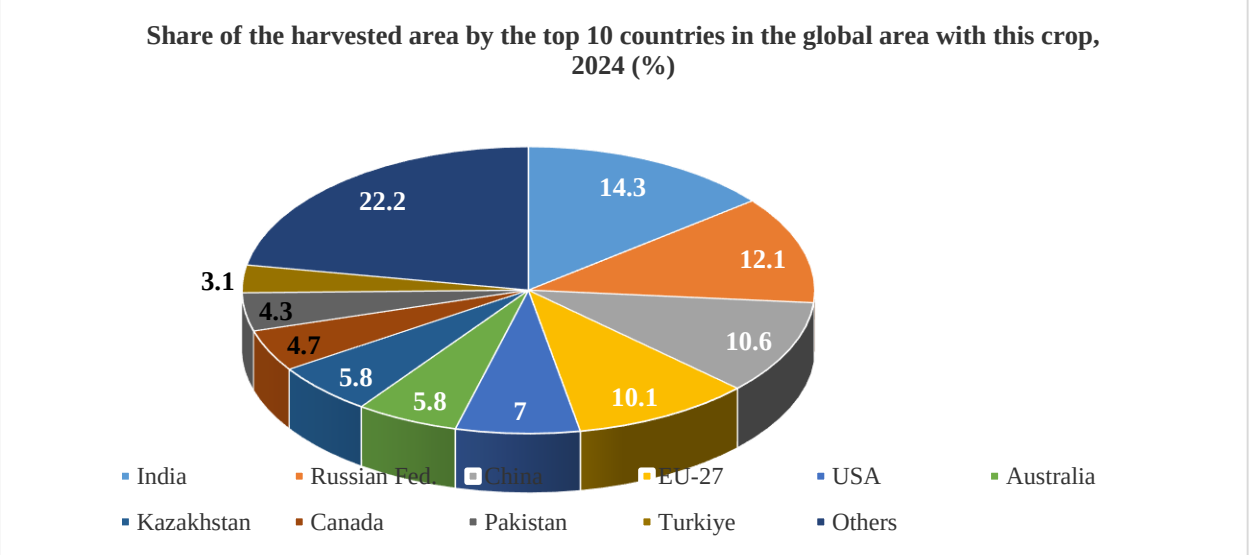

Fig. 3. The weight of the top 10 countries in the world for the wheat harvested area in the global acreage with this crop in 2024 (%)
Source: Own design and calculations based on the data from [9].

The descriptive statistics for wheat acreage in the top 5 countries, in the period 2020-2024 is synthetized in Table 1.
The cultivated area with wheat in the top global producers varied as follows in the analyzed interval: In India between the minimum 30.45 Million ha and the maximum 31.82 Million ha. In the Russian Federation, the acreage ranged between 26.95 Million ha and 29.35 Million ha. In China, the surface

was a little smaller fluctuating between 23.38 Million ha and 23.62 Million ha. In the EU, the minimum surface was 22.61 Million ha and the maximum 24.32 Million ha. In the USA, the variation ranged between 14.26 Million and 15.56 Million. Therefore, the variations were enough small in case of each country as proved by the variation coefficients whose values were smaller than 4% in all the cases (Table 1).

Table 1. The descriptive statistics for wheat acreage in top 5 producing countries in the world in the period 2020-2024

	Global	India	Russian Federation	China	EU-27	USA
Mean	220.14	31.23	28.36	23.53	23.65	14.98
St. Dev.	1.41	0.50	0.94	0.09	0.84	0.43
R square	0.43	0.75	0.52	0.78	0.95	0.67
Kurtosis	-1.07	1.55	-0.07	2.34	-3.01	1.46
Skewness	0.90	-0.81	-0.89	-1.48	-0.63	-0.24
Min	219	30.45	26.95	23.38	22.61	14.36
Max	222.2	31.83	29.35	23.62	24.32	15.56
CV%	0.64	1.60	3.31	0.38	3.55	2.87
CAGR %	0.29	0.30	-1.36	0.17	-0.22	0.90

Source: Own calculations.

Global wheat production

Global wheat production is analyzed in many official documents and research publications emphasizing the trends and the most representative producing countries [28, 50, 56]. Wheat production increased from 763.7 Million MT in 2020 to 799 Million MT in 2024, meaning by + 4.62% more, a higher growth rate than in case of the cultivated area, which reflects that yield performance has better contributed to the global output (Fig. 4).

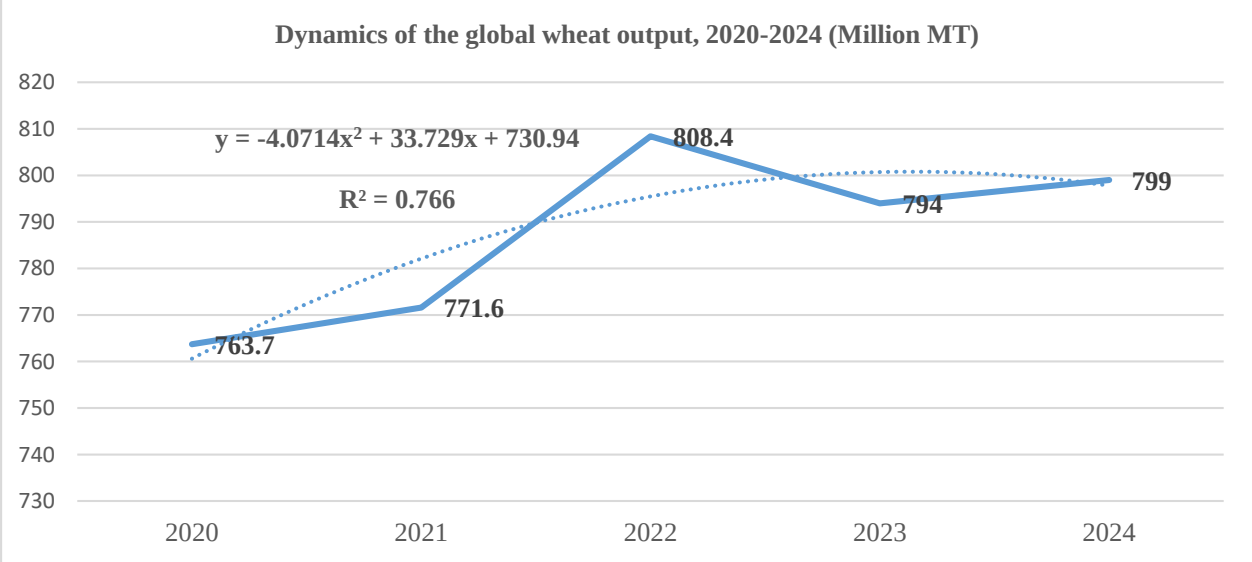

Fig. 4. Dynamics of the world wheat output, 2020-2024 (Million MT)
Source: Own design based on the data from [9].

Across the studied interval, a peak of 808.4 Million MT was recorded in the year 2023, but then production declined to 794 Million MT in 2023 and finally to get a low gain of 5 Million MT and reach 799 Million in 2024 (Fig. 4).

In 2024, in the decreasing order, the top 5 leaders in wheat production have been: China, EU-27, India, Russian Federation and USA, therefore the same countries working the largest areas, but the hierarchy is a little changed, as shown in Fig. 5.

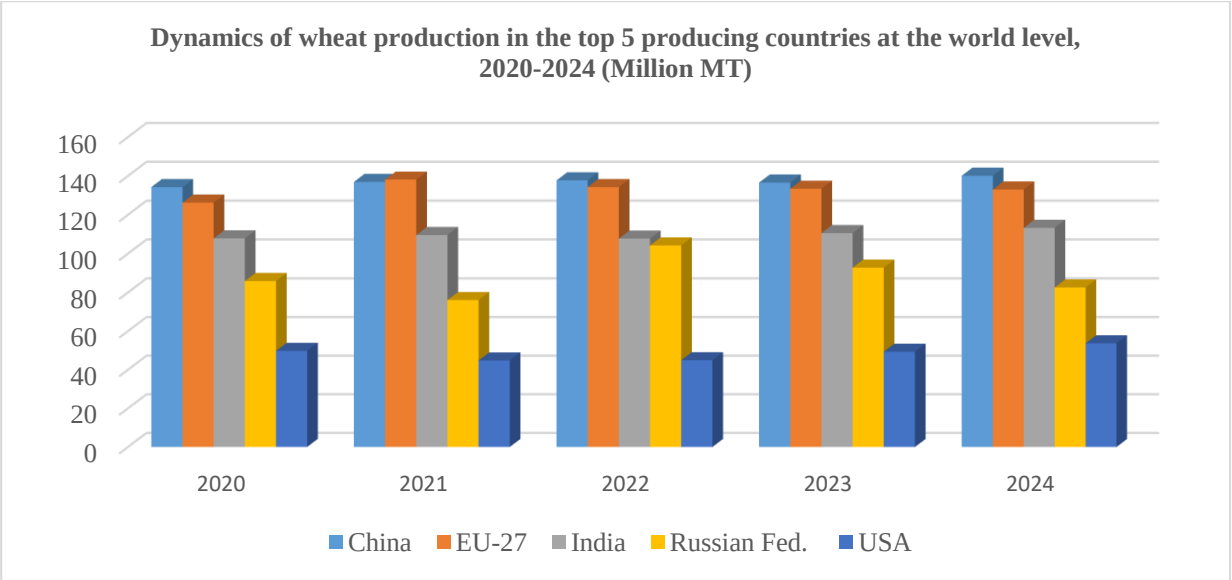

Fig. 5. Dynamics of the wheat production in the top 5 producing countries at the world level, 2020-2024 (Million MT)
Source: Own design based on the data from [9].

Versus 2020, in 2024, wheat production was higher by: +4.3% in China, +5.3% in the EU-27, +5.03% in India, +7.8% in USA, but smaller by -3.86% in the Russian Federation.
These five countries contributed by 65.4% to the global wheat output.

They are followed by another group of 5 countries producing wheat, which in 2024 came on the 6th and to the 10th positions. It is about: Canada, Australia, Pakistan, France and Ukraine (Fig. 6).

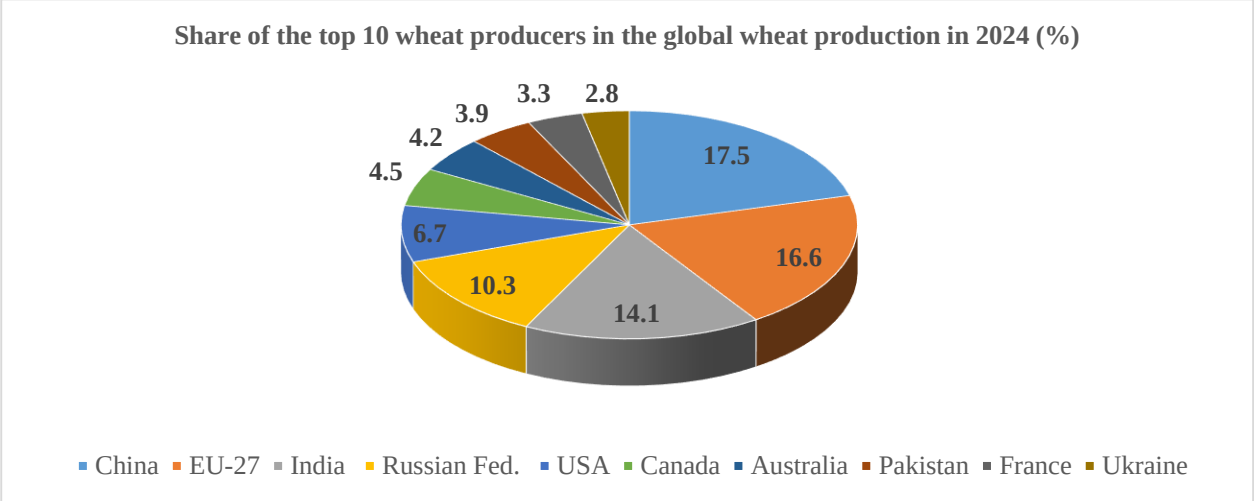

Fig. 6. The weight of the top 10 wheat producing countries in the world wheat output in 2024 (%)
Source: Own design and calculations based on the data from [9].

In these states, production went up by +26.03% in Pakistan, +6.86% in Australia, +1.41% in Canada, while in France it declined by -11.87% due to climate change and in Ukraine by -10% due to the military conflict.
The share of the top 10 wheat producing countries in the world in the global production in 2024 is reflected by Fig. 6.

The production variation was weak in general in the EU-27, CV+ 1.42%, in China, CV= 1.53% and India, CV=2.07%. In the USA, CV= 7.67 is also low, but in the Russian Federation is over 10% reflecting a normal to moderate change (Table 2).

Table 2. The descriptive statistics for wheat production in top 5 producing countries in the world in the period 2020-2024

	Global	China	EU-27	India	Russian Federation	USA
Mean	787.34	137.12	133.01	109.80	88.27	48.48
St. Dev.	18.91	2.10	1.89	2.28	10.67	3.72
R square	0.76	0.72	0.55	0.82	0.27	0.94
Kurtosis	-2.22	1.28	2.22	0.34	0.22	-1.06
Skewness	-0.36	0.12	-0.89	0.93	0.68	0.36
Min	763.7	134.25	126.35	107.74	76.06	44.8
Max	808.4	140.10	138.1	113.29	104.03	53.65
CV%	2.40	1.53	1.42	2.07	12.08	7.67
CAGR %	0.91	0.86	1.03	0.99	-0.78	1.52

Source: Own calculations.

Global wheat yield

Average production per surface unit increased at the world level from 3,487 kg/ha in the year 2020 to 3,595 kg/ha in the year 2024, meaning a surplus of +3.09%. However, the years when wheat yield attained higher levels were 2022 – 3,691 kg/ha and 2023- 3,617 kg/ha, these years being the most favorable from a climate point of view (Fig. 7).

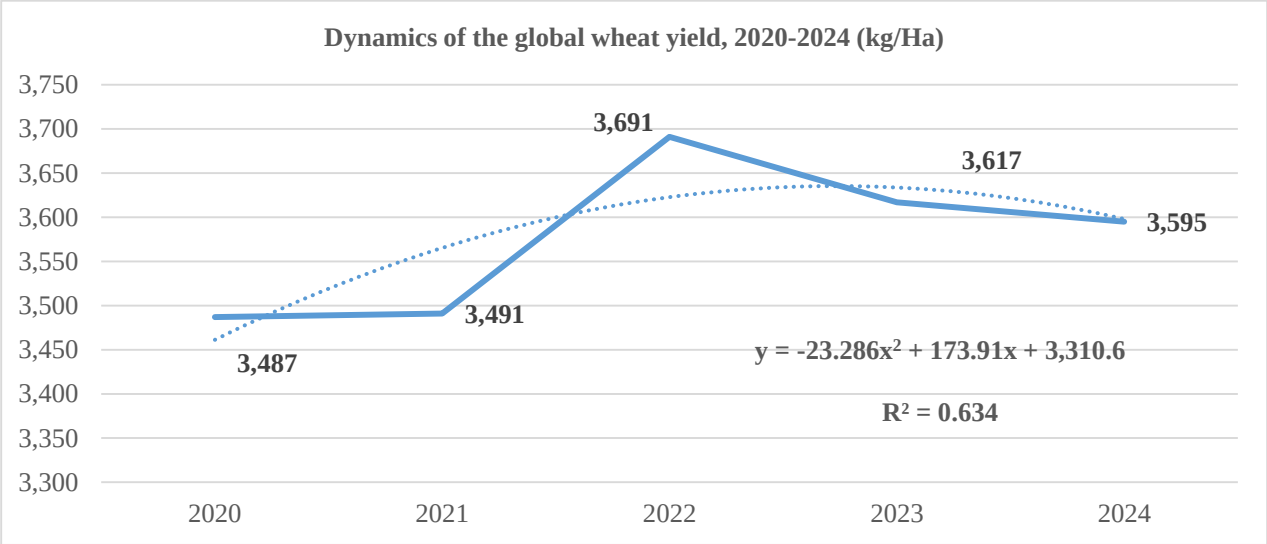

Fig. 7. Dynamics of wheat yield at the global level, 2020-2024 (kg/ha)
Source: Own design based on the data from [9].

In 2024, the highest wheat yield was registered in the following producing countries: Germany 7,084.2 kg/ha, China 5,939.3 kg/ha, EU-27 5,279 kg/ha, Ukraine 4,595 kg/ha and India 3,559 kg/ha.

The wheat yield in the top 5 producing countries in the world in the year 2024 versus 2020 is shown in Fig. 8. From this figure it could be observed that yield increased in China, Ukraine and India, while in Germany and EU-27 it registered a decline, justified by the negative impact of climate change in some EU member states.

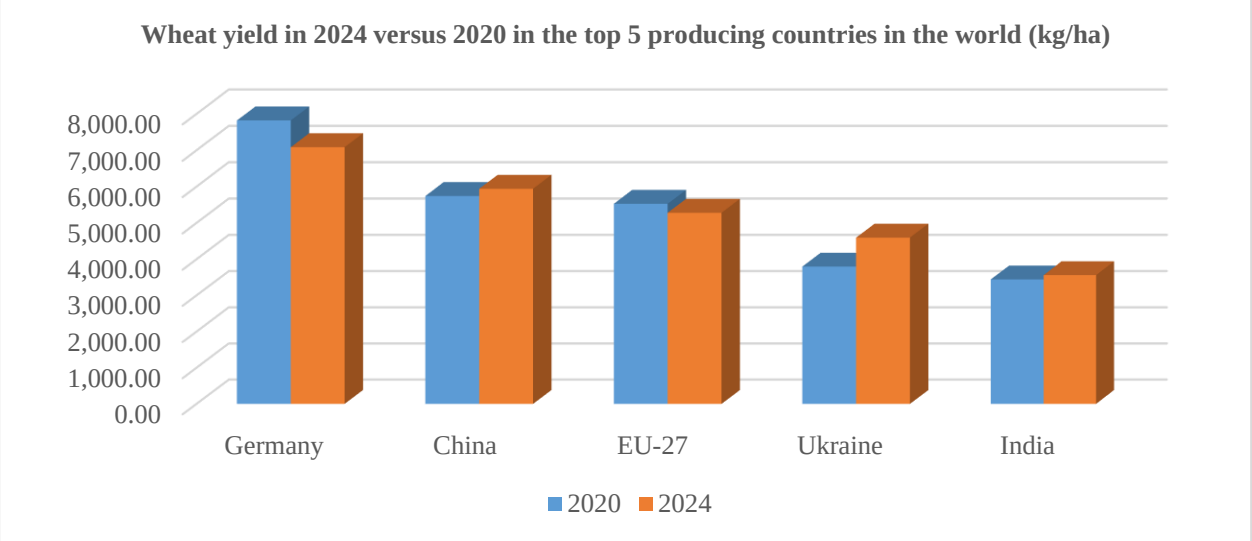

Fig. 8. Wheat yield in 2024 versus 2020 in the top 5 producing countries at the global level
Source: Own design based on the data from [9].

These five countries are followed by a group of other five states situated on the 6th to 10th positions in the global hierarchy for wheat yield. In the decreasing order, it is about: USA 3,446.2 kg/ha, Canada 3,373.9 kg/ha, Pakistan 3,268.3 kg/ha, Russian Federation 3,064.1 kg/ha and Turkiye 3,003.6 kg/ha.

In the top five wheat producers, yield recorded a slight variation in the analyzed interval as shown in Table 3.

Table 3. The descriptive statistics for wheat yield in top 5 producing countries in the world in the period 2020-2024

	Global	Germany	China	EU-27	Ukraine	India
Mean	3,576.2	7,442.86	5,825.4	5,505.6	4,298.06	3,515.52
St. Dev.	87.19	277.79	76.01	155.19	180.86	45.14
R square	0.63	0.59	0.59	0.84	0.45	0.81
Kurtosis	-1.67	-0.15	0.32	1.82	-2.93	3.03
Skewness	0.16	0.13	0.78	-0.27	-0.62	-1.54
Min	3,487	7,084.2	5,741.6	5,279	3,795	3,439.8
Max	3,691	7,819.5	5,939.3	5,715	4,642.2	3,559
CV%	2.43	3.73	1.30	2.81	4.20	1.28
CAGR %	0.61	-1.96	0.68	-0.91	3.9	0.68

Source: Own calculations.

Wheat at the EU-27 level

Wheat cultivated area, production and yield was approached in many official documents and research papers [6, 9, 32, 35, 50].

Wheat acreage

The EU-27 is a strong competitor in the wheat market, besides China, Ukraine and India. In the analyzed period, in the EU-27, the wheat harvested surface decreased a little by 1.11% from 22.862 Million ha in 2020 to 22.609 Million ha in 2024. The largest surface with wheat was carried out in the year 2023 and accounted for 24.319 Million ha (Fig. 9).

In 2024, the top 5 member states with the largest wheat area, in the decreasing order were: France, Germany, Poland, Romania and Spain, summing 9,458.2 Million ha, accounting for 41.8% of the EU total area with wheat.

These five countries are followed in the descending order by: Italy, Bulgaria, Hungary, Lithuania and Czechia.

All these 10 countries together keep 14.879 Million ha with wheat, representing 65.8% of the EU-27 cultivated area with this crop.

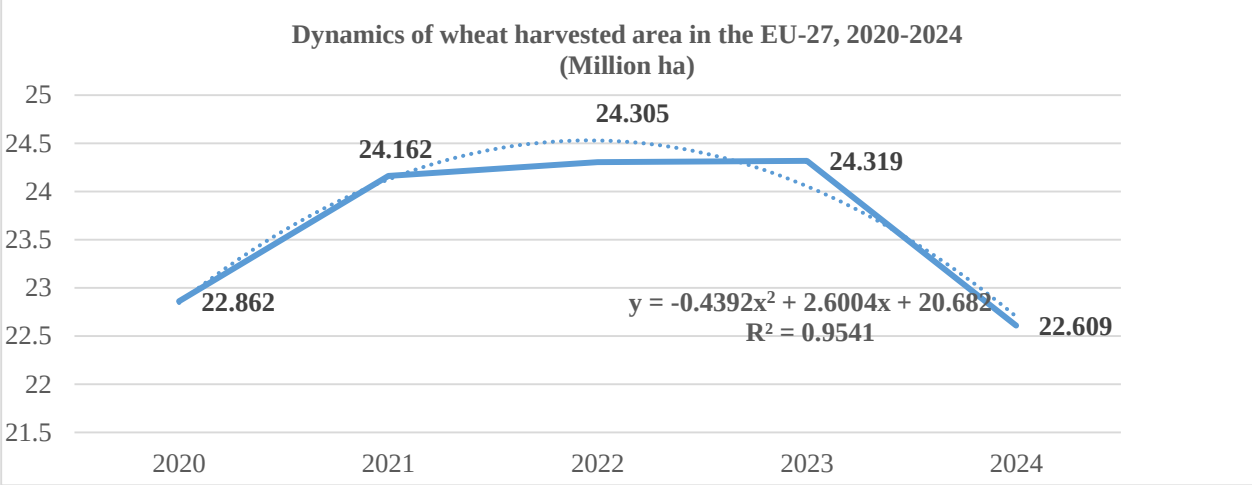

Fig. 9. Dynamics of the wheat harvested area in the EU-27, 2020-2024 (Million ha)
Source: Own design based on the data from [9].

From Fig.10, we may notice that in France and Germany the harvested surface with wheat declined, while in Romania and Spain it increased. In Poland, the wheat acreage remained relatively at a constant level.

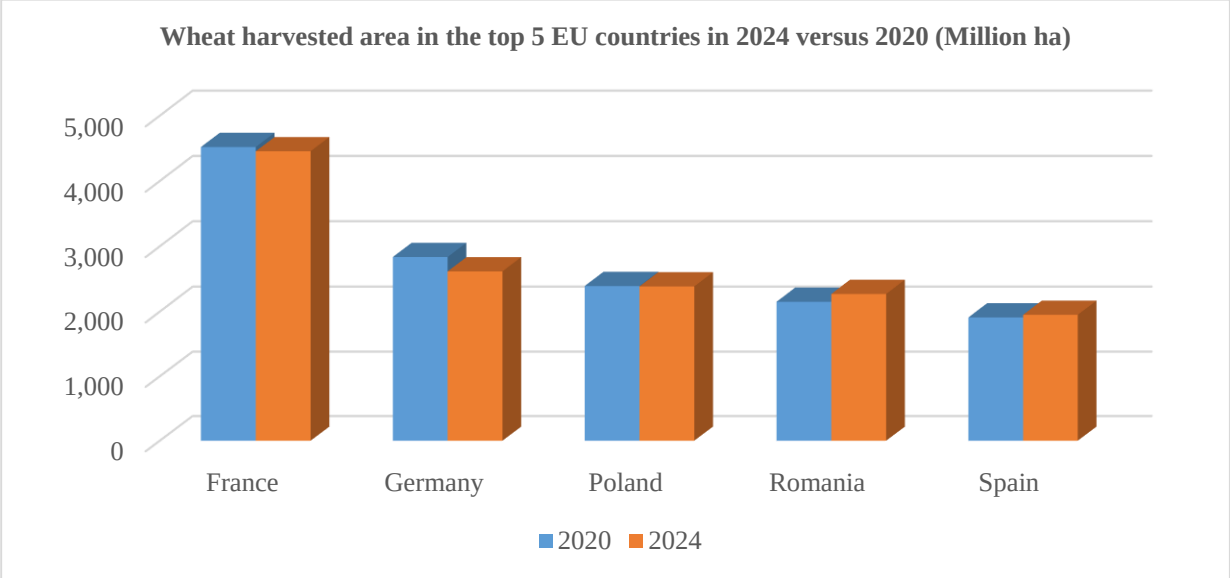

Fig. 10. Wheat harvested area in the top five EU countries in 2024 versus 2020 (Million ha)
Source: Own design based on the data from [9].

In the interval 2020-2024, the cultivated area with wheat increased only in Romania (+5.5%) and Spain (+2.09%).
In the other 8 countries it was recorded a decrease as follows: Germany – 9.05%, Lithuania -6.4%, Hungary – 1.50%, France -1.44%, Italy – 0.9, Bulgaria -0.9% and Poland -0.3%.
In 2024, the weight of these 10 EU countries in the EU-27 wheat harvested area summed 84.3% (Fig. 11).
Smaller changes in the cultivated area were performed during the interval 2020-2024 in each top member state producing wheat.
They are explained by the soil and climate conditions and harmonization between the technological factors and the expected production performance in each country (Table 4).

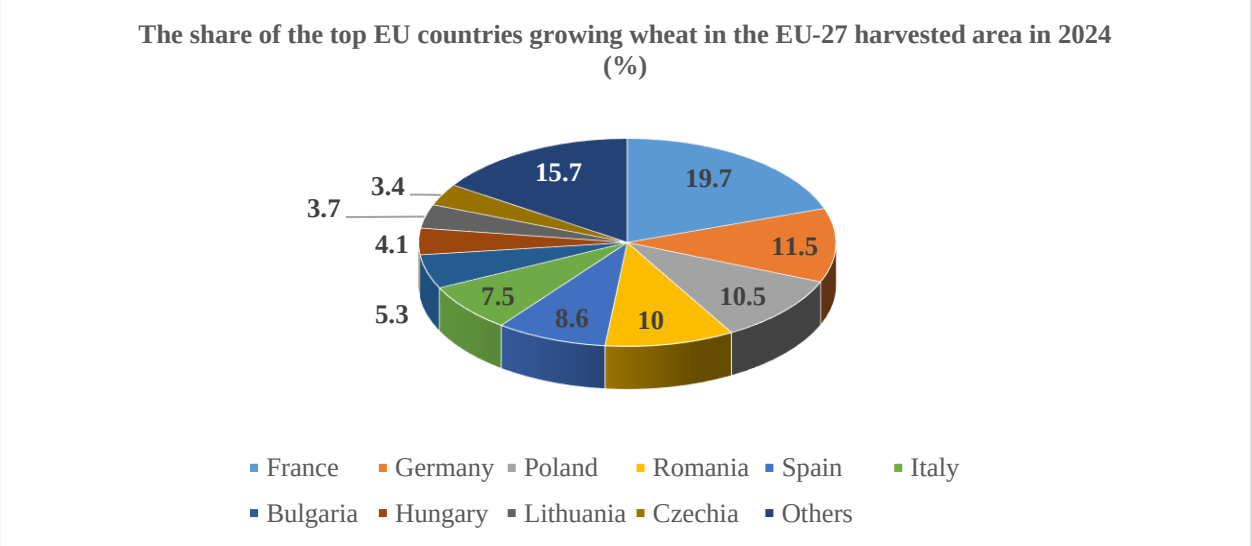

Fig. 11. The share of the top 10 EU countries in the EU-27 wheat harvested area in 2024 (%)
Source: Own design and calculation based on the data from [9].

Table 4. The descriptive statistics for wheat acreage in top 5 EU producing countries in the period 2020-2024

	EU-27	France	Germany	Poland	Romania	Spain
Mean	23.65	4,829.2	2,853.2	2,426.6	2,212	2,020
St. Dev.	0.84	346.04	143.55	15.68	72.93	116.61
R square	0.95	0.77	0.97	0.58	0.68	0.64
Kurtosis	-3.01	-1.92	2.40	0.78	-2.31	-2.58
Skewness	-0.63	-0.01	-1.51	1.33	0.73	0.61
Min	22.61	4,454	2,615	2,385	2,150	1,910
Max	24.32	5,276	2,980	2,518	2,310	2,170
CV%	3.55	7.16	5.03	0.64	3.29	5.77
CAGR %	-0.22	-0.29	-1.6	-0.05	1.09	0.42

Source: Own calculations.

Wheat production in the EU-27

In the interval 2020-2024, wheat output declined by 5.54% from 126.35 Million MT in the first year to 119.36 Million MT in the last one. The peak of production of 138.1 Million MT was carried out in the year 2021 (Fig. 12).

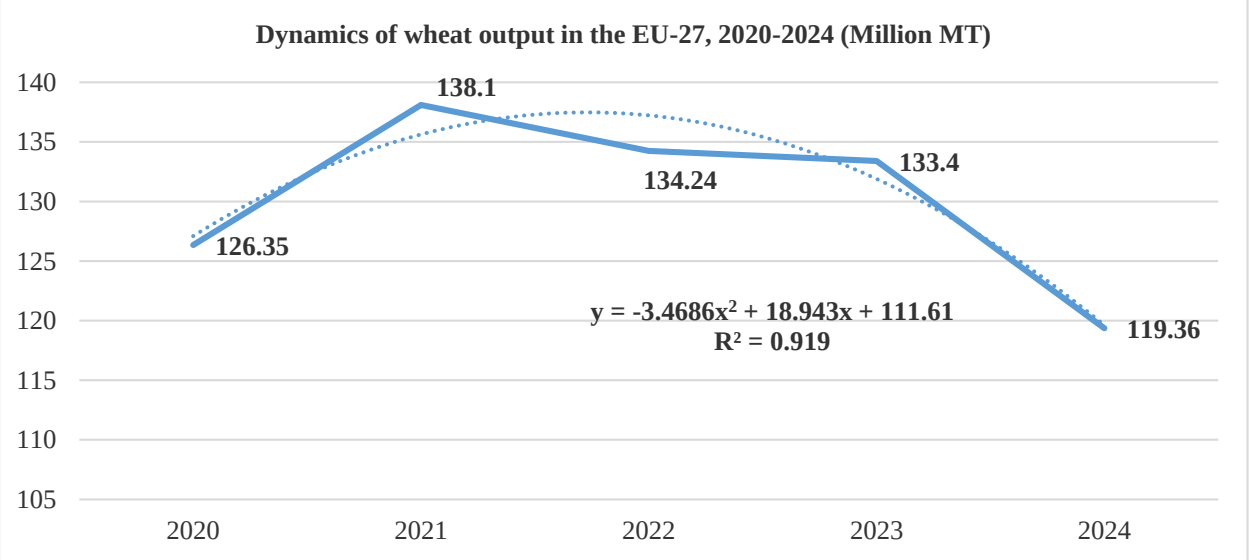

Fig. 12. Dynamics of wheat production in the EU-27, 2020-2024 (Million MT)
Source: Own design based on the data from [9].

The wheat production in the top five EU member states growing wheat in 2024 versus 2020 is presented in Fig.13. We may easily notice that production decreased in France, Germany, Poland and Spain, Romania being the only country where wheat output registered an important gain.

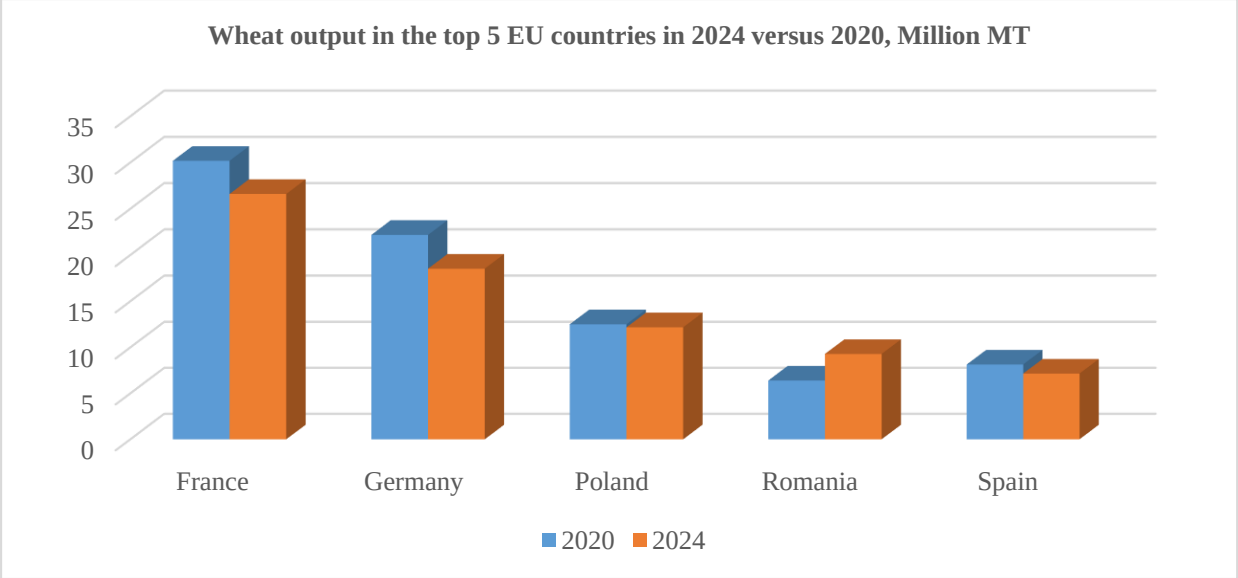

Fig. 13. Wheat output in the top five EU countries in 2024 versus 2020 (Million MT)
Source: Own design based on the data from [9].

The share of the top 10 wheat producing member states in the EU-27 wheat production is shown in Fig. 14. They are definitely important contributors to the EU output, as in 2024, their share summed 79.1%.

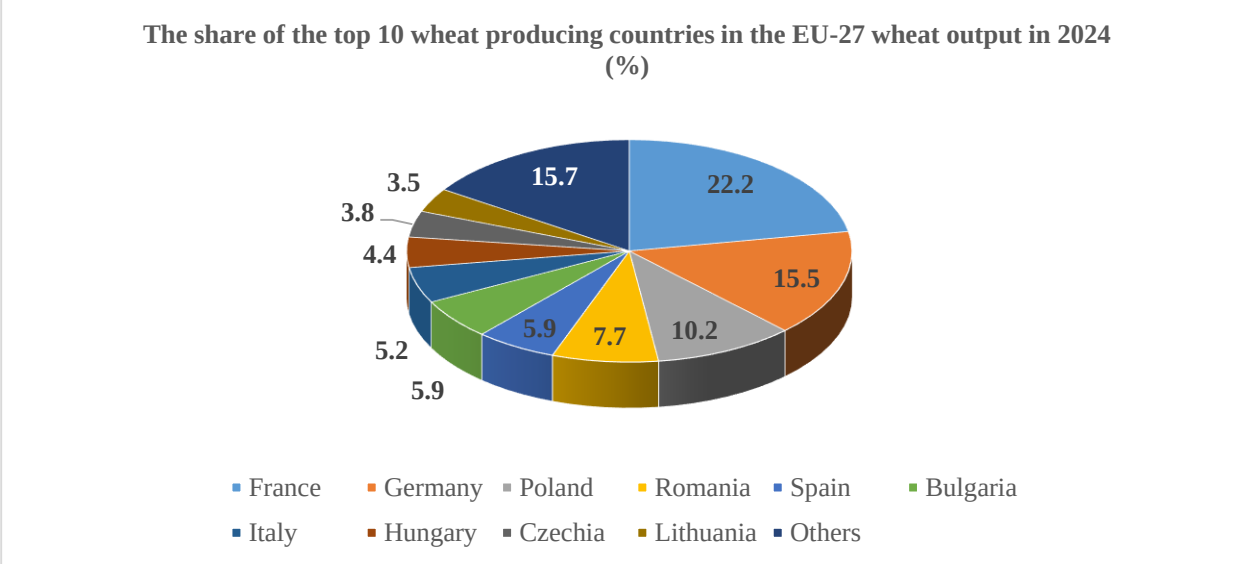

Fig. 14. The weight of the top 10 wheat producing member states in the EU-27 wheat output in the year 2024 (%)
Source: Own design and calculations based on the data from [9].

Production varied especially in the countries where in this interval were noticed extreme meteorological phenomena like high temperatures and low precipitations which produced damages to farmers.

This affirmation is sustained by the high coefficient of variation registered in France (12.9%), Romania (17.2%) and Spain (25.7%) (Table 5).

Table 5. The descriptive statistics for wheat production in top 5 EU producing countries in the period 2020-2024

	EU-27	France	Germany	Poland	Romania	Spain
Mean	133.01	32.79	21.25	12.54	8.82	6.88
St. Dev.	1.89	4.26	1.59	0.53	1.52	1.77
R square	0.55	0.86	0.83	0.22	0.54	0.33
Kurtosis	2.22	-1.10	3.44	-1.75	2.19	1.37
Skewness	-0.89	-0.87	-1.76	0.03	-1.31	-1.19
Min	126.35	26.6	18.52	11.89	6.39	4.05
Max	138.1	36.55	22.58	13.19	10.43	8.56
CV%	1.42	12.9	7.4	4.2	17.2	25.7
CAGR %	1.03	-2.49	-3.53	-0.53	7.77	-2.56

Source: Own calculations.

Wheat yield in the EU-27

Wheat yield varied from a country to another depending on the soil and climate conditions. In 2024, the yield attained 5,279 kg/ha, by 4.47% less than in 2020, when it reached 5,526 kg/ha. The decline was caused by deep changes in climate during the last five years in France, Romania, Spain where the rainfalls were not sufficient and high temperatures affected the plant growing. However, the best wheat yield was performed in the year 2021 and accounted for 5,715 kg/ha (Fig. 15).

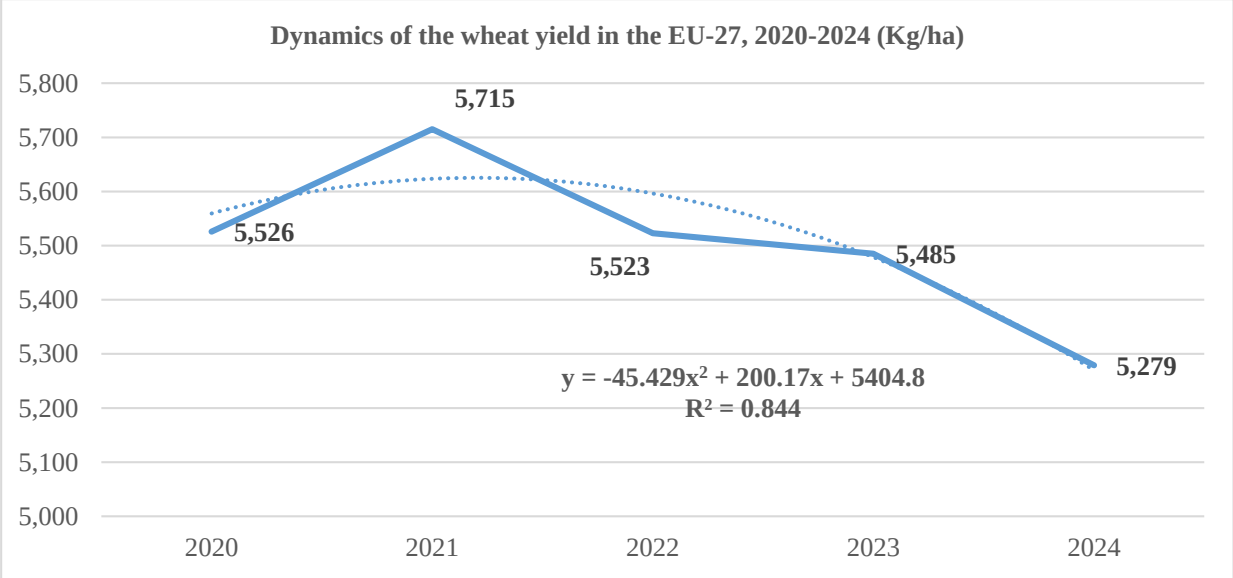

Fig. 15. Dynamics of wheat yield in the EU-27, 2020-2024 (Kg/ha)
Source: Own design based on the data from [9].

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Fig. 16 illustrates wheat yield level in each EU member state and compared to the UE-27 mean.

The EU-27 wheat yield of 5,279 kg/ha in 2024 was exceeded only by 14 member states, whose rank in the decreasing order is: Ireland, Germany, Denmark, Netherlands, Belgium, Sweden, France, Czechia, Bulgaria, Croatia, Austria, Hungary, Slovenia and Slovakia. Therefore, in 13 EU countries, wheat yield performance looks to be still low.

Fig. 17 reflects that in 2024 compared to 2020 wheat yield was smaller in France, Germany, Poland and Spain. In Romania, yield performance was higher in the last year of the interval in comparison with the first year.

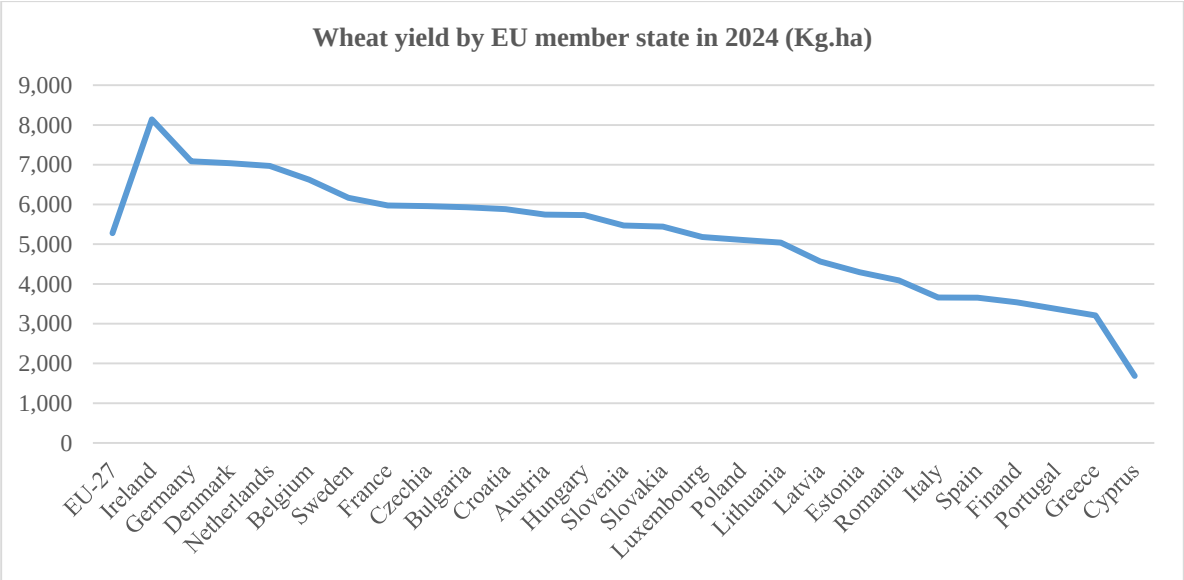

Fig. 16. Wheat yield by EU member state in 2024 (Kg/ha)
Source: Own design based on the data from [9].

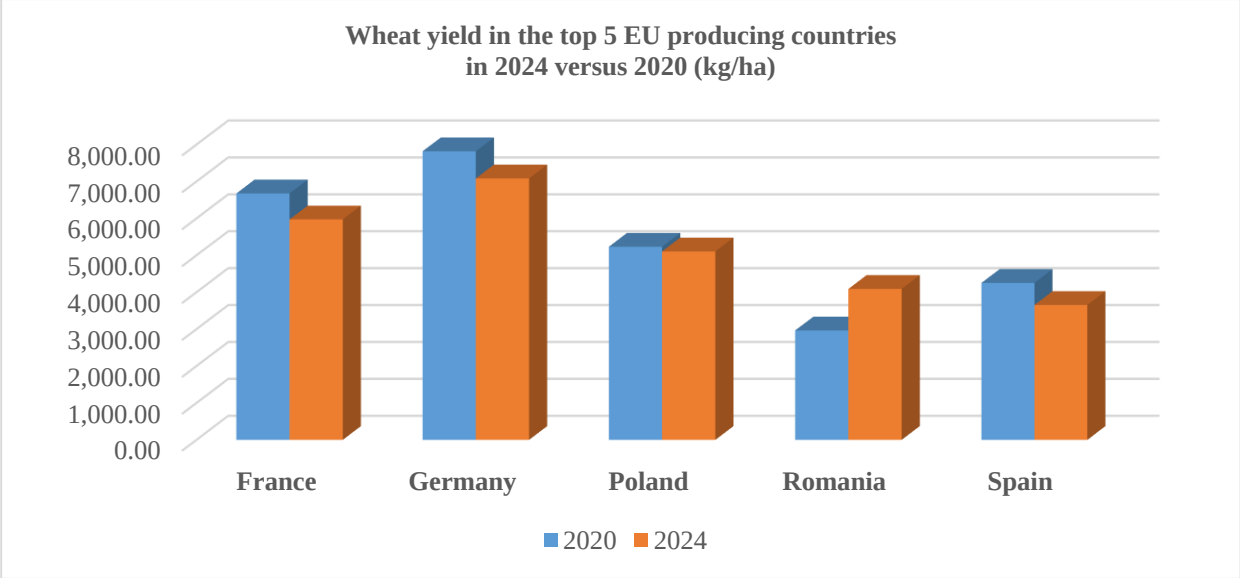

Fig. 17. Wheat yield in 2024 versus 2020 in the top 5 producing member states (Kg/ha)
Source: Own design based on the data from [9].

Table 6. The descriptive statistics for wheat yield in top 5 EU producing countries in the period 2020-2024

	EU-27	France	Germany	Poland	Romania	Spain
Mean	5,505.6	6,755.56	7,442.86	5,167.18	4,002.08	3,399.00
St. Dev.	155.19	475.57	277.79	125.37	658.72	882.95
R square	0.84	0.77	0.58	0.07	0.48	0.63
Kurtosis	1.82	2.21	-0.15	-0.01	2.30	-0.07
Skewness	-0.27	-1.43	0.13	-0.09	-0.88	-0.93
Min	5,279	5,973.5	7,084.2	4,975.3	2,966	2,068.3
Max	5,715	7,201.6	7,819.5	5,280	4,796.9	4,253.2
CV%	2.8	7.0	3.7	2.4	16.45	25.97
CAGR %	-0.91	-2.2	-1.96	-0.49	6.64	-2.99

Source: Own calculations.

Like in case of wheat production, wheat yield varied in different way from a country to another. While in France, Germany and Poland, the values of the coefficient of variation reflect small changes below 7%, in case of Romania and Spain, the coefficients of

variation were: 16.45%, and respectively 25.97% (Table 6).

Global wheat consumption

The need of wheat is continuously increasing in accordance with consumption and population growth [43, 51].

In 2024, wheat consumption attained 797 Million MT, being by 5.7% higher than in the year 2020, when it accounted for 754 Million MT (Fig. 18).

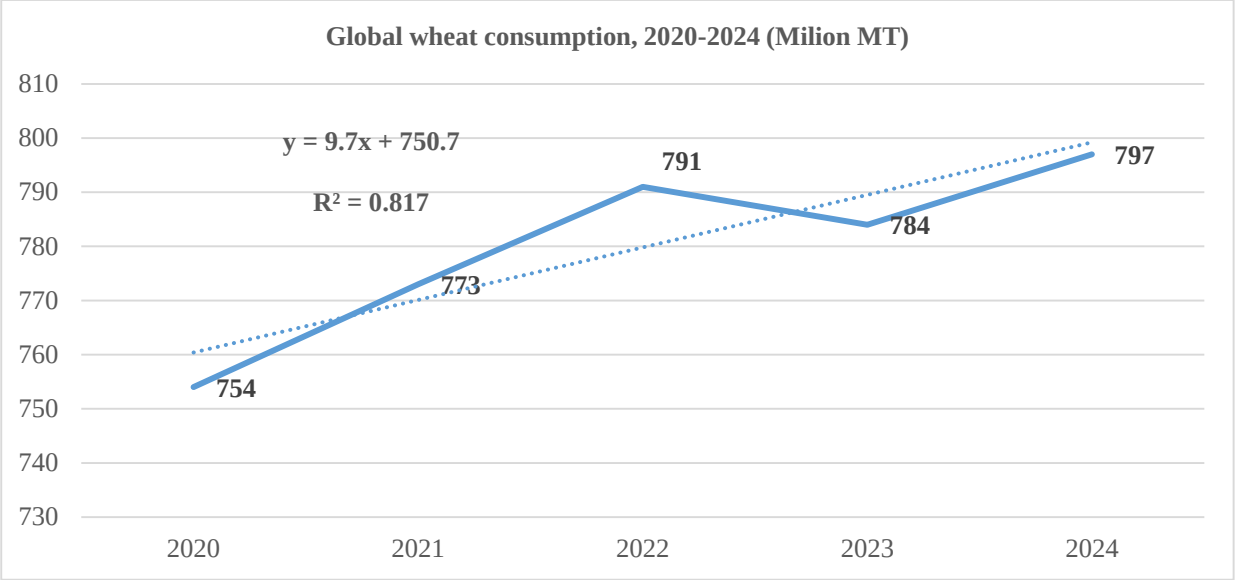

Fig. 18. Global wheat consumption, 2020-2024 (Million MT)
Source: Own design based on the data from [51, 60].

Consumption is allotted on three major destinations. On a larger scale, wheat is destined to contribute to food security a reason why about 70% is for human direct consumption (bread, pasta, noodles and other baked goods etc). It nourishes about 2.5 Billion people from about 89 countries [38].

About 20% of total consumption is represented by feed and residual and the remaining 10% is for industrial purposes for producing ethanol and starch.

The major wheat consumers are represented in general by the countries with a large population like: China, India, the EU, Russian Federation, USA and Pakistan.

The consumption level in these countries in the period 2021-2024 is shown in Table 7.

Table 7. The top countries in the world based on wheat consumption, 2021-2024 (Million MT)

	2021		2022		2023		2024	
	Amount Million MT	%	Amount Million MT	%	Amount Million MT	%	Amount Million MT	%
Global consumption	773	100.0	791	100.0	784	100.0	797	100.0
China	147	19.0	148	18.7	148	18.8	148	18.5
India	98	12.8	108.6	13.7	107	13.6	109	13.6
EU-27	112	14.4	108	13.6	106	13.5	108	13.5
Russian Fed,	40	5.2	42.2	5.3	42	5.3	44	5.5
USA	30	3.9	30.4	3.8	31	3.9	30	3.7
Pakistan	29	3.7	29.2	3.6	20	3.6	29	3.6

Source: Own calculation based on the data from [51, 60].

An important indicator is consumption per inhabitant. From this point of view, consumption could be divided into three categories:

-High consumption, whose level is higher than 130 kg/capita, category in which could be mentioned Egypt with 186.2 kg and Israel with 131.2 kg;

-Middle or moderate consumption, varying between 100-130 kg/capita, like: Ukraine with 104.9 kg/capita and United Kingdom with 102.7 kg/capita;

-Low consumption, its level being below 100 kg/capita like in Paraguay 52.3 kg, South Korea 47.7 kg and Philippines 23.64 kg [36]. (Fig. 19).

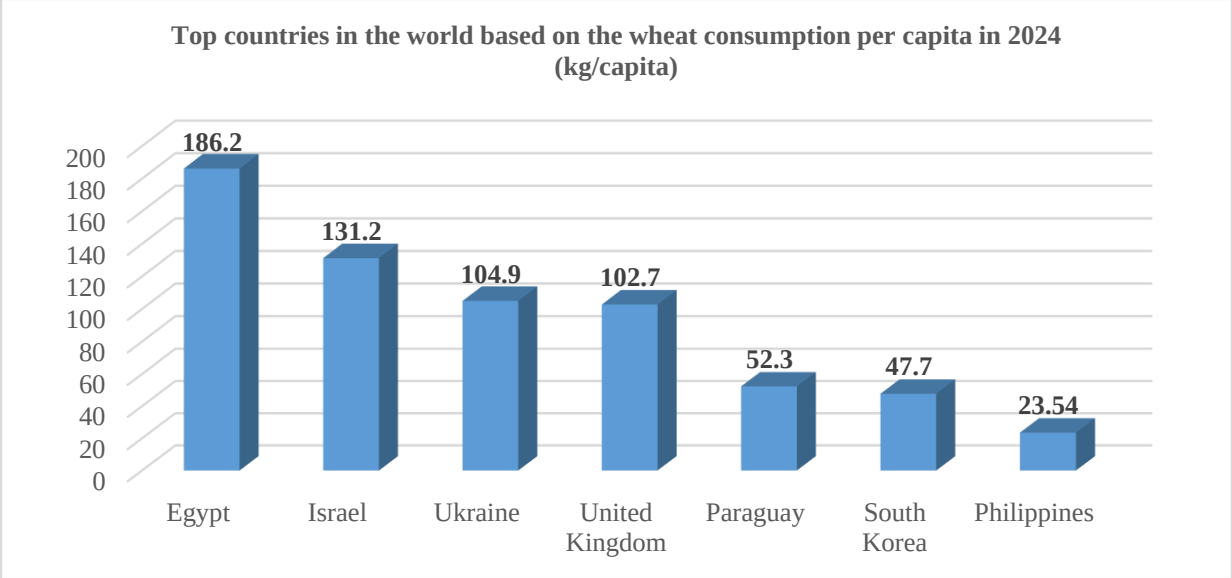

Fig. 19. The top countries in the world based on wheat consumption per capita in 2024 (Kg/inhabitant)
Source: Own design based on the data from [36].

Global wheat price

Wheat price is another indicator of high interest first of all for producers and traders. Its level is deeply influenced by large range of factors, among which the most important ones are: wheat production regions (The Black Sea, North America, Europe, Australia, Argentina), harvested production, the demand/supply ratio in the international market, the impact of weather conditions on wheat yield and production in the growing regions, global costs for farm inputs especially for fertilizers, fuel, and energy, freight costs, variations of currency exchange rate, government strategy regarding international trade and geopolitical conflicts like in the Black Sea basin and the Strait of Hormoz in the Persian Gulf [62].

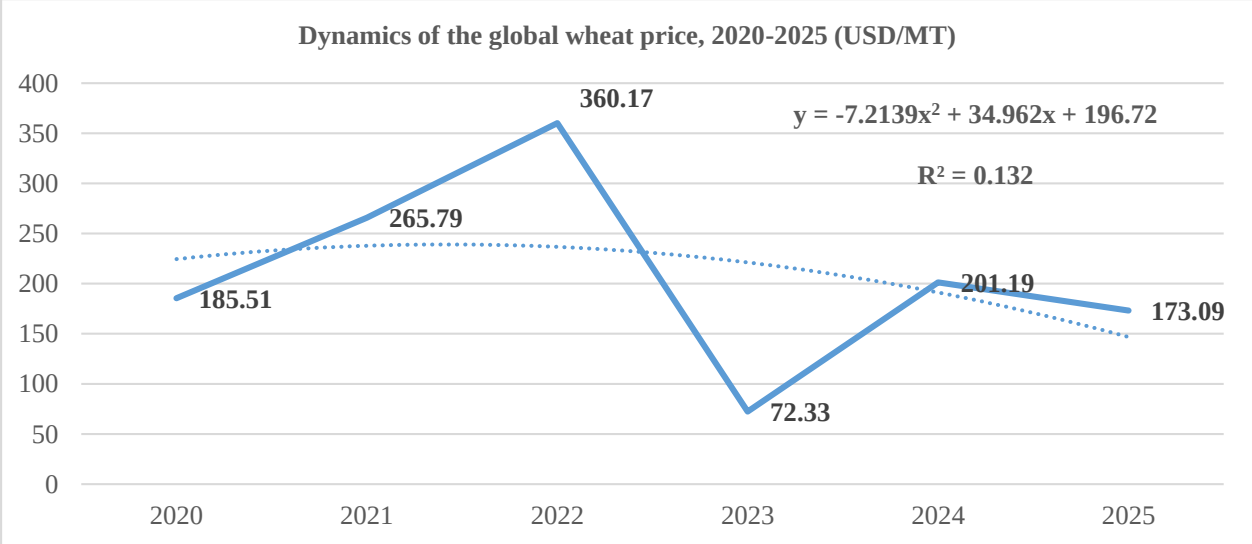

Fig. 20. Dynamics of wheat price at the global level, 2020-2024 (USD/Ton)
Source: Own design based in the data from [10, 17].

In the analyzed period, average wheat price at the global level varied between USD 185.51/Ton in the year 2020 and USD 201.19/Ton in 2024. In this case, we may affirm that in 2024, the price was by 11.42 higher than in 2020.

However, in 2025, it dropped to USD 173.09, the lowest level during the analyzed period. From Fig. 20, we may see the variations up and down across the time.

Compared to the level achieved in 2020, in 2021, wheat price increased to USD 265.79/MT due to the smaller supply, disruptions in the supply chain determined by the Covid-19 pandemic and severe droughts mainly in the North America.

In 2022, the average price was facing a boom to USD 360.17 per MT, but in March it went up again reaching USD 446.66/MT after the emergence of the army conflict between Russia and Ukraine. Also, the droughts continued to cause damages to farmers in many parts of the world.

In 2023, the wheat price registered a deep decline to USD 272.33/MT which continued in the next year 2024, so that in this year the average price accounted for only USD 201.19/MT, in accordance with the world production and the high geopolitical risk from the previous years.

Global wheat trade

Global wheat export

Production growth and the increased requirements for covering consumption have stimulated wheat export [52].

In 2024, at the global level, it was exported a quantity of 214.6 Million MT, by 16.44% more than in the year 2020.

The export value registered an ascending trend from USD 48 Billion in 2020 to USD 57.3 Billion in 2024, reflecting an increase by 19.37% (Table 8).

Table 8. Dynamics of global wheat export quantity and value, 2020-2024

	MU	2020	2021	2022	2023	2024	2024/2020 %
Export quantity	Million MT	184.3	199	186.7	201	214.6	116.44
Export value	USD Billion	48	56.9	68.3	59.2	57.3	119.37

Source: Own calculation based on the data from [58, 48].

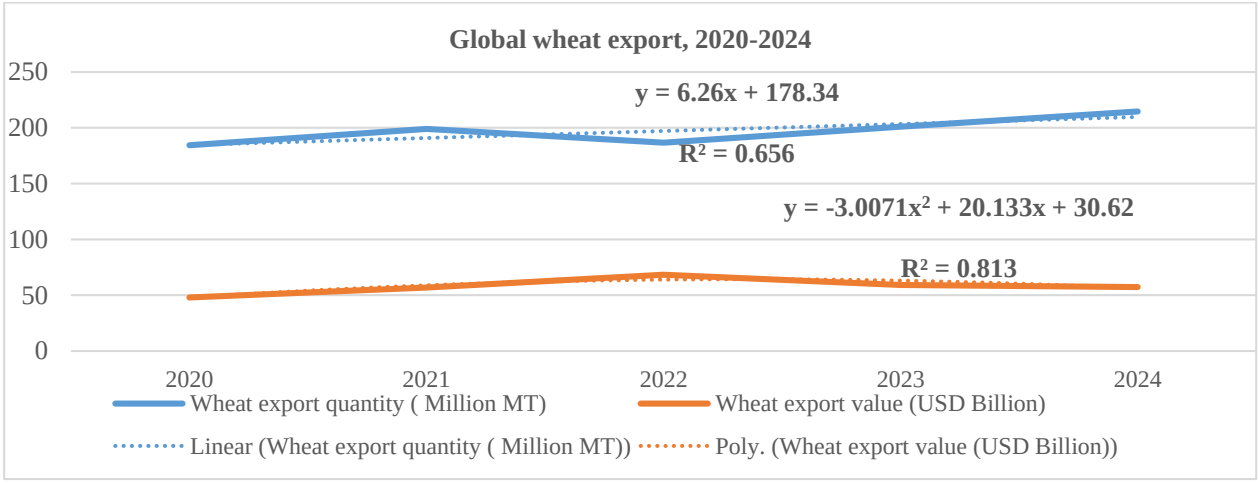

Fig. 21. Global wheat export quantity (Million MT) and value (USD Billion), 2020-2024
Source: Own design and calculations based on the data from [58, 48].

However, the export value depends on the traded amount and wheat market price. The highest export value was registered in the year 2022 for the exported amount of 186 Million MT. The trends in export quantity and value in the analyzed interval are illustrated in Fig. 21. The major wheat exporting countries in the world are: Russia, the EU-27, Canada, USA, Australia and France. The amounts of wheat exported and the export value for each

exporter are shown in Table 9. The figures reflect that EU-27, Australia and Russia increased their exports, while France diminished its export both quantitatively and as value because it was needed to cover the internal market affected by the decline in production caused by the climate change.

In case of Canada and USA, the exported amount declined, but the export value increased.

Table 9. The quantity of exported wheat and export value of the top suppliers in the global market, 2020-2024

Country	Specification	2020	2021	2022	2023	2024	2024/2021 %
Russia	Quantity Million MT	37.4	33.0	37.26	31.59	54	144.38
	Value USD Billion	7.88	7.24	7.91	10.0	9.2	116.75
EU-27	Quantity Million MT	26.8	29.7	31.9	33.3	59	220.14
	Value USD Billion	5.2	7.3	11.6	11.7	15.1	288.46
Canada	Quantity Million MT	26.1	19.6	15.16	25.5	25.6	98.08
	Value USD Billion	4.95	8.3	6.21	8.84	7.8	157.57
USA	Quantity Million MT	25.28	25.6	23.14	19.7	22.68	89.71
	Value USD Billion	6.09	7.3	7.13	7.8	6.59	108.21
Australia	Quantity Million MT	23.8	29.7	31.9	33.3	59	247.89
	Value USD Billion	3.3	6.5	7.1	9.3	6.0	181.81
France	Quantity Million MT	19.89	16.5	19.0	13.48	14.2	71.39
	Value USD Billion	4.49	4.8	6.9	3.5	3.5	77.95

Source: Own calculations based on the data from [57, 46, 53].

The beneficiaries of wheat differ from an exporting country to another depending on wheat quality, market price, transportation distance and cost and trade relationships.

The wheat from Russia is exported in Turkiye, Egypt, Saudi Arabia, Bangladesh.

The wheat produced in Canada is exported in China, Indonesia, Japan, Bangladesh.

USA sell wheat to Mexico, Japan, Philippines, Nigeria.

Australia exports of wheat go to Indonesia, Philippines, Vietnam, Thailand and China.

France is a supplier both for the EU market; Belgium, Netherlands and also for extra-EU beneficiaries like: Morocco, Egypt, Saudi Arabia, Nigeria, China.

The top exporters of wheat in the EU are France and Romania which dominate the market. Also in a lower measure, Poland and Germany are wheat suppliers.

Romanian wheat is successfully exported on the EU market, but also in Egypt, Saudi Arabia and countries from the North Africa.

Global wheat import

Wheat quantitative imports have shown a relatively weak increase from 196 Million MT in 2020 to 198 Million MT, meaning a surplus of 1.02%.

Imported quantities varied depending on the measure in which the domestic market requirements are covered by internal production, harvested yield level, consumption needs and wheat price at the global level.

Import value also went up from USD Billion 51.4 in 2020 to USD 59.1 Billion in 2024, meaning a surplus of 14.98%.

The dynamics of the global wheat import is shown in Fig. 22.

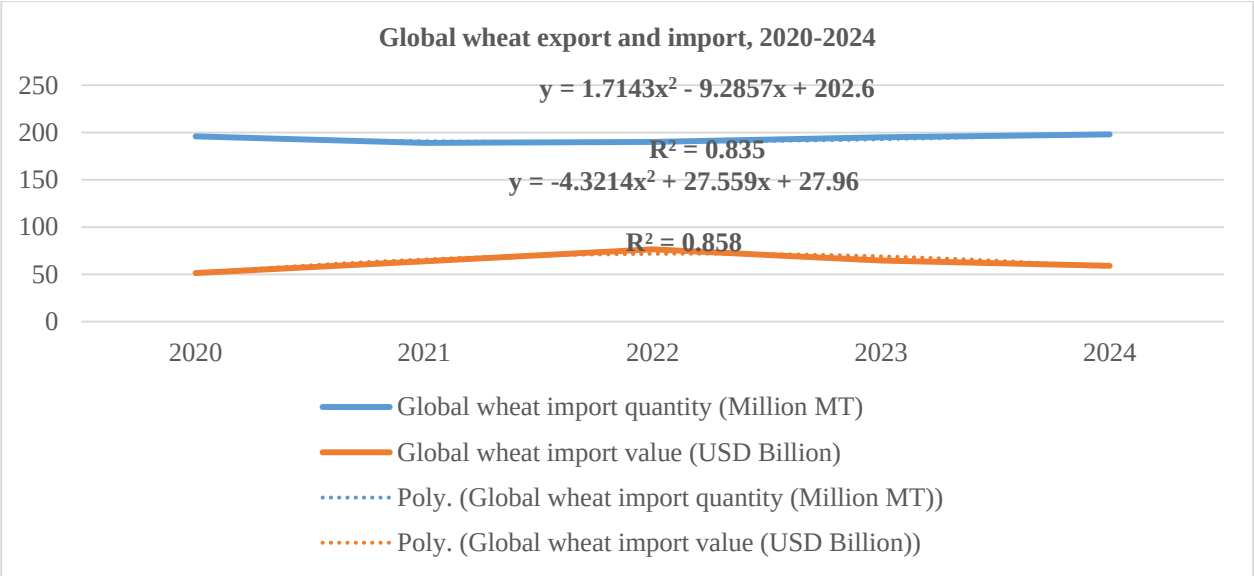

Fig. 22. Global wheat import quantity (Million MT) and value (USD Billion), 2020-2024
Source: Own design based on the data from [49, 47].

The main wheat importers are Egypt, Indonesia, China, Algeria, Turkey, Bangladesh and the EU-27. The amounts of the imported wheat and the import value is shown in Table 10.

Table 10. The quantity of imported wheat and import value in the top importing countries at the global level, 2020-2024

Country	Specification	2020	2021	2022	2023	2024	2024/2021 %
Egypt	Quantity Million MT	12.15	11.25	11.2	12.3	14.4	118.51
	Value USD Billion	3.2	3.4	4.8	3.7	5.2	162.50
Indonesia	Quantity Million MT	9.95	11.48	9.45	10.87	12.6	126.63
	Value USD Billion	2.62	3.5	3.38	3.76	3.63	138.54
China	Quantity Million MT	8.38	9.71	9.96	12.1	11.0	131.26
	Value USD Billion	2.2	3.04	3.7	4.3	3.17	144.09
Algeria	Quantity Million MT	7.68	8.6	8.7	9.5	9.0	117.18
	Value USD Billion	1.64	2.25	2.66	1.8	1.76	107.31
Turkiye	Quantity Million MT	8.2	7.2	8.76	11.56	9.50	115.95
	Value USD Billion	2.33	2.44	3.28	3.40	1.29	55.36
Bangladesh	Quantity Million MT	8	7.2	5.12	6.65	7.3	91.25
	Value USD Billion	1.4	2.0	1.5	1.50	0.74	52.85
EU-27	Quantity Million MT	5.5	4.63	12.23	12.65	11.50	209.09
	Value Euro Billion	1.3	1.2	4.5	3.8	3.5	269.23

Source: Own calculations based on the data from [57, 46, 53].

We may notice that in almost all the main importing countries of wheat, both the amounts and value increased.
In case of Bangladesh both the quantity

imported and import value decreased, while in Turkey only the import value declined.

The beneficiaries mentioned in Table imported wheat from the following suppliers:

-Egypt imports wheat especially from Russia, Romania and Bulgaria.

-Indonesia buys wheat from Australia, Canada, Ukraine, Argentina, Russia.

-China prefers to import wheat from France, Australia, Russia, Kazakhstan.

-Algeria's imports come from Bulgaria, Canada, France, Ukraine and Romania.

-Turkey prefers Russia and Ukraine as suppliers.

-Bangladesh buys wheat from Ukraine, Canada, Australia, USA and Russia.

-The EU-27 has as main wheat suppliers Ukraine, Canada and USA.

The EU wheat trade

There are many studies on wheat production and trade in the EU and on its producers, exporters and importers [3, 21, 29, 30, 33, 37].

The EU is among the top 5 global wheat producers and the 2nd large exporter of wheat in the world. It commercializes both common wheat and durum but the highest share of 96.84% in the total exported amount belongs to common wheat.

The EU wheat export

The exported quantity varied in the interval 2020-2025, from 38.19 Million tons (grain equivalent) in the year 2020 to 26.25 Million tons in 2025, reflecting a decline by 31.27%.

The reason is that the EU must to cover first the requirements on it own market and then to proceed to sell the surplus to other countries.

During the analyzed period, wheat production was affected by climate change. The same situation characterizes the export quantity of the all cereals as a group which decreased by about 30% from 55.15 Million tons in 2020 to 38.93 Million tons in 2025.

Wheat is ranked first in the cereals export, its share accounting for 67-69% [7].

The leading EU wheat producing member states are France, Germany, Poland and Romania, which are also the top exporters, adding Lithuania to this group (Fig. 23).

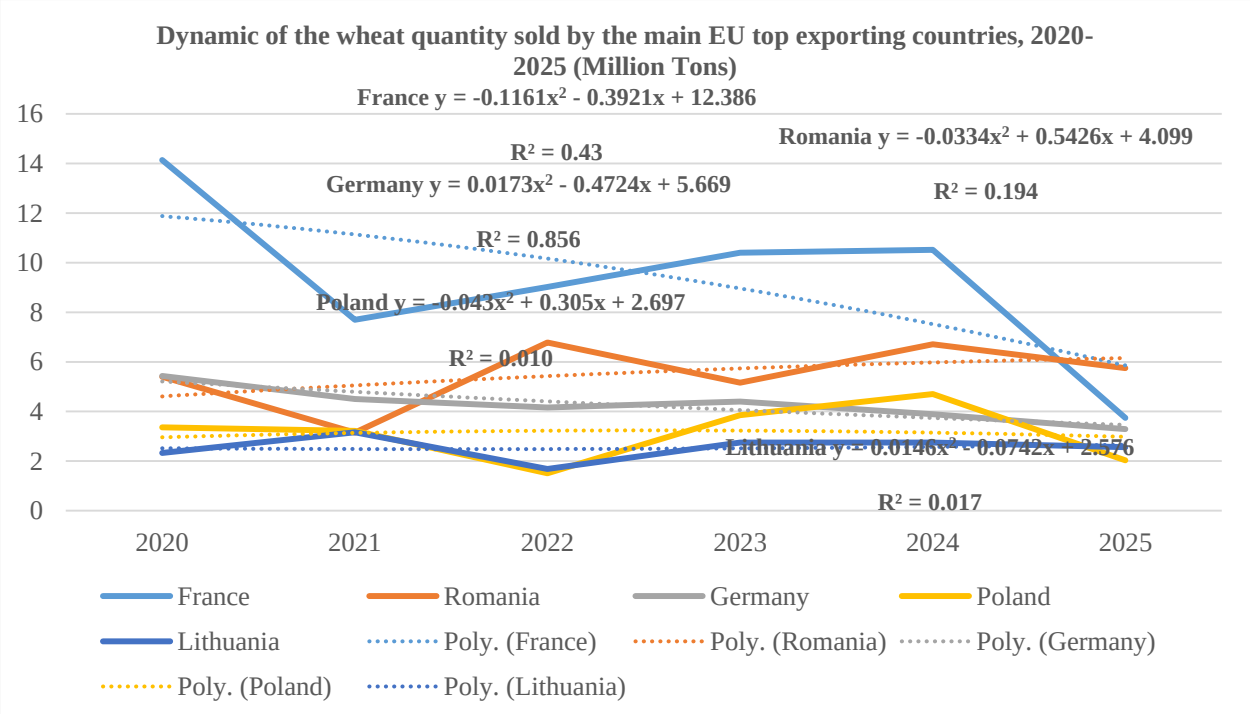

Fig. 23. Wheat exported quantity by the top 5 EU exporting countries, 2020-2025 (Million tons)
Source: Own design and calculations based on the data from [7].

France is situated among the most important wheat exporters at the global level as well.

Romania is also a large producer and exporter of soft wheat, being part of the block of

producers situated in the Black Sea region and deliver about 5 Million tons wheat by means of the Port of Constanta.
Germany has the top wheat yield in the world, a high production and commercializes milling and feed wheat to other EU states and global partners through the port of Hamburg.
Lithuania is a major supplier for Africa and Middle East countries through the Port of Klaipeda.
Poland is profiled on soft wheat export shipping the grains through the Port of Gdansk.
The amounts of wheat exported by the main EU member states are shown in Fig. 23.
The amount of wheat commercialized by these suppliers had the following situation in the year 2025 versus 2020:

France sold through the Ports of Rouen and La Pallice the amount of 3.74 Million tons, by 74.6% less than in 2020.
Romania increased its amounts by 6.48% from 5.40 Million tons to 5.75 Million tons in 2025.
Germany's export declined by about 40% from 5.43 Million tons to 3.29 Million tons.
Poland also registered a decrease by about 40% from 3.36 Million tons to 2.03 Million tons in 2025.
Lithuania performed a slight growth of 9.8% from 2.33 Million tons to 2.56 Million tons in 2025.
The EU wheat export value
The value of wheat exports increased from Euro 1.18 Billion in 2020 to Euro 2.68 Billion in 2025, accounting for +127%.

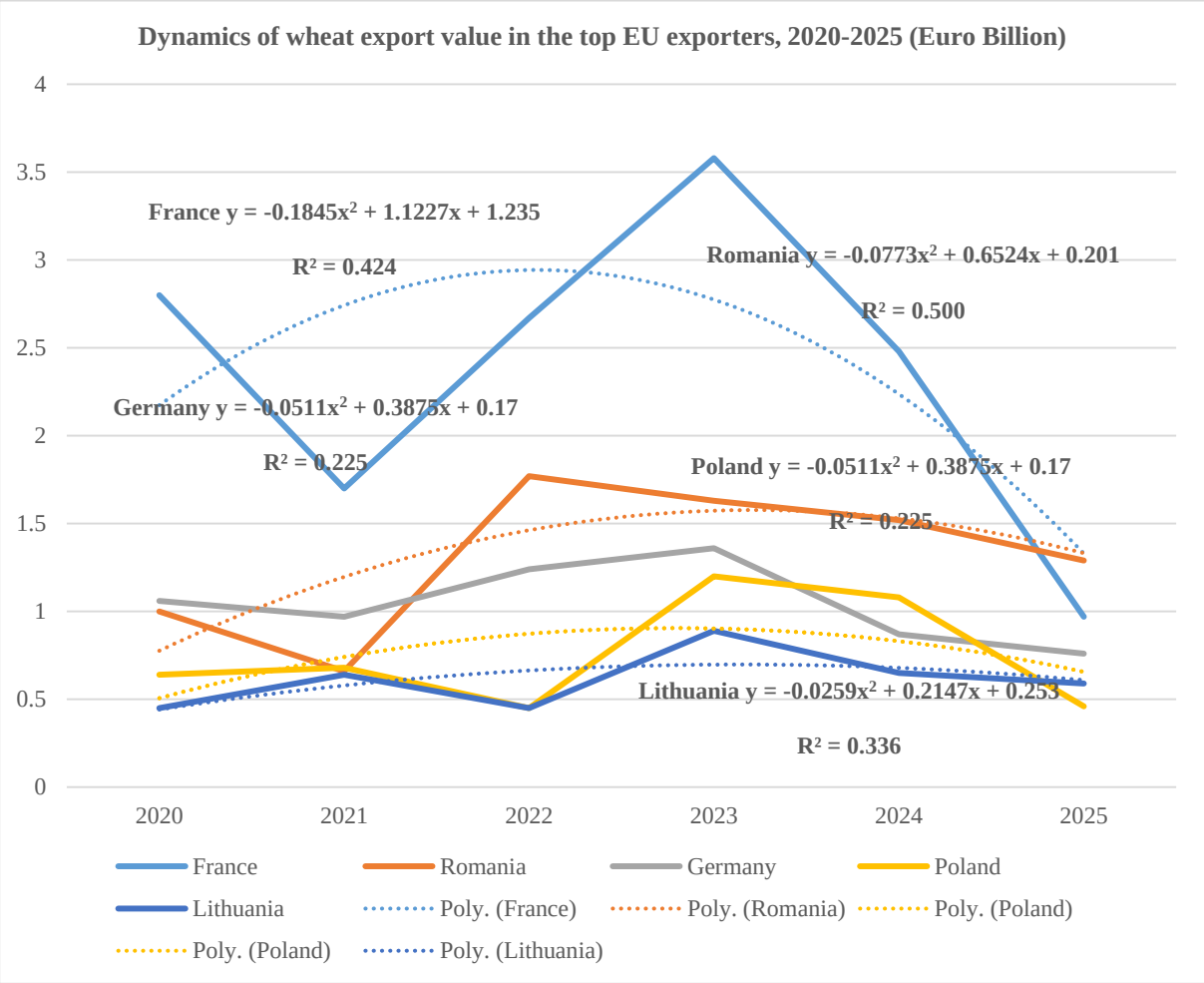

Fig. 24. Wheat exported value in the top 5 EU exporting countries, 2020-2025 (Euro Billion)
Source: Own design and calculations based on the data from [7].

Taking into account of value of the all cereals exported increased from Euro 4.95 Billion to Euro 7.7 Billion, that is by +55% in the same interval, the share of wheat export value went

up from 23.85 in 2020 to 34.7% in 2025, meaning +10.9 percentage points.

The wheat export value of the top EU exporters had the following level in 2025 versus 2020:

In France, the export value decreased from Euro 2.80 Billion to Euro 0.87 Billion, meaning a decline by 68.93%.

Also, in Germany, it happened a similar situation, registering a decrease by 28.31 % from Euro 1.06 Billion to Euro 0.76 Billion.

In Poland, export value went down by 28.325 from Euro 0.64 Billion to Euro 0.46 Billion.

In Romania, export value increased by 29%, in accordance with the growth of the supplied quantity, from Euro 1 Billion to Euro 1.29 Billion in 2025.

Lithuania increased its export value from Euro 0.45 Billion to Euro 0.59 Billion, meaning by + 31.1% (Fig. 24).

The EU wheat import

The wheat imported quantity

Despite that the EU has the capacity to produce enough wheat to cover in internal market needs, in a word, it is largely sufficient in wheat, it is still a purchaser of wheat durum and specialized grains.

The main EU importing member states are Italy, Spain, Slovenia, Ireland and Greece. In the studied interval, the imported quantity has doubled from 5.11 Million tons (grain equivalent) in 2020 to 10.10 Million tons in 2025, meaning +97.65%.

Having in mind that the amount of all the cereals imported increased from 25.84 Million tons in 2020 to 31.72 Million tons in 2025, that is by +22.75%, this means that the share of the imported wheat amount raised from 19.7% in 2020 to 31.84% in 2025.

Figure 25 shows the wheat quantity imported by the EU top 5 beneficiaries.

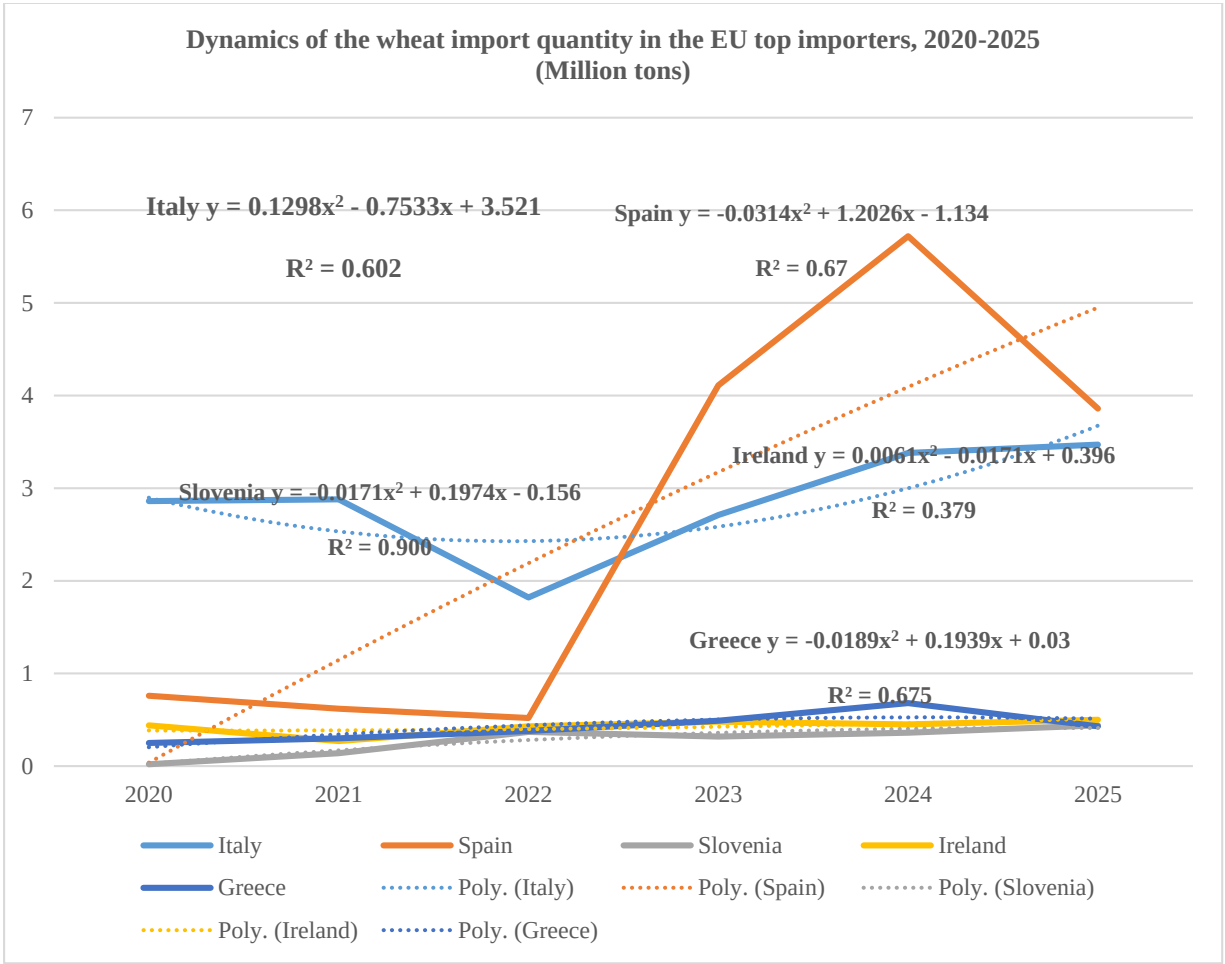

Fig. 25. Wheat imported amount by the top 5 EU importing countries, 2020-2025 (Million tons)
Source: Own design and calculations based on the data from [7].

All the top 5 EU member states mentioned above purchased the following amounts of wheat in the year 2025 versus 2020: Italy registered 3.47 Million tons compared to 2.86 Million tons, that is by 21.3% more. Italy is the leading EU imported of wheat accounting for 32% in total imported amount. It is important for Italy to import more wheat of high quality for the manufacturing industry which has to produce more premium pasta.

Spain increased its import 4 times up to 3.86 Million tons compared to 0.76 Million tons in 2020. It also keeps a share of 32 % in the total amount of imported wheat. It needs to purchase especially grain feed for livestock and to sustain the milling industry sector.

Slovenia also is a wheat importer. In 2025, it imported 0.44 Million tons by +120 more than 0.02 Million tons in 2020. Ireland attained 0.50 Million tons imported wheat by +13.63% more than 0.44 Million tons in 2020.

Greece has also performed a higher wheat import amount by +72%, as in 2025 it reached 0.43 Million tons versus 0.25 Million tons in 2020.

The main wheat suppliers for the EU are of two categories:

-First of all the EU member states like France, Germany and Romania, which are the top producers, reflecting the intra-trade wheat transactions.

-Secondly, the extra-EU suppliers like Canada, Ukraina, USA, Kazakhstan for providing durum wheat for pasta and other specialized needs.

The wheat import value

This indicator registered an ascending trend from Euro 1.18 Billion in 2020 to Euro 2.68 Billion in 2025, meaning +235%.

In consequence, its share in the value of the all imported cereals raised from 23.8% in 2020 to 34.76% in 2025, reflecting +10.96 percentage points. Figure 26 shows the dynamics of the wheat import value in the EU top importing member states in the period 2020-2025.

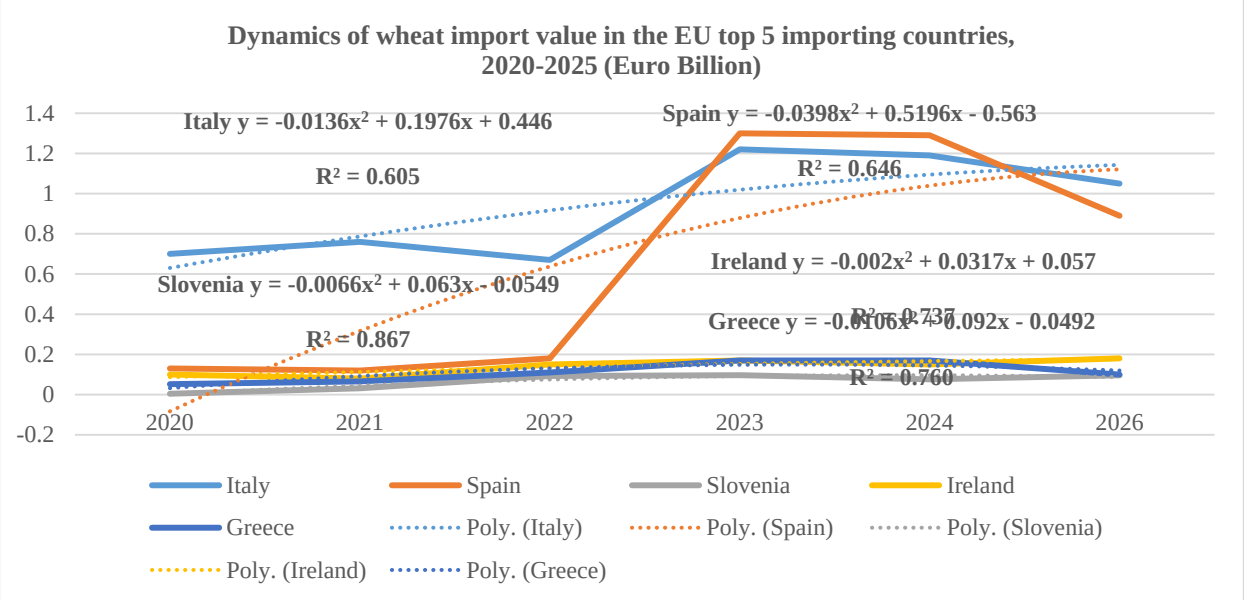

Fig. 26. Wheat import value in the top 5 EU importing countries, 2020-2025 (Euro Billion)
Source: Own design and calculations based on the data from [7].

The curves from Fig. 26 reflects an increase by 50% in Italy, 6.8 times in Spain, 24.7 times in Slovenia, +80% in Ireland and +92.35 in Greece in the year 2025 versus 2020.

CONCLUSIONS

This research aimed to analyze the actual situation of wheat market, the most widely cultivated staple crop in the world. The study regards the following indicators: harvested area, production, yield, consumption, price, export and import, in their dynamics at the global and EU level in the last five years 2020-2025 for identifying the tendencies and challenges in the context of the pressure

exerted by climate change and geopolitical instability.

The main results of this research are the following ones:

-The global area covered by wheat increased by 1.46% from 219 Million in 2020 to 222.2 Million ha in 2024. About 54.24% of the total harvested area belong five countries: India, Russian Federation, China, EU-27 and USA.

-The cultivated area with wheat was expanded in India, USA and China, while in Russian Federation I declined.

-if we add other five wheat growing countries: Australia, Kazakhstan, Canada, Pakistan and Turkiye, the cultivated area of these 10 countries will account for 173.95 Million ha, representing 78.28% of the global wheat area.

- Wheat output reached 799 Million MT in 2024, meaning by + 4.62% more than in the year 2020. The main producers are, in the decreasing order: China, EU-27, India, Russian Federation and USA. These five countries contributed by 65.4% to the world wheat production. The output had an ascending trend in the same countries like in care of the surface expand, therefore in the Russian Federation is was achieved a lower production. Canada, Australia, Pakistan, France and Ukraine are also other important wheat producers.

- Average yield at the global level raised by +3.09% from 3,487 kg/ha in 2020 to 3,595 kg/ha in 2024.

- The highest wheat yield was recorded in Germany 7,084.2 kg/ha, China 5,939.3 kg/ha, EU-27 5,279 kg/ha, Ukraine 4,595 kg/ha and India 3,559 kg/ha.

- In EU-27, the wheat harvested area was 22.609 Million ha in 2024, by 1.11% larger than in 2020.

-France, Germany, Poland, Romania and Spain cultivate together 9,458.2 Million ha, accounting for 41.8% of the EU total wheat area. Also, Italy, Bulgaria, Hungary, Lithuania and Czechia are wheat growers, and all these 10 member states together keep 65.8% of the EU-27 cultivated area with this crop.

- In the EU, wheat production decreased by 5.54% from 126.35 Million MT in 2020 to 119.36 Million MT in 2025.

-France, Germany, Poland, Romania, Spain and Bulgaria account for 61.5% of the EU wheat production.

- In the EU, yield declined by 4.4% in 2024, attaining 5,279 kg/ha compared to 5,526 kg/ha in 2020.

- Versus 2020, global wheat consumption increased by 5.7%, attaining 797 Million MT in 2025.

- The major consumers are China, India, the EU, Russian Federation, USA and Pakistan.

- The highest consumption per inhabitant is in Egypt 186.2 kg and Israel 131.2 kg.

- Average wheat price at the global level increased by 11.42% from USD 185.51/Ton in 2020 to USD 201.19/Ton in 2024.

- The exported wheat amount in 2024 at the global level accounted for 214.6 Million MT, being by y 16.44% higher than in 2020. Russia, the EU-27, Canada, USA, Australia and France are the major wheat exporting countries.

-The export value also went up by 19.37% registering USD 57.3 Billion in 2024.

-Global imported quantity registered a slight increase of only 1.02% from 196 Million MT in 2020 to 198 Million MT in 2024.

- Egypt, Indonesia, China, Algeria, Turkey, Bangladesh and the EU-27 are the main wheat importers.

- The EU is among the top 5 global wheat producers and the 2nd large exporter of wheat in the world.

- In 2025, the EU exported 26.25 Million tons wheat grains equivalent, by 31.27% less than in 2020.

- France, Germany, Poland, Romania and Lithuania are the top EU wheat exporters.

- The value of the EU wheat exports increased by +127% from Euro 1.18 Billion in 2020 to Euro 2.68 Billion in 2025.

-Italy, Spain, Slovenia, Ireland and Greece are the main EU wheat importers. The imported amount in the period 2020-2025 increased by +97.65% from 5.11 Million tons (grain equivalent) in 2020 to 10.10 Million tons in 2025.

- The EU wheat import value recorded an ascending trend from Euro 1.18 Billion in 2020 to Euro 2.68 Billion in 2025, meaning +235%.

Wheat future will be definitely marked by the

actual context linked to the restraining factors which could affect production, consumption, trade and food security.

The climate shocks will oblige farmers to move wheat cropping to the more favorable regions, to pass to adapted technologies which could mitigate the climate negative impact, to use more resistant varieties to drought, pest attack and diseases and with a higher production potential and to pay more attention to precision agriculture.

Rising input price is one of the big problems which could restrain the capacity to cover wheat technological requirements regarding high quality and certified seeds of top wheat varieties, fertilizers, pesticides, fuel, machinery. The most affected will be the small farmers who cannot the financial capacity to support higher input and production costs.

Environment quality conservation will impose restrains in using special categories of chemicals (fertilizers, pesticides etc) to reduce soil pollution, which could affect yield level. Therefore, conventional agricultural technologies will have to become more environment friendly.

More than this, organic agriculture is expected to be extended on a larger surface for obtaining healthier grains for humans and animals and diminish the pressure of pollution on the soil, water and air and preserve environment quality.

Water resource depletion will create difficulties to the farmers using irrigation systems and will grow water price. In the regions where climate extreme phenomena like higher temperatures, heat waves, longer droughts and low precipitations will be stronger, it is will be a higher risk of desertification with a negative impact of food security.

The Black Sea region, which is one of the most important supplier of wheat in the world is facing with the geopolitical instability caused by the conflict between Russia and Ukraine, which diminished the cultivated area, wheat yields and production and quality, damaged infrastructure, reduced storage, imposed new transportation routes, delays in wheat supply to importing countries, distortions in trade flows and disruptions in the wheat chain.

The tensions in the Middle East affect international trade with fuel and fertilizers, due to the blockade of maritime shipping through the Strait of Hormuz, increase transport and insurance costs and amplify fuel and fertilizers crisis which will cause disturbances in the agricultural production systems and affect food security.

Financial pressures on the importing countries caused by the wheat price volatility will spoil national budgets for covering the value of the imported amounts and also will determine the governments to offer aids for the poor population or to subsidize bread. This could happen in the countries from the North Africa, the Middle East and the Sub-Saharan area which are deeply dependent on wheat imports.

Changes in the imported wheat structure are expected to appear from the side of the import dependent countries, which would prefer to buy wheat raw grains instead of flour, to enhance the local milling industry to process them and in this way to diminish the acquisition costs.

All these aspects could affect the precision of the future estimations of the level of these indicators, but it is no doubt that wheat will continue to be produced and traded for better satisfying the population requirements all over the world.

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YIELD VARIABILITY OF WINTER WHEAT UNDER SOIL DROUGHT CONDITIONS IN DOBROGEA (ROMANIA)

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Abstract

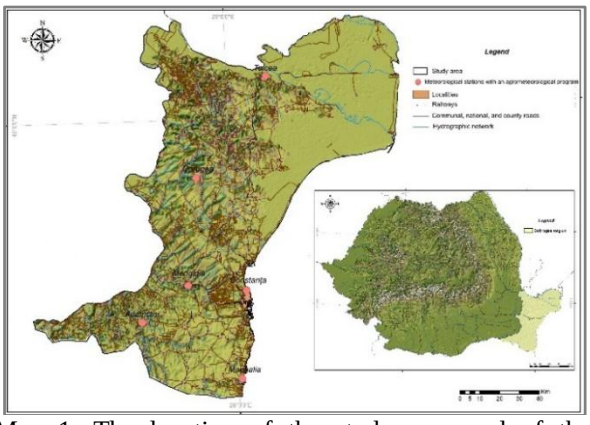
The production of winter wheat crops shows year-to-year fluctuations, being strongly influenced by variations in climatic conditions and by extreme weather events. In agriculture, one of the main meteorological phenomena that has a direct and irreversible impact on crops is drought. The study focuses on the analysis of winter wheat yields obtained during the period 1991–2023 under conditions of pedological drought in the Dobrogea region (Romania). For the purpose of this study, data on the average yield per hectare provided by the National Institute of Statistics were used and processed, as well as meteorological data on precipitation and monthly average air temperatures provided by the National Meteorological Administration. In addition, data on soil moisture reserves were processed, provided by the Agrometeorological Service of the National Meteorological Administration, for dry agricultural years (2002-2003, 2006-2007, 2019-2020). Such analyses are essential in agricultural management, providing farmers with precise tools to maximize agricultural yields by minimizing risks and improving the efficiency of pedoclimatic resource use.

Key words**:** *agricultural yields, agricultural management, pedological drought, climatic variability, Dobrogea region*

INTRODUCTION

Worldwide, winter wheat (*Triticum aestivum L.*) is one of the most important cultivated food crops and also an essential source for about 35% of the global population [14, 6]. The winter wheat crop cultivated in Romania is known for its very good baking quality, which allows it to be marketed both for domestic consumption and for export (both within and outside Europe) [7]. In Romania, winter wheat is more productive than spring wheat, and therefore it occupies 99% of the country's total arable land [13, 5]. Over time, winter wheat yields have been affected by various abiotic factors, among which the phenomenon of pedological drought can be mentioned. Drought is a meteorological phenomenon that is harmful to agriculture and directly affects the crop as well as its yields. This phenomenon occurs due to insufficient soil moisture and an increase in potential evapotranspiration [4]. Soil moisture is an important, but also limiting, factor for the growth and development of winter wheat. The analysis of pedological drought focuses on the soil water deficit, assessed by calculating the soil moisture reserve, which illustrates the soil's usable water capacity during the key vegetation periods of the winter wheat crop. The regions of Romania most affected by drought are South-West Oltenia, Southern Muntenia, the South-East, and the East of the country, where climate change, particularly droughts, is strong and severe [11]. The study area for which this research was conducted is Dobrogea (Map 1). It is located in the south-eastern part of Romania and covers 6.5% of the country's surface, with 60% of the region being occupied by agricultural land

[10]. Within the structure of this agricultural land, 80% consists of arable land, but due to long periods of drought, the development of large irrigated areas has become necessary [10]. The Dobrogea region is characterized as one of the areas most affected by drought, with high temperatures and low amounts of precipitation compared to the other regions of Romania [11].



Map 1. The location of the study area and of the meteorological stations with agrometeorological program analyzed
Source: own processing from GIS open sources.

The Dobrogea region is prone to a high level of drought, with drought periods lasting from four to six months [3], as in this part of Romania the average annual temperature exceeds 11°C and annual precipitation ranges between 351 and 450 mm [11].

MATERIALS AND METHODS

To highlight the variability of winter wheat yields obtained under conditions of pedological drought in the Dobrogea region (Romania), the values of average annual yield per hectare for the period 1991–2023, provided by the National Institute of Statistics (INS), were processed and analyzed. These data highlight the variation in yields in relation to the occurrence of pedological drought. To reflect the impact that pedological drought has on winter wheat yields, both tabular and cartographic analyses were carried out on the soil moisture reserve data recorded in the agricultural years 2002-2003, 2006-2007, and 2019-2020. These data were examined for the periods September-October (the autumn sowing period) and May-June (the period of maximum water demand for the winter wheat crop). These data were provided by the Agrometeorology Service within the National Meteorological Administration for six meteorological stations with agrometeorological program, Adamclisi, Constanța, Corugea, Mangalia, Medgidia, and Tulcea, which are considered representative for the study area. The data were centralized and tabulated using Microsoft Excel, and with the help of GIS techniques, the soil moisture reserves as well as the location of the study area were highlighted.

RESULTS AND DISCUSSIONS

Yields, as well as the areas cultivated with cereals, depend greatly on climatic resources, which play an extremely important role in crop quality. The yields of winter wheat are influenced by a series of factors, both meteorological and pedological. Plants require water throughout the entire vegetation period, from seed germination to full maturity; therefore, the onset of pedological drought over an extended period negatively affects crop yields.As a result, the analysis of winter wheat yields shows significant variability over the 1991-2023 interval, production does not follow a linear trend but increases sharply in one year only to decrease in the following year.

Agricultural production

At the level of the Dobrogea region, the analysis of the average yields of winter wheat (kg/ha) for the period 1991-2023 indicates that the year 2003 was a weak agricultural year in terms of the yields obtained, with a production of 296.0 kg/ha (Fig. 1).

The low yields recorded in this year were the result of prolonged drought throughout the year and the lack of efficient irrigation systems. The productivity of winter wheat is predominantly influenced by changes in the thermal regime, leading to significant annual yield fluctuations [12], as well as by low precipitation amounts. Alongside 2003, the years 2007 and 2020 also stand out, as they recorded the lowest winter wheat yields, namely 1,154 kg/ha in 2007 and 1,282 kg/ha in 2020.

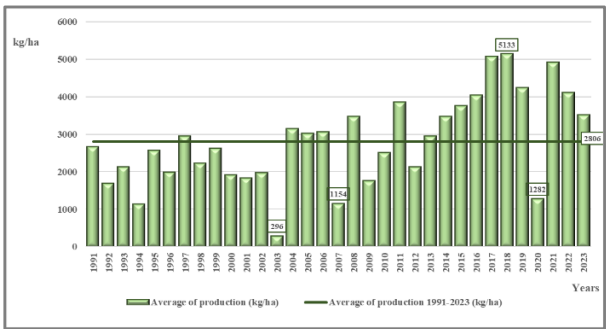


Fig. 1. The average production per hectare (kg/ha) of the winter wheat in the study area (1991-2023)
Source: processed data from NIS, 2025 [9].

The years considered extreme in terms of maximum air temperatures and the low amounts of precipitation recorded during the periods with the highest water requirements for winter wheat, namely, the years affected by drought, are the agricultural years 2002-2003, 2006-2007, and 2019-2020, which are regarded as some of the driest within the decades 2001-2010 and 2011-2020.

Across the entire analyzed region, the average yield obtained for the period 1991-2023 is 2,806 kg/ha.

The yield shows significant fluctuations, determined by climatic variability, and drought years are associated with substantial decreases in productivity, highlighting the vulnerability of agriculture to water deficit. Thus, the agricultural years 2002-2003, 2006-2007 and 2019-2020 coincide with a pronounced precipitation deficit, high temperatures, and water stress during the winter wheat vegetation period. These events generated significant effects on agriculture and the economy due to the severe water shortage [2]. The substantial reduction in wheat yields during these agricultural years occurred because of the shortening of the vegetation season, resulting from increased air temperatures and water stress during the grain-filling stage, caused by reduced precipitation amounts.

Soil moisture reserve

Drought develops when precipitation is absent or when recorded rainfall amounts fall below the long-term normal values established for a reference period. When the lack of precipitation persists and both air and soil temperatures are high, combined with low relative air humidity, the phenomenon of pedological drought sets in. Thus, for the analysis of the pedological drought phenomenon in the agricultural years 2002-2003, 2006-2007, and 2019-2020, the soil moisture reserve was examined for two key intervals of the winter wheat crop: September-October, corresponding to the autumn sowing period, and May-June, representing the interval with the crops maximum water requirements. This was calculated for soil depths of 0-20 cm (field) and 0-100 cm. The agrometeorological indicator, the soil moisture reserve, was calculated as a percentage relative to the soil's An assessment of Available Water Capacity (AWC) was conducted for the three analyzed agricultural years. The threshold values serving as reference criteria for generating and interpreting soil moisture reserve maps are summarized in Table 1 [8].

Table 1. Soil moisture reserve

Available Water Capacity (AWC) % of the Soil AWC	**Soil moisture condition**
0-20	Extreme pedological drought
20-35	Severe pedological drought
35-50	Moderate pedological drought
50-70	Satisfactory supply
70-85	Supply close to optimum
85-100	Optimum supply
>100	Excess moisture

Source: [8].

Analysis of drought-affected agricultural years

The analysis of the soil moisture reserve in the agricultural years 2002-2003, 2006-2007, and 2019-2020 (the years in which the lowest yields were recorded) was carried out during key vegetation intervals, namely September–October and May-June, in order to highlight the impact of the pedological drought phenomenon on winter wheat yields.

Agricultural year 2002-2003

On 30 September 2002, the soil moisture reserve in the Dobrogea region was within low and very low limits, with the drought phenomenon being pronounced (extreme and moderate pedological drought). The

occurrence of soil pedological drought throughout the entire agricultural region during the period of seedbed preparation for winter wheat sowing resulted in this operation being carried out under poor conditions (Fig. 2a). As a result of the amounts of precipitation recorded during October 2002, by the end of the month the soil moisture reserve had improved, and thus the soil water supply reached optimal values across the entire analyzed region (Fig. 2b).

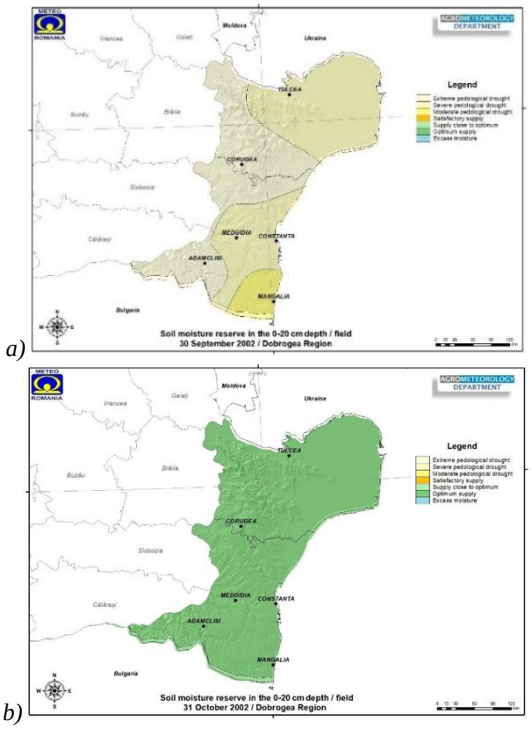


Fig. 2. Soil moisture reserves in the 0–20 cm layer for winter wheat on September 30 (a) and October 31 (b), 2002, Dobrogea region.
Source: processed data from Agrometeorology Department, NMA, 2026 [1].

The amounts of precipitation that fell during May 2003 maintained the soil moisture reserve within satisfactory supply limits in the southern (Adamclisi, Mangalia), eastern (Constanța), and western parts of the Dobrogea region (Corugea) (Fig. 3a). In the central and northern parts of the region, namely at meteorological stations with agrometeorological programs of Corugea and Tulcea, the soil moisture reserve was within low and very low limits. At the end of June 2003, the soil moisture content in the 0–100 cm soil layer under winter wheat cultivation exhibited very low values throughout Dobrogea, indicating the occurrence of severe pedological drought conditions (Fig. 3b).

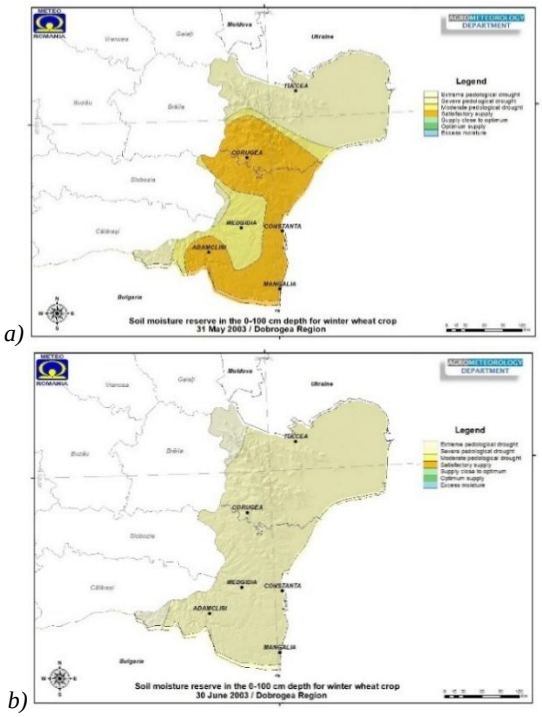


Fig. 3. Soil moisture reserves in the 0–100 cm soil layer under winter wheat on May 31 (a) and June 30 (b), 2003, Dobrogea region.
Source: processed data from Agrometeorology Department, NMA, 2026 [1].

Agricultural year 2006-2007

Compared to the previous year, during September and October 2006, over almost the entire agricultural area analyzed, soil moisture conditions varied between satisfactory and optimal supply. Toward the end of September 2006, precipitation contributed to comparable conditions across most of Dobrogea, with local occurrences of excess soil moisture in the central and southern sectors (Fig. 4a). The soil moisture excesses recorded in September may create unfavorable conditions for seedbed preparation and for winter wheat sowing, as they hinder soil tillage operations. At the end of October 2006, the soil water content showed satisfactory values at the stations with agrometeorological program in Adamclisi, Mangalia, Constanța, and Corugea. At the stations with agrometeorological program in Tulcea and Medgidia, compared to the previous month, the soil moisture reserve declined reflecting a moderate pedological drought conditions (Fig. 4b).

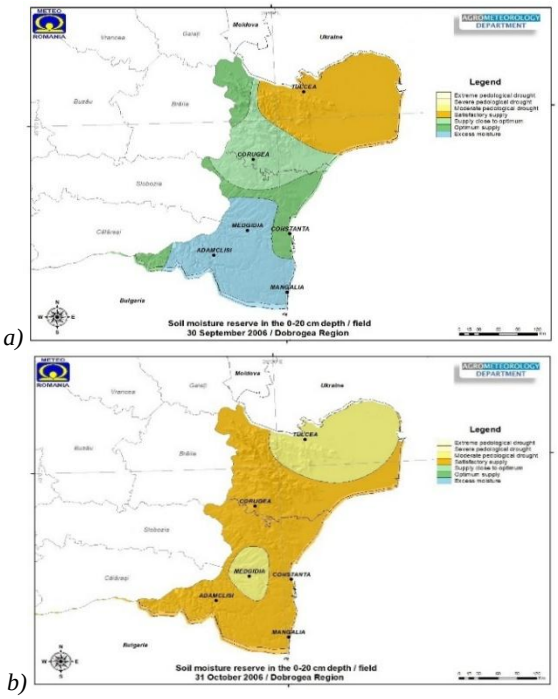


Fig. 4. Soil moisture reserves in the 0–20 cm layer for winter wheat on September 30 (a) and October 31 (b), 2006, Dobrogea region.
Source: processed data from Agrometeorology Department, NMA, 2026 [1].

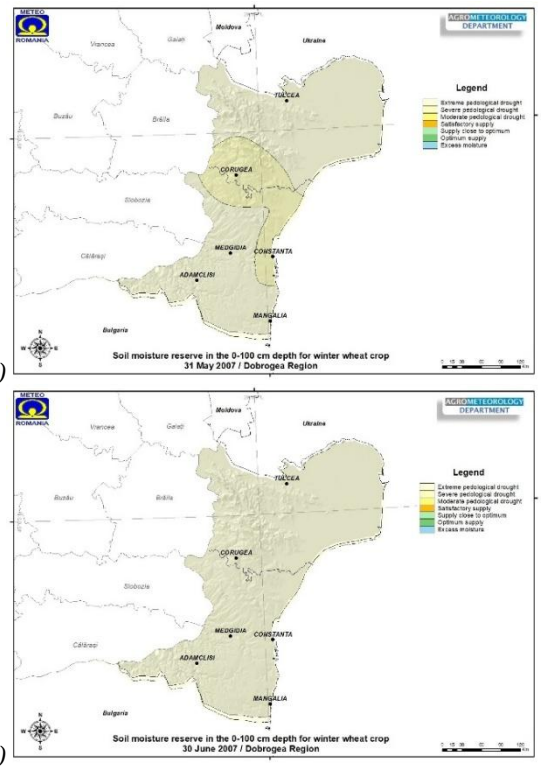


Fig. 5. Soil moisture reserves in the 0–100 cm soil layer under winter wheat on May 31 (a) and June 30 (b), 2007, Dobrogea region.
Source: processed data from Agrometeorology Department, NMA, 2026 [1].

During the 'critical' period in terms of thermal-pluvial requirements, namely the May–June interval, in the year 2007, the soil moisture content was within very low limits, causing the onset of severe to extreme pedological drought across the entire agricultural region (Fig. 5a and 5b).
As a result, direct effects were produced on the physiological processes of winter wheat.

Agricultural year 2019-2020

The agricultural year 2019-2020 began with a soil moisture reserve which, at the end of September 2019, fell within low values in the northern, south-western, and central parts of the region. Pedological drought was both severe and extreme, driven by deficient precipitation amounts at the stations with agrometeorological program Adamclisi, Medgidia, and Tulcea were analyzed, while the Constanța and Mangalia stations, located in the eastern and south-eastern regions, exhibited satisfactory to optimal soil moisture supply (Fig. 6a).

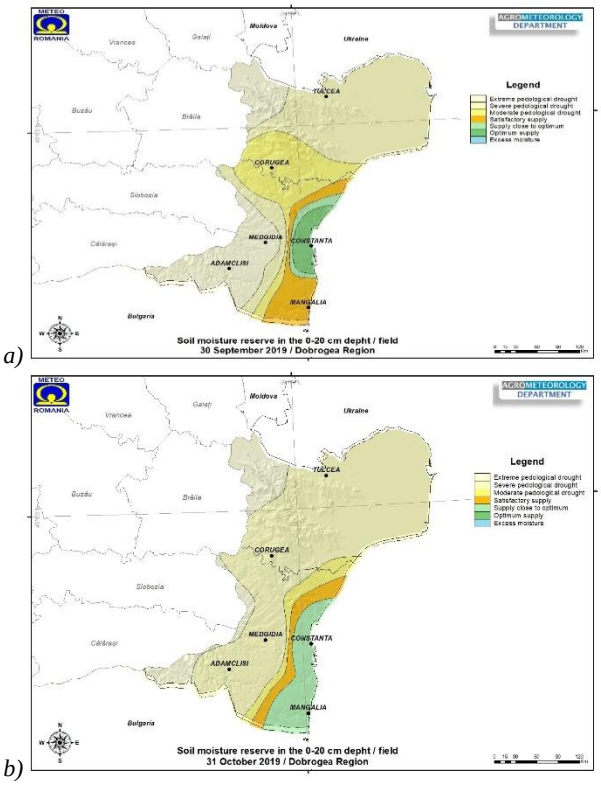
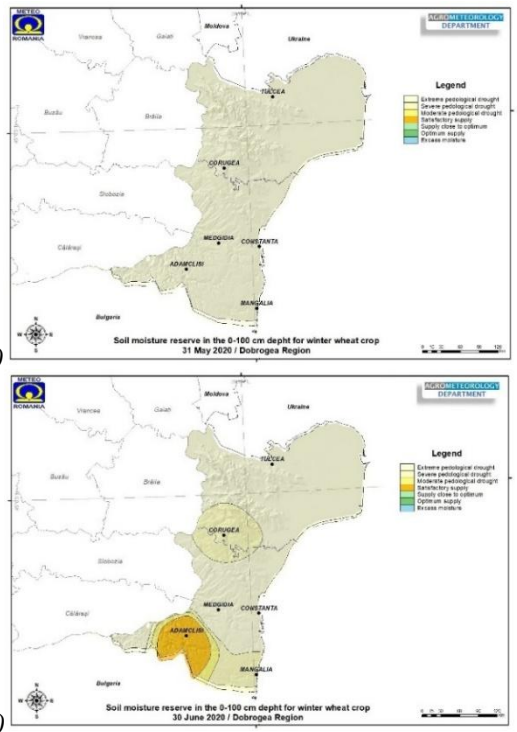


Fig. 6. Soil moisture reserves in the 0–20 cm layer for winter wheat on September 30 (a) and October 31 (b), 2019, Dobrogea region.
Source: processed data from Agrometeorology Department, NMA, 2026 [1].

Toward the end of October 2019, pedological drought conditions largely persisted at levels comparable to those recorded in September, apart from the Constanța and Mangalia stations with agrometeorological program, where the soil moisture reserve was supply close to optimum at both stations (Fig. 6b).

During the May-June period, the soil moisture reserve recorded in the Dobrogea region was extremely low, with pedological drought being severe and extreme. The end of May 2020 was marked by the persistence of pedological drought across the entire study area (Fig. 7a). At the end of June 2020, the soil water supply showed satisfactory values at only one of the six meteorological stations with agrometeorological program, namely Adamclisi; at the other meteorological stations with agrometeorological program, severe and extreme pedological drought persisted (Fig. 7b).



a)

b)

Fig. 7. Soil moisture reserves in the 0–100 cm soil layer under winter wheat on May 31 (a) and June 30 (b), 2020, Dobrogea region.
Source: processed data from Agrometeorology Department, NMA, 2026 [1].

The uneven distribution of precipitation amounts recorded during the agricultural years September 2002-August 2003, September 2006-August 2007, and September 2019-August 2020 led to the persistence and even the intensification of the soil water deficit in September and October (the autumn sowing period). During the months with maximum water demand for winter wheat (May-June), pedological drought manifested with varying degrees of intensity (moderate, severe, and extreme pedological drought), with extreme pedological drought being predominant in all agricultural years. The pedological drought phenomenon, recorded at maximum intensities, caused significant impairments to the winter wheat crops sown across the Dobrogea region, such as delays in sowing, delays in the milk, dough, and full-maturity stages, as well as delays in harvesting. All these phenomena had negative consequences on the yields obtained in all these years, a fact also illustrated in the analysis of agricultural production in the years 2003, 2007, and 2020.

Péguy Climograms

To highlight in detail the thermo-pluviometric characteristics of the months, Péguy Climograms were produced, which classify the months of the year as frosty, cold and wet, temperate, warm and wet, as well as arid. Thus, Péguy Climograms were created for the years 2003, 2007, and 2020, the years with the lowest yields recorded during the 1991-2023 period. For improved visualization at the level of each meteorological station with an agrometeorological program in the Dobrogea region, climograms were developed. These were based on monthly mean air temperature values and corresponding monthly precipitation amounts recorded for each analyzed year at the respective stations (Tables 2, 3, and 4).

Table 2. Monthly air temperature averages (°C) and precipitation amounts (mm) at meteorological stations with agrometeorological programs in 2003.

Meteorological stations with agrometeorological program	Average monthly air temperature (°C)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual Average
Adamclisi	-0.2	-4.8	1.9	8.3	19.1	22.5	22.7	23.8	15.9	10.8	7.4	1.2	10.7
Constanța	1.0	-2.8	2.8	7.7	17.9	22.4	23.1	24.2	17.6	12.3	8.7	3.2	11.5
Corugea	-1.4	-5.0	1.2	8.2	18.9	21.9	22.5	23.3	15.7	9.8	6.2	0.3	10.1
Mangalia	1.6	-3.0	2.5	7.5	16.5	21.7	22.2	23.6	17.2	12.2	8.4	3.3	11.1
Medgidia	-0.3	-4.3	2.1	8.3	19.2	22.5	22.5	23.6	15.9	10.8	7.6	1.4	10.8
Tulcea	-1.0	-4.5	2.1	8.9	19.6	22.4	22.7	23.5	16.0	10.8	7.4	1.4	10.8
Dobrogea average	-0.1	-4.1	2.1	8.2	18.5	22.2	22.6	23.7	16.4	11.1	7.6	1.8	10.8
Meteorological stations with agrometeorological program	Monthly precipitation amounts (mm)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual total amounts
Adamclisi	55.8	37.2	32.5	39.5	19.0	10.4	61.6	2.6	128.0	88.0	23.7	35.1	533.4
Constanța	53.0	14.9	16.9	25.4	5.2	9.1	32.9	0.2	80.1	63.7	25.5	23.3	350.2
Corugea	56.4	21.0	6.8	26.2	28.6	16.7	69.0	17.8	83.7	38.7	14.1	19.6	398.6
Mangalia	46.1	15.3	31.0	22.0	7.2	11.8	20.8	26.6	119.8	103.2	24.5	26.5	454.8
Medgidia	35.8	12.1	19.1	21.9	8.4	16.2	121.3	51.8	126.9	51.8	14.9	27.3	507.5
Tulcea	51.6	37.7	9.8	29.6	7.0	10.4	97.5	15.8	40.0	40.2	17.8	40.1	397.5
Dobrogea average	49.8	23.0	19.4	27.4	12.6	12.4	67.2	19.1	96.4	64.3	20.1	28.7	440.3

Source: NMA, processed data (2026).

Table 3. Monthly air temperature averages (°C) and precipitation amounts (mm) at meteorological stations with agrometeorological programs in 2007.

Meteorological stations with agrometeorological program	Average monthly air temperature (°C)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual Average
Adamclisi	5.7	3.6	6.9	10.4	17.7	23.3	25.7	23.8	16.8	12.4	4.7	0.2	12.6
Constanța	6.5	4.8	7.7	11.0	16.9	23.0	25.2	24.5	18.2	14.0	7.1	2.1	13.4
Corugea	3.8	2.4	6.1	10	17.4	22.8	25.0	23.9	16.2	12.0	4.0	-0.4	11.9
Mangalia	6.6	4.7	7.1	10.2	16.0	21.9	24.2	24.1	17.7	13.8	7.1	2.1	13.0
Medgidia	5.3	3.7	7.0	10.3	17.5	23.3	25.6	23.9	17.0	12.6	5.1	0.5	12.7
Tulcea	5.3	3.2	7.0	11.4	18.3	23.2	25.7	24.2	17.2	12.2	5.3	1.3	12.9
Dobrogea average	5.5	3.7	7.0	10.6	17.3	22.9	25.2	24.1	17.2	12.8	5.6	1.0	12.8
Meteorological stations with agrometeorological program	Monthly precipitation amounts (mm)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual total amounts
Adamclisi	39.8	19.6	28.8	39.0	22.4	21.4	3.4	66.6	57.8	63.6	86.5	56.8	505.7
Constanța	28.1	16.4	35.2	21.2	19.2	21.4	4.0	84.4	54.8	53.4	107.8	47.8	493.7
Corugea	24.1	24.4	43.2	32.9	14.5	37.1	4.9	20.3	41.2	69.6	77.7	40.0	429.9
Mangalia	19.6	15.7	23.1	20.4	23.4	39.0	5.2	94.4	53.2	60.6	68.5	57.2	480.3
Medgidia	44.0	14.3	29.9	20.6	21.8	34.6	2.0	60.0	42.6	84.2	80.5	47.6	482.1
Tulcea	26.9	19.7	37.8	20.4	12.0	36.6	1.6	47.8	55.4	81.8	74.1	94.2	508.3
Dobrogea average	30.4	18.4	33.0	25.8	18.9	31.7	3.5	62.3	50.8	68.9	82.5	57.3	483.3

Source: NMA, processed data (2026).

Table 4. Monthly air temperature averages (°C) and precipitation amounts (mm) at meteorological stations with agrometeorological programs in 2020.

Meteorological stations with agrometeorological program	Average monthly air temperature (°C)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual Average
Adamclisi	1.1	5.2	8.2	11	16.3	21.1	23.9	24.3	20.5	15.9	6.1	5.2	13.2
Constanța	3.2	6.4	8.9	10.7	16.0	21.1	24.6	24.9	21.6	17.2	8.1	6.9	14.1
Corugea	0.9	3.6	7.4	10.3	15.1	20.7	23.7	23.9	20.3	15	5.6	4.5	12.6
Mangalia	3.0	6.1	8.3	10.0	15.1	20.3	24.1	24.5	21.3	17.1	8.2	7.2	13.8
Medgidia	1.7	5.2	8.2	11	16.7	21.7	24.6	24.7	20.8	16.3	6.1	5.7	13.6
Tulcea	2.1	5.6	9.1	11.6	16.2	22.1	24.2	23.8	20.0	16.1	6.2	5.2	13.5
Dobrogea average	2.0	5.4	8.4	10.8	15.9	21.2	24.2	24.4	20.8	16.3	6.7	5.8	13.5
Meteorological stations with agrometeorological program	Monthly precipitation amounts (mm)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual total amounts
Adamclisi	0.2	61.4	19.4	11.6	49.2	131.8	32.0	9.0	33.8	25.4	44.8	53.1	471.7
Constanța	1.7	28.9	15.6	3.8	15.3	55.5	28.9	7.3	14.7	14.1	20.6	72.4	379.8
Corugea	5.3	26.3	3.2	14.8	54.2	104.8	13.4	9.8	34.2	36.6	27.8	49.4	278.8
Mangalia	1.7	40.5	15.3	3.8	44.1	12.2	36.2	15.0	9.4	11.2	19.1	67.6	276.1
Medgidia	1.2	32.3	4.5	7.2	15.6	66.4	14.4	0.4	16.2	13.4	24.0	57.8	253.4
Tulcea	4.0	43.3	3.3	2.4	44.4	20.9	38.3	0.0	15.8	33.8	44.7	58.1	309.0
Dobrogea average	2.4	38.8	10.2	7.3	37.1	65.3	27.2	6.9	20.7	22.4	30.2	59.7	328.1

Source: NMA, processed data (2026).

Figures 9–11 show the Péguy climograms for six meteorological stations with agrometeorological programs in Dobrogea, corresponding to years with the lowest winter wheat yields.

Following the analysis of the Péguy Climograms for the years 2003 (Fig. 8) and 2007 (Fig. 9), it can be observed that the months classified as arid were May, June, July, and August.

The cold and wet months were January, February, and December. The months of May-June correspond to the critical period regarding the water requirements of the winter wheat crop, with the climograms highlighting pronounced water stress during this interval. This situation had negative consequences on the winter wheat crops, leading to grain shriveling and, consequently, to substantial yield losses.

In July, the month in which winter wheat normally reaches full maturity and enters the harvesting stage, the crop is affected by high temperatures and precipitation deficits, resulting in forced maturation, shriveled grains, and even premature harvesting.

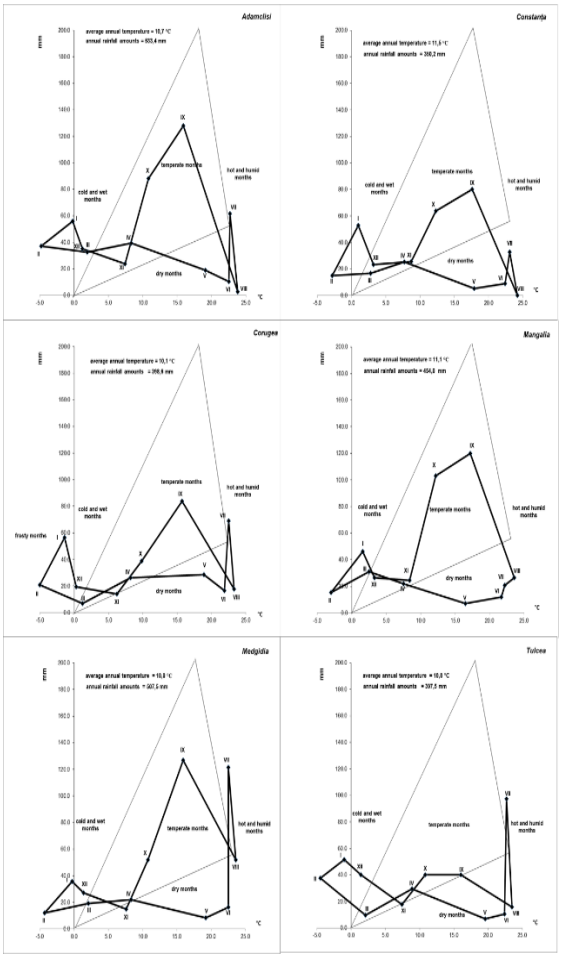


Fig. 8. Péguy climograms for the analyzed meteorological stations with agrometeorological programs, 2003.
Source: processed data from NMA, 2026.

August 2003, a month in which soil stubble-breaking and shredding operations are normally carried out, was affected by pedological drought and high temperatures, causing the failure of seedbed preparation for the sowing of winter wheat crops for the upcoming agricultural year.

Following the analysis of the Péguy Climograms for the year 2020 (Fig. 10), it can be observed that the winter months were classified as temperate, in contrast to the previous years, in which they had been classified as cold and wet.

The months classified as arid from a thermal and hydric perspective are February (at the meteorological stations with agrometeorological program in Constanța and Mangalia), and for the Constanța station this category also includes March, April, May, June, July, August, September, and, in certain cases, even November.

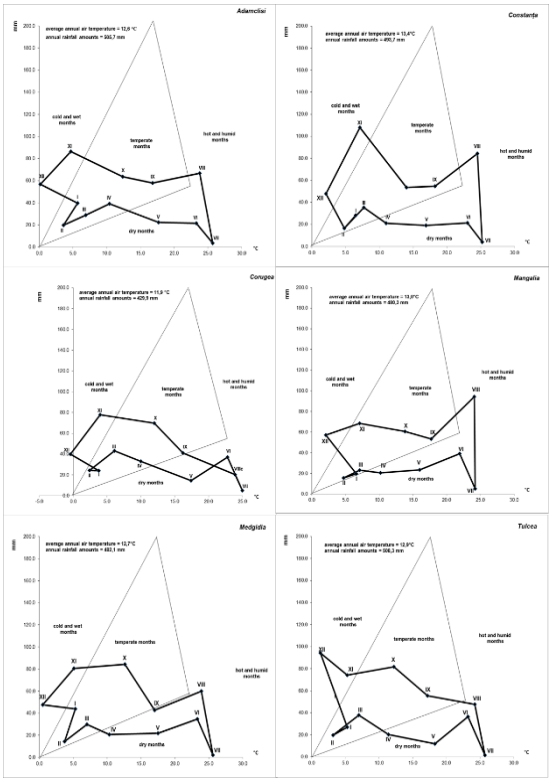


Fig. 9. Péguy climograms for the analyzed meteorological stations with agrometeorological programs, 2007.
Source: processed data from NMA, 2026.

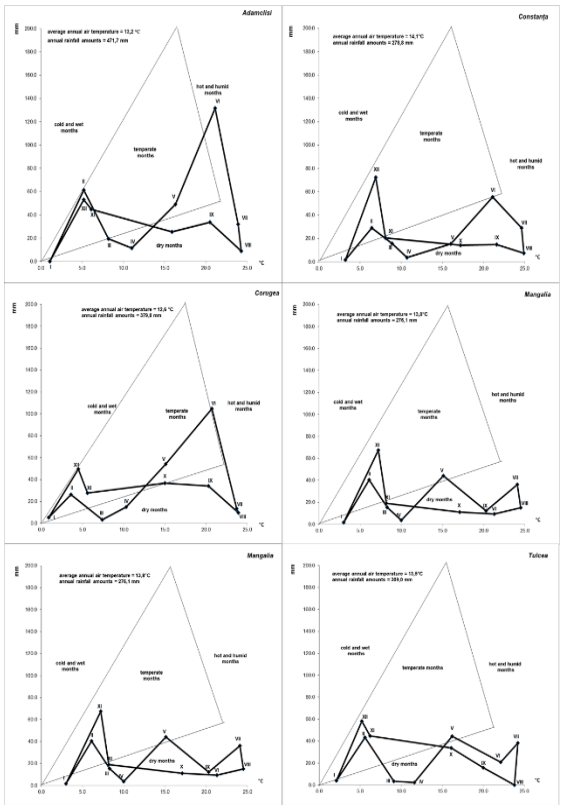


Fig. 10. Péguy climograms for the analyzed meteorological stations with agrometeorological programs, 2020.
Source: processed data from NMA, 2026.

During 2020, arid conditions prevailed throughout most of the year, reflecting both moisture deficits and elevated thermal regimes. Relative to the years 2003 and 2007, the later stage of the 1991–2023 interval exhibited a decline in precipitation totals alongside an increase in average air temperatures. These climatic changes contributed to unusually mild winter months and a higher number of months classified as arid. Under these circumstances, the normal development of winter wheat phenological stages was constrained, given that precipitation represents a major controlling factor of vegetative growth, alongside air temperature. Furthermore, insufficient seedbed preparation and postponed or hindered sowing activities negatively affect the successful establishment of the crop prior to the cold period. The atmospheric precipitation recorded during the May–June interval, the period in which winter wheat has its highest water requirements has the greatest effect on the growth and development of the crop. The amounts recorded during this interval were deficient across the Dobrogea region in the years 2003, 2007, and 2020, which created unfavorable conditions for the progression of the heading, flowering, grain formation, and grain filling stages

CONCLUSIONS

In this study, the average winter wheat yields obtained in the Dobrogea region during the 1991-2023 period were analyzed in relation to the influence of pedological drought.
The analysis of the average yield (kg/ha) shows that the lowest yields were recorded in the years 2003, 2007, and 2020.
The agricultural years 2002-2003, 2006-2007, and 2019-2020 at the end of which the lowest yields in the Dobrogea region were obtained are considered among the driest agricultural years within the decades 2001-2010 and 2010-2020.
From the perspective of soil moisture reserves, although the soil water supply showed satisfactory supply, supply close to optimum, optimum supply, and even excess moisture and locally low and very low values

at the beginning of the analyzed agricultural years (September-October), over the analyzed interval, soil moisture reserves declined markedly in May–June, reaching levels indicative of moderate, severe, and extreme pedological drought conditions. The months of May and June coincide with the critical phenological stage characterized by the highest water requirements of winter wheat. Under these conditions, water deficits caused impairments to winter wheat crops in the Dobrogea region, including delays in the milk, dough, and full maturity stages, as well as postponed harvesting. All these phenomena had a negative impact on the yields obtained in the analyzed years.

Based on the analysis of the Péguy Climograms, produced to reflect the thermo-pluviometric characteristics of the months, it can be observed that air temperature shows an upward trend and precipitation amounts a downward trend in the year 2020 compared to 2003 and 2007. Most months display distinct thermo-pluviometric characteristics, with the number of arid months increasing in 2020, while cold and wet months are no longer recorded, becoming instead temperate from both a thermal and hydric perspective. For maximizing agricultural yields, it is necessary to conduct a detailed study of both thermal and water resources, as this analysis is essential for optimally coordinating crops while taking into account the meteorological conditions of each period or each year.

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THE FUTURE OF EUROPEAN INVESTMENT POLICY FOR RURAL DEVELOPMENT IN BULGARIA

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Abstract

This article examines the future of European investment policy for rural development in Bulgaria in the context of the reformed Common Agricultural Policy (CAP) and the European Union's strategic priorities for sustainable growth. The analysis focuses on investments financed through EU funds as key instruments for modernising agricultural holdings, supporting small and medium-sized farms, and fostering innovation in rural economies. Particular attention is given to structural challenges of Bulgarian rural regions, including demographic decline, farm fragmentation, and limited investment capacity. The methodology is based on a review of EU and national strategic documents, combined with an analysis of relevant statistical indicators. In conclusion, the study emphasizes the need for more targeted, flexible, and locally adapted investment instruments to enhance policy effectiveness. The paper underlines that successful rural development in Bulgaria depends on efficient fund management and greater engagement of local stakeholders.

Key words**:** *Common Agricultural Policy, sustainability, investments, rural development, investment policy, operational programmes*

INTRODUCTION

The Changing Context of European Investment Policy

A key question is whether the European Union truly learned from the missteps of its previous programming periods. We are currently facing a radically altered political landscape and ongoing shifts in global economic power. Because of this, the next few years will completely redefine the architecture of Europe's investment framework. As Mario Draghi (2024) [1] recently pointed out, if Europe wants to maintain stability, kickstart productivity, and stay competitive in a transformed world, it desperately needs to strengthen entirely new policy areas.

The real test for the European Commission is whether it can finally put regional development at the center of its strategy [2]. For far too long, rural areas have been treated as an afterthought seen as peripheral beneficiaries rather than essential engines of long-term growth. Leaving these territories structurally underdeveloped directly limits the whole Union's ability to grow evenly. This vulnerability is especially glaring today, given geopolitical friction, trade wars, and the gradual decline of Europe's traditional industrial heavyweights.

Naturally, this renewed attention forces us to look back at the actual track record of Common Agricultural Policy (CAP) [5] and the actual implementation of programmes for rural development and their absorption of funding. What have they really achieved when it comes to shrinking regional wealth gaps? Why is Brussels suddenly pivoting so hard back to these areas? It makes you wonder if policymakers are quietly admitting to past planning failures, or if they are simply scrambling to adapt to new economic and environmental shocks.

For Bulgaria, this is not just a theoretical debate. The country suffers from stark regional divides [9, 12], with rural areas acting as ground zero for an array of crises—from rapid demographic collapse to stubborn productivity gaps (Y. Yarkova, 2007) [16]. We are standing at a critical crossroads. If European investment policy genuinely adopts a stronger territorial focus, it could hand Bulgaria the exact catalyst it needs to catch up

economically and diversify local industries beyond basic farming.

But that money won't manage itself. Success depends entirely on Bulgaria's own ability to actually design and pull off smart, localized projects. Plus, as a Eurozone member, the country operates under strict macroeconomic pressure to maintain fiscal discipline and push structural reform. In this environment, absorbing European funds isn't just about ticking administrative boxes—it has to act as a real, strategic lever for long-term stability and growth within the monetary union.

This article aims to highlight the need to rebuild the current investment framework for rural areas at the EU level, particularly in Bulgaria, so that these areas can have equal opportunities for development in the future. It focuses on the importance of providing targeted support to rural areas not only through direct payments but also through investments in policy reforms that can have a long-term impact. The analysis will be based on the results of the assessment of the level of absorption of EU funds at both the national and European levels, with particular attention to programmes related to rural development and overall spending under the Common Agricultural Policy, one of the main pillars supporting rural areas. It will also examine the problems and implications associated with the level of fund absorption and explore how the new investment policy framework could contribute to the economic development of rural areas. The scientific contribution of this study lies in providing timely information on the effectiveness of the current rural investment framework and in assessing whether a revision of the management system is needed. This strategy could serve as a cornerstone for more comprehensive territorial investment strategies and to guide future policy reforms.

MATERIALS AND METHODS

The analysis covers the period from 1980 to 2024, with a particular emphasis on the programming periods of 2007–2013, 2014–2020, 2021–2027, and the planned 2028–2034 framework for the Common Agricultural Policy (CAP) and related rural development programmes. Spatial coverage includes all 215 rural municipalities in Bulgaria, representing the majority of the country's rural population. The study uses sources of information like the National Statistical Institute (NSI) of Bulgaria, European Structural and Investment Funds (ESIF) data in Bulgaria to evaluate fund allocation, contracting, and absorption rates, European Union budget and CAP documents, studies on rural development, agricultural policy, and regional economics. The methods that were used could be classified as:

-Statistical analysis to track trends in budget allocations, fund absorption, demographic change, and economic development in rural areas.

-Comparative analysis between programming periods to identify improvements or persistent gaps in fund utilization.

-Time series analysis of CAP expenditure and absorption rates to evaluate efficiency and temporal patterns.

-Cross-sectional analysis at municipal level to assess regional disparities and identify the most vulnerable areas.

RESULTS AND DISCUSSIONS

Evolution of EU Rural Development Policy

Track the CAP budget from 1980 to 2024, and you'll spot an interesting paradox. In absolute numbers, spending has undoubtedly climbed from a modest €13 billion back in the 1980s to somewhere between €65 and €68 billion today. Given the massive expansion of the EU itself and the rollout of new policy tools, that increase makes perfect sense. But look at the CAP's actual slice of the total EU budget pie, and the picture changes entirely. During the early 1980s, agriculture devoured almost two-thirds of all European spending. By the 2000s, that figure dropped to half. Post-2010, it sank to roughly a quarter.

What this divergence tells us is that Brussels has fundamentally rewritten its priorities. Huge streams of funding are now flowing into climate transition, cohesion policy, and tech innovation. The CAP is still a massive financial beast, of course. Yet, as the Union's

agenda grows increasingly complex, agriculture simply doesn't dominate the room the way it used to.

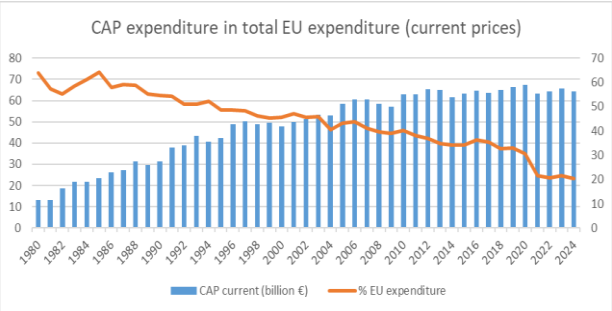

Fig. 1. CAP expenditure development
Source: European commission, 2024 [4].

Expenditure of the Common Agricultural Policy (CAP) is funded within the multiannual financial framework for the years 2021-2027 as provided for in Council Regulation (EU, Euratom) 2020/2093[1].

Looking at the 2021–2027 framework, spending under Heading 3 (Natural Resources and Environment) stays remarkably flat, hovering tightly between €53 and €56 billion a year (Table 1).

The vast majority of those funds around €40 to €41 billion annually is pumped straight into direct payments and market interventions.

Table 1. 2021–2027 framework, spending under Heading 3 Natural Resources and Environment (in EUR million; current prices)

Heading 3*	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**
Total	55,713.0	53,365.9	53,626.9	53,757.9	53,890.9	54,021.9
of which:						
-Market related expenditure and direct payments, a), b), c), d)	40,368.0	40,638.2	40,692.2	40,602.1	40,528.9	40,541.2
-Rural development a), b), c)	15,345.0	12,727.7	12,934.7	13,155.8	13,226.0	13,331.7

Source: European commission, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52025DC0519 [7].

Rural development gets what's left, usually scraping by with €12.7 to €15.3 billion. The takeaway here is undeniable. Despite all the talk about structural reform, the CAP is still essentially a giant income-support machine. Genuine investments aimed at transforming the physical and economic fabric of rural regions remain surprisingly limited.

Fast forward to the planned 2028–2034 period, and it looks like the EU is gearing up for a massive consolidation [6]. Policymakers want to merge the existing CAP instruments into a single, unified fund. With an eye-watering €295.7 billion earmarked primarily for income support, alongside a €6.3 billion crisis reserve to cushion against market shocks, the CAP will definitely hold its ground. By blending the two current funds together, Brussels hopes to finally achieve some strategic coherence and cut down on waste.

We are also hearing big promises about slashing red tape. For years, the suffocating bureaucracy of EU funding has been a nightmare for farmers, particularly the smaller ones who don't have teams of accountants at their disposal (Pe'er et al., 2020) [13]. The proposed reforms aim to shift away from strict, penalty-driven compliance rules and move toward a performance-based model. If it works, farmers will be rewarded for actual, measurable results. The upcoming policy rhetoric strongly favors boosting on-farm investments and turning rural communities into localized engines of economic resilience. Plus, the 2028–2034 framework suggests that regions will be handed far more control through National and Regional Partnership Plans.

European Investment Support and Financial Constraints in Rural Bulgaria

If you trace the flow of European money into Bulgaria's rural areas, it's obvious just how heavily the country has leaned on the European Agricultural Fund for Rural Development since joining the bloc in 2007.

During the first major cycle (2007–2013), the Rural Development Programme was practically the only heavy-duty tool available to fix deep territorial imbalances. The initial strategy wasn't complicated: improve basic living conditions in villages and give locals a way to make money outside of farming. Roughly €1.04 billion about 41% of the total budget went straight into local infrastructure, services, and non-agricultural businesses.

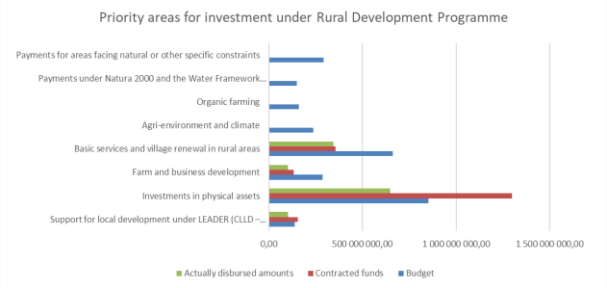

Fig. 2. Priority areas for investments
Source: UMIS 2020 – Unified Management Information System 2020 [15].

The other big priority was dragging the farming and forestry sectors into the modern age. Around €933.5 million (36% of the pot) was allocated for new tech, modernization, and productivity upgrades. It was a classic dual-track approach: trying to structurally reinvent the rural economy while simultaneously supercharging the traditional primary sectors (Fig. 2).
But having money allocated on a spreadsheet is very different from actually spending it. Bulgaria struggled immensely. Contracting hit massive delays early on, and a huge gulf opened up between the money planned and the money utilized. By the end of that first programming period, barely half the funds were even contracted. The share of money that actually landed in beneficiaries' bank accounts was much worse. The culprits were obvious: overly complex procedures, crippling administrative bottlenecks, and a glaring lack of local know-how meant that many municipalities simply couldn't put a viable project together. Although the implementation of rural development investments in Bulgaria during the programming period 2007–2013 initially progressed relatively slowly, with delays in project contracting and the early stages of fund absorption, the overall performance improved significantly in the later years of the programme. This initial underperformance can be linked to several factors, including limited administrative capacity in both the public and private sectors, the novelty and complexity of the procedures, and the limited experience of beneficiaries in preparing and managing EU-funded projects. In addition, many projects were implemented within contractual timeframes of two to three years after signing, which postponed the bulk of payments to later stages of the programming cycle. As a result, disbursements increased substantially over time, and by 2016 official reports indicated that more than 90% of the allocated budget under the Rural Development Programme had ultimately been absorbed. This suggests that despite the slow start, the programme achieved a relatively high final absorption rate once implementation capacity improved.

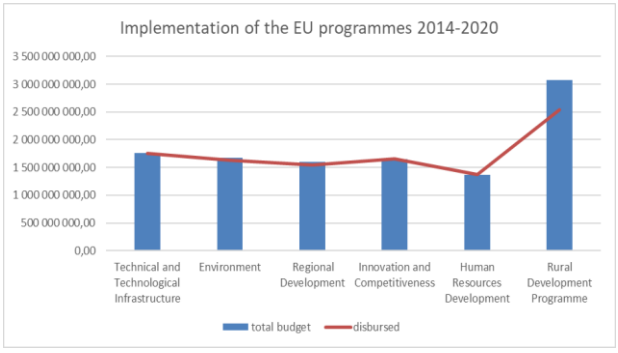

Fig. 3. Implementation of the Operational programmes in Bulgaria for the period 2014-2020
Source: UMIS 2020 – Unified Management Information System 2020 [15].

Moving into the 2014–2020 window, rural development remained the star of the show (Fig. 3). It gobbled up almost 25% of Bulgaria's total European Structural and Investment Funds (ESIF) budget. The state clearly viewed EU cash as the ultimate defibrillator for its rural economies. But again, a massive budget means absolutely nothing if the institutions are too sluggish to distribute it and local stakeholders don't know how to navigate the system.
This brings us to a massive, ongoing roadblock: access to capital. The credit market in rural Bulgaria is fundamentally broken. Small and medium-sized farms, especially

those out in the periphery, are virtually locked out of commercial bank financing. If you don't own prime real estate or high-value assets to put up as collateral, banks usually won't even look at you. Without that external cash, farmers cannot modernize, upgrade their tech, or expand their operations.

Early assessments of the 2014–2020 programme highlighted exactly who was getting squeezed the hardest. Take livestock farms, for instance. Banks label them as high-risk borrowers. As a result, they get hit with punishing interest rates, which completely kills their ability to invest in better productivity, animal welfare, or green compliance.

The barriers don't stop there. Innovation hubs and producer groups constantly struggle to secure outside funding for new projects. And the situation for young farmers trying to break into the industry is uniquely grim. With zero credit history and no collateral, their borrowing capacity is practically non-existent. This financial chokehold is the main reason we aren't seeing a new generation take over Bulgarian agriculture.

Then COVID-19 hit, blowing the lid off these structural vulnerabilities. Farms suddenly found themselves completely starved of cash. The pandemic proved that long-term investment loans aren't enough—agricultural producers desperately need flexible, short-term working capital just to keep the lights on when markets crash.

All of this underscores exactly why European investment policy needs to get creative with targeted financial tools. We need blended finance schemes, guarantee facilities, and preferential loan arrangements to bridge the gaps where commercial banks fail. This aligns perfectly with the reformed 2023–2027 CAP, which is supposedly pushing hard for smarter, performance-based support to build real resilience.

Current State of Rural Areas in Bulgaria

What exactly counts as "rural" in Bulgaria? According to the new national definition, it's any municipality where the largest settlement has fewer than 15,000 residents. By that standard, a staggering 215 of Bulgaria's 265 municipalities fit the bill. Geographically speaking, the country is overwhelmingly rural.

Yet, these areas are emptying out at a terrifying speed [8]. Rural depopulation here isn't just a trend; it's a full-blown demographic crisis [3]. It's driven by a brutal combination of low birth rates, high mortality, and massive out-migration. As K. Petrov (2021) [14]. pointed out, migration is undeniably the biggest factor hollowing out the countryside.

Fast forward to 2024, and Bulgaria's total population sits at roughly 6.43 million, weighed down by a stubbornly negative natural growth rate (Fig. 4). The countryside is aging much faster than the cities. Out in the villages, the average age is 47.6 years, noticeably older than the urban average of 44.5.

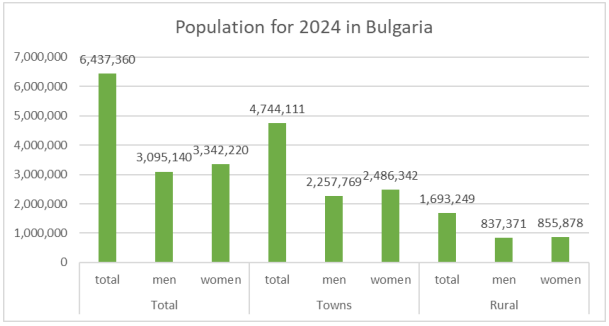

Fig. 4. Population in Bulgaria/urban and rural areas
Source: NSI [11].

Data from the National Statistical Institute paints a bleak picture. Only about 1.73 million people just 26.7% of the population live in the country's 5,200+ villages (Fig. 4). Between 2011 and 2021, the rural population shrank by over 14.2%, significantly outpacing the urban decline of 10.4%. For some perspective, the EU average for rural populations hovers around 30%. The situation is catastrophic in the North-Western, North-Central, and mountainous regions. We are quite literally watching entire villages disappear.

This heavily skewed age structure creates massive socioeconomic strain. Nationwide, people aged 65 and over make up about 24% of the population, but that ratio is far higher out in the villages. Between 2017 and 2022, data showed over half a million elderly individuals living in rural zones. This demographic reality places immense pressure on local social systems and completely

decimates the active workforce. When there aren't enough working-age people left, farms can't find labour, businesses can't expand, and basic public services begin to collapse.

Dominance of Agriculture and Limited Diversification

Economically, these regions are heavily handcuffed to agriculture. Diversifying into high-value activities has been a painfully slow process. Sure, you have a scattering of food processing, basic manufacturing, local transport, and a bit of rural tourism. But micro-enterprises are doing most of the heavy lifting. They are the absolute lifeline for local jobs. The problem is that a micro-business inherently lacks the production muscle of a larger enterprise, putting a hard ceiling on its competitiveness and ability to grow.

The flight of the youth is the ultimate paralyzing factor. Because young people are leaving in droves, outside companies refuse to set up shop in rural areas. They know they won't be able to staff their facilities. Add the crumbling state of local infrastructure to the mix, and it’s no wonder these locations lack investment appeal. Consequently, the businesses that do stick around suffer from chronically low competitiveness (K. Petrov, 2021) [14].

If we want to close the widening gap between the booming urban hubs and the struggling villages [8], we can't just pave more roads. We need aggressive investments in human capital and direct financial backing for local business initiatives.

Infrastructure Deficits

Between 2014 and 2020, the EAFRD did try to tackle the infrastructure deficit. Millions were poured into fixing roads, upgrading water and sewage networks, and renovating social facilities. The fact that this funding must continue into future programming periods just highlights how deep the hole really is. Even with those upgrades, rural zones lag far behind the cities in labour productivity, wages, and basic purchasing power. High unemployment kills household incomes and suffocates local economic momentum.

Photo 1. Title Bulgarian Urban Area, Thracian Plain
Source: Ministry of Agriculture and Food [10].

We’ve seen some micro-enterprises in the service sector invest in physical assets, but their scale is just too small to shift the macroeconomic dial. The structural divide remains stubbornly entrenched, demanding far smarter, highly targeted investment policies.

Looking Ahead: Potential Development Paths for Bulgaria

So, where does Bulgaria go from here? The future of its rural areas depends entirely on whether national institutions have actually learned how to manage European money. Past mistakes make it obvious: we need drastically less bureaucracy, faster administration, and a much sharper targeting of funds. The 2023–2027 CAP promises simplification at the European level, but those promises are meaningless if the local execution turns into a chaotic administrative maze. We need a highly

strategic deployment of financial tools to rescue the areas bleeding population the fastest.

Ultimately, rural survival hinges on basic infrastructure and public services. The gap between town and country keeps expanding because rural transport networks, water grids, and social services are still critically underfunded. You simply cannot attract investors or retain residents if the basic amenities aren't there. Looking at the current landscape, Bulgaria is essentially staring down three possible futures:

Accelerated Convergence and Rural Revitalization

In a best-case scenario, the government gets its act together. Administrative hurdles are cleared, and European funds actually start flowing efficiently. Local and national authorities coordinate seamlessly, moving projects from paper to reality. Strategic cash gets pumped into digital connectivity, smart infrastructure, and decent public services. Concurrently, local farmers and startups finally get access to fair bank loans. This sparks a wave of business innovation. Slowly, the rural-urban divide begins to shrink, the demographic bleeding stops, and younger generations start viewing the countryside as a viable place to live and work.

Gradual but Uneven Progress

A more realistic outlook assumes a mixed bag. Institutional capacity improves somewhat, and the EU money keeps coming, but old bureaucratic habits die hard. Implementation remains patchy. Some proactive municipalities manage to capture the funds, fix their infrastructure, and breathe a little life into their local economies. But other regions get left behind due to a lack of administrative know-how. Progress inches forward, but regional disparities remain glaring, leaving many peripheral villages to quietly fade away.

Structural Stagnation and Deepening Disparities

If nothing changes, we hit the worst-case scenario. Bureaucratic gridlock continues to choke off fund absorption. Poor coordination between Sofia and local mayors ensures that European investments are largely wasted. Infrastructure continues to rot, credit markets remain frozen, and rural economies stay entirely dependent on low-yield farming. Combined with the ongoing demographic freefall, these regions become totally marginalized. The territorial divide rips wide open, completely defeating the entire point of European cohesion policy.

CONCLUSIONS

The takeaway from these scenarios is crystal clear. European money doesn't automatically build local economies. It requires capable national and regional institutions to convert those euros into tangible realities. If we want these investments to actually work, strengthening local administrations, drastically slashing red tape, and rolling out modern financial tools are non-negotiable.

When you examine the track record of European investment policy in Bulgaria, it is a story of immense potential bogged down by persistent roadblocks. Despite the billions pumped into the country through the EAFRD and the ESIF, weak administration, terrible infrastructure, and frozen credit markets have severely blunted the impact of these funds. As a result, the villages keep emptying out, the populations keep aging, and economic diversity remains an illusion.

Whether Bulgaria can reverse this trend comes down entirely to strategy and execution. A rapid rural revitalization is genuinely possible, but only if the government forces through real administrative reforms, targets infrastructure spending where it hurts the most, and unfreezes rural credit markets. If the old systemic barriers are allowed to persist, we risk pushing these territories into permanent marginalization.

Going forward, the strategy for rural Bulgaria must be deeply place-based. It has to fuse infrastructure upgrades with aggressive institutional capacity building and hardcore support for local innovation. By addressing these structural flaws head-on, there is a real chance to boost productivity, slow the demographic collapse, and bring life back to the countryside. Doing so won't just save rural communities; it will strengthen national

competitiveness and finally deliver on the EU's promise of balanced, inclusive growth.

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CLIMATE CHANGE AND HYDROCLIMATIC CONSTRAINTS FOR AGRICULTURE IN THE HISTORICAL BANAT REGION OF ROMANIA

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Abstract

Climate change increasingly affects hydroclimatic conditions, with important implications for agriculture, ecosystem functioning, and regional water balance. This study examines hydroclimatic variability in the historical Banat region of Romania, located in the southeastern sector of the Pannonian Plain, an area characterized by plains, low hills, fertile soils, and a moderately continental climate influenced by western and southern air masses. The analysis was based on ERA5-Land reanalysis data for precipitation and air temperature covering the period 1990–2023. Monthly data were aggregated into annual values, spatially processed in ArcGIS Pro, and interpreted using the Standardized Precipitation Evapotranspiration Index (SPEI-3) in order to assess drought conditions and climatic water deficit. The results indicate a tendency toward increasing air temperature, pronounced interannual variability in precipitation, and a higher frequency of drought episodes, especially in the most recent years of the analyzed period. These changes suggest increasing hydroclimatic pressure on agricultural systems, mainly through intensified evapotranspiration and reduced water availability during critical vegetation periods. The findings underline the need for adaptive strategies focused on climate resilience, including improved water management, modernization of agricultural infrastructure, and the integration of sustainable practices adapted to regional conditions.

Key words**:** *climate change, hydroclimatic variability, drought, SPEI, historical Banat region, agriculture*

INTRODUCTION

Freshwater resources are a fundamental element for the functioning of natural ecosystems and for the socio-economic development of society. Available water resources directly influence agricultural production, food security, population health and environmental balance (Gleick, 2018a; Gleick, 2018b; FAO, 2021; Butnariu, 2026) [18, 19, 15, 4]. In recent decades, sustainable management of water resources has become a major global challenge against the backdrop of climate change and increasing anthropogenic pressure on the environment (Kang et al., 2019; FAO, 2025) [23, 16]. Water scarcity is a key limiting factor for global agriculture, exacerbated by increased variability in precipitation.

Drought is considered one of the main factors limiting agricultural productivity and contributing to the instability of food production worldwide (Spinoni et al., 2018; Howden et al., 2007) [36, 22]. At the same time, rising temperatures and intensifying extreme weather events are reducing soil water availability and increasing pressure on agricultural systems (Kopytko & Perkins, 2011) [25].

Globally, the agricultural sector is the largest consumer of freshwater, accounting for approximately 70% of water use (FAO, 2011) [14]. This high dependence on water resources makes agriculture particularly vulnerable to climate variability and changes in precipitation patterns (Falkenmark & Rockström, 2010) [13].

At the European Union level, pressures on water resources have increased significantly in recent decades. European water management policy is based on the Water Framework Directive (2000/60/EC), which

defines the framework for the protection and sustainable use of water resources (European Commission, 2024) [10]. Although Europe has relatively abundant water resources in some regions, water scarcity and droughts are becoming increasingly common across much of the continent (European Environment Agency, 2025 [11].

According to the World Water Development Report, a country is considered to be affected by water stress when the annual available water resources fall below the threshold of 1700 m³ per capita (UNESCO, 2023) [38]. Climate change is contributing to the intensification of droughts in Europe. Drought episodes have increased in recent decades, affecting large areas of the continent and directly impacting ecosystems and agricultural production (Spinoni et al., 2018; Hanel et al., 2018) [37, 20].

At the same time, extreme precipitation can trigger floods and soil erosion processes, affecting the stability of agricultural ecosystems and land productivity (Motta et al., 2025; Pisoni et al., 2025) [30, 32]. European agriculture is considered one of the sectors most vulnerable to climate change, as crop productivity directly depends on climatic conditions and water availability (Némethy et al., 2022; Brumă et al., 2024) [31, 2]. In this context, the concept of climate resilience has become a central element in European climate change adaptation policies.

In Romania, the impacts of climate change on water are becoming increasingly visible, especially in agricultural areas. Agriculture is closely linked to water availability, and rising temperatures, fluctuating precipitation, and frequent droughts can reduce crop productivity and the efficiency of livestock systems (Howden et al., 2007) [22]. Recent climatological studies show an increase in drought phenomena in recent decades, especially in the agricultural regions of southern and western Romania (Filimon et al., 2024; Bădăluță et al., 2024) [17, 1]. Romania has a relatively dense hydrographic network, of approximately 78,000 km of watercourses, and the structure of water resources is significantly influenced by the Danube River, which contributes almost 44% of the total volume of internal resources. The other resources come from inland rivers and groundwater, which together complete the national hydrological balance (Ionescu et al., 2024). [26]. However, their distribution is uneven, being strongly influenced by climate and relief. In lowland regions, such as Dobrogea or the Banato-Arădean Plain, the average specific flow is very low. In contrast, mountainous areas, such as the Făgăraș and Retezat Mountains, experience more abundant precipitation. Romania's annual renewable water resources are estimated at approximately 40 billion m³ (Platon & Constantinescu, 2019) [33].

It is observed that the water deficit associated with climate variability significantly affects the profitability and level of agricultural productivity and implicitly the balance and sustainability of ecosystems (Holerga, 2025) [21]. In this sense, a case study and analysis of the interdependence between climate change and the sustainability of water resources in the historical region of Banat is relevant because agriculture is predominant in this area. Due to its location in the southeast of the Pannonian Plain, Banat represents an area dominated by plains and low hills with fertile soils and climatic conditions that place the region in a temperate-continental climate (Cojocariu et al., 2025; Samfira et al., 2025) [7, 34]. Climate research reveals an evolution oriented towards increasing average temperatures, especially in the summer season, and usually an association with increasing trends in evapotranspiration, which generates soil moisture loss (Charalampopoulos et al., 2025; Spinoni et al., 2018) [6, 36]. In the last decade, climate forecasts for the area represented by the Pannonian Plain highlight that at the same time, climate projections for the Pannonian Plain indicate a possible decrease of 5-15% in the amount of precipitation in the summer period by the middle of this century, with considerable influences on the availability of water resources but especially on agricultural production [5] Ceglar et al., 2018. In the Pannonian Basin region, an increase in the occurrence and intensity of drought periods has been documented in recent decades. These

phenomena caused losses in agricultural production but more importantly highlighted a, leading to significant losses in agricultural production and accentuated the fragility of an agricultural system that is dependent on precipitation (Bueechi et al., 2023; Crocetti et al., 2020) [3, 8]. These phenomena have disadvantaged the development of agricultural crops because the increase in temperatures was also accompanied by a change in the seasonal distribution of precipitation, these being especially absent during the season of intense plant growth. It can be appreciated that at the level of the Banat region, climatological investigations signal an upward trend in average temperatures in recent decades, with some studies indicating an increase of approximately 1–1.5 °C compared to the previous period, especially after 2000. This evolution is accompanied by a more pronounced variability in precipitation and a higher frequency of climate anomalies, which can negatively influence the hydrological regime and soil fertility (Mircov et al., 2024) [29]. In addition, the analysis of long-term climate series highlights a trend of increasing evapotranspiration and a change in the regional water balance, which can reduce the availability of water for agricultural crops (Lukić et al., 2019; Șmuleac et al., 2020; Srdjevic et al., 2022) [27, 35, 37].

Unlike studies explicitly designed to analyze climate–yield relationships at county scale, which use crop-specific production data and correlation analyses (Dahbi et al., 2026) [9], the present study focuses on hydroclimatic variability and its general implications for agriculture.

In this context, studying the sustainability of water resources in the Banat region is important for understanding the effect of climate change on hydrological systems and agroecosystems.

MATERIALS AND METHODS

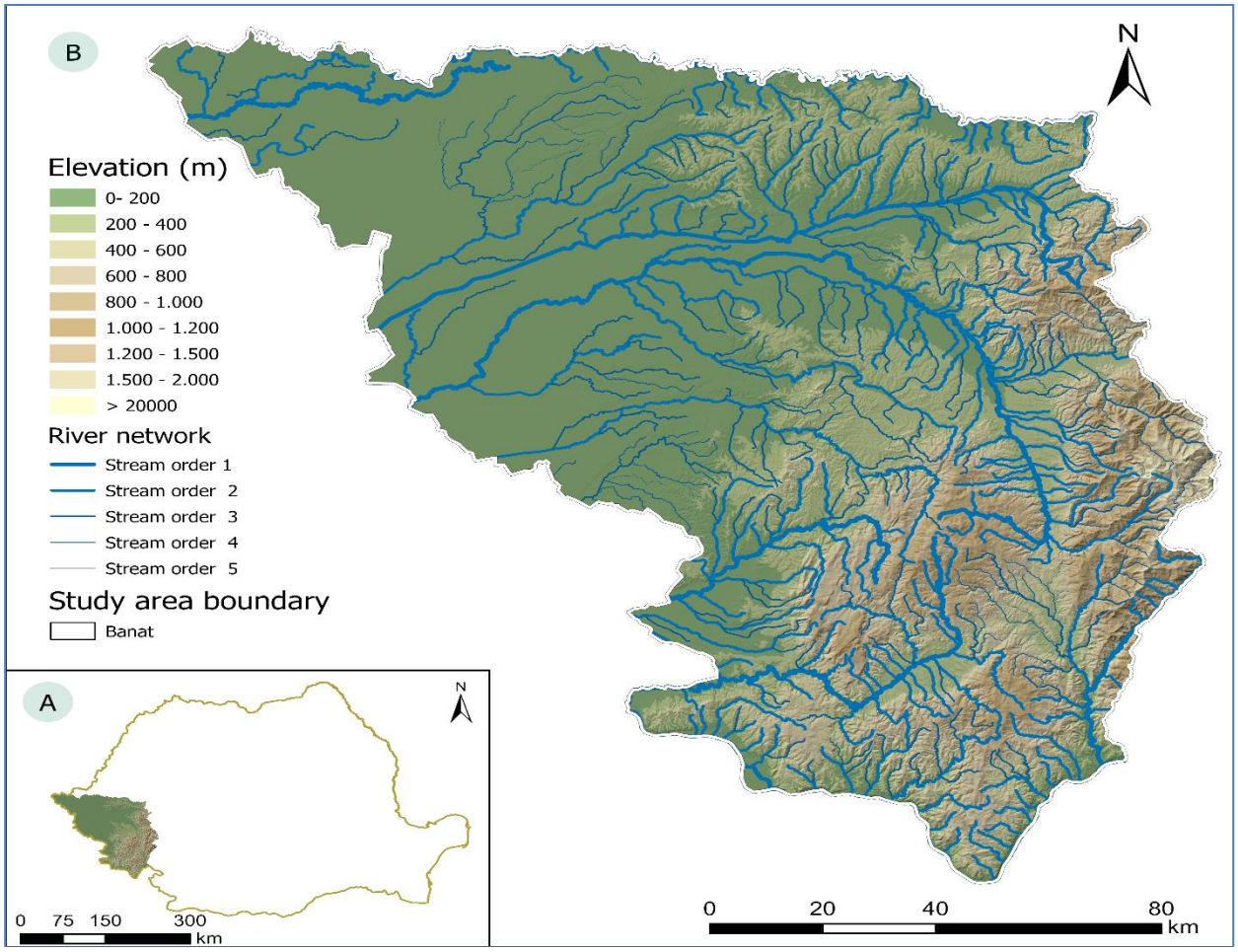
The research was carried out in the historical Banat region, located in the southeastern sector of the Pannonian Plain, in western Romania. This region is characterized by predominantly plain and low hills, fertile soils, and a temperate-continental climate, influenced by western and southern air masses. From a climatic perspective, the region is characterized by significant variability in precipitation and temperature, which can influence the water balance and agricultural productivity. Annual precipitation and temperature series for Banat were obtained based on ERA5-Land reanalysis climate data, provided by the Copernicus Climate Data Store. Monthly precipitation and temperature data for the period 1990–2023 were aggregated to determine annual values of total precipitation and average air temperature. Precipitation values were converted to millimeters, and temperature values from Kelvin to degrees Celsius. The spatial average for the study area was calculated using the Zonal Statistics tool. The processing and analysis of climate data were performed using ArcGIS Pro 3.5 software (Esri Inc., Redlands, USA), which was used for raster data processing and spatial analysis of climate variables. The Standardized Precipitation Evapotranspiration Index (SPEI) was used to assess the variability of hydroclimatic conditions and the frequency of drought episodes in the Banat region. This indicator is widely used in climate studies because it integrates both precipitation variability and the influence of temperature on potential evapotranspiration, thus providing a more realistic estimate of water deficit or surplus at the climate level. The climate data used were extracted from the ERA5-Land reanalysis dataset, provided by the Copernicus Climate Data Store, which provides detailed and continuous climate information over time. The analysis included monthly air temperature and precipitation series for the period 1990–2023 for the Banat region. Based on these variables, potential evapotranspiration (PET) was estimated using the Thornthwaite empirical formula, which uses the average monthly temperature and the length of the day to estimate atmospheric water demand. The SPEI index was calculated using the climatic water balance: $D=P-PET$, where P represents precipitation/month; PET represents potential evapotranspiration. The resulting series was aggregated on a 3-month time scale (SPEI-3),

frequently used for the analysis of meteorological and agricultural drought. The values were subsequently statistically standardized to allow comparison of different climatic periods. The interpretation of SPEI values was carried out according to the standard classification. This integrated approach enables assessment of the relationship between climate change and agricultural productivity and helps identify climatic factors that influence the sustainability of agricultural systems in the Banat region.

Table 1. SPEI value interpretation scale

SPEI	Interpretation
>2	extremely humid conditions
1-2	humid conditions
-1-1	normal conditions
-1-2	moderate drought
< -2	severe drought

Source: adapted from McKee et al. (1993) [28] and Vicente-Serrano et al. (2010) [40]

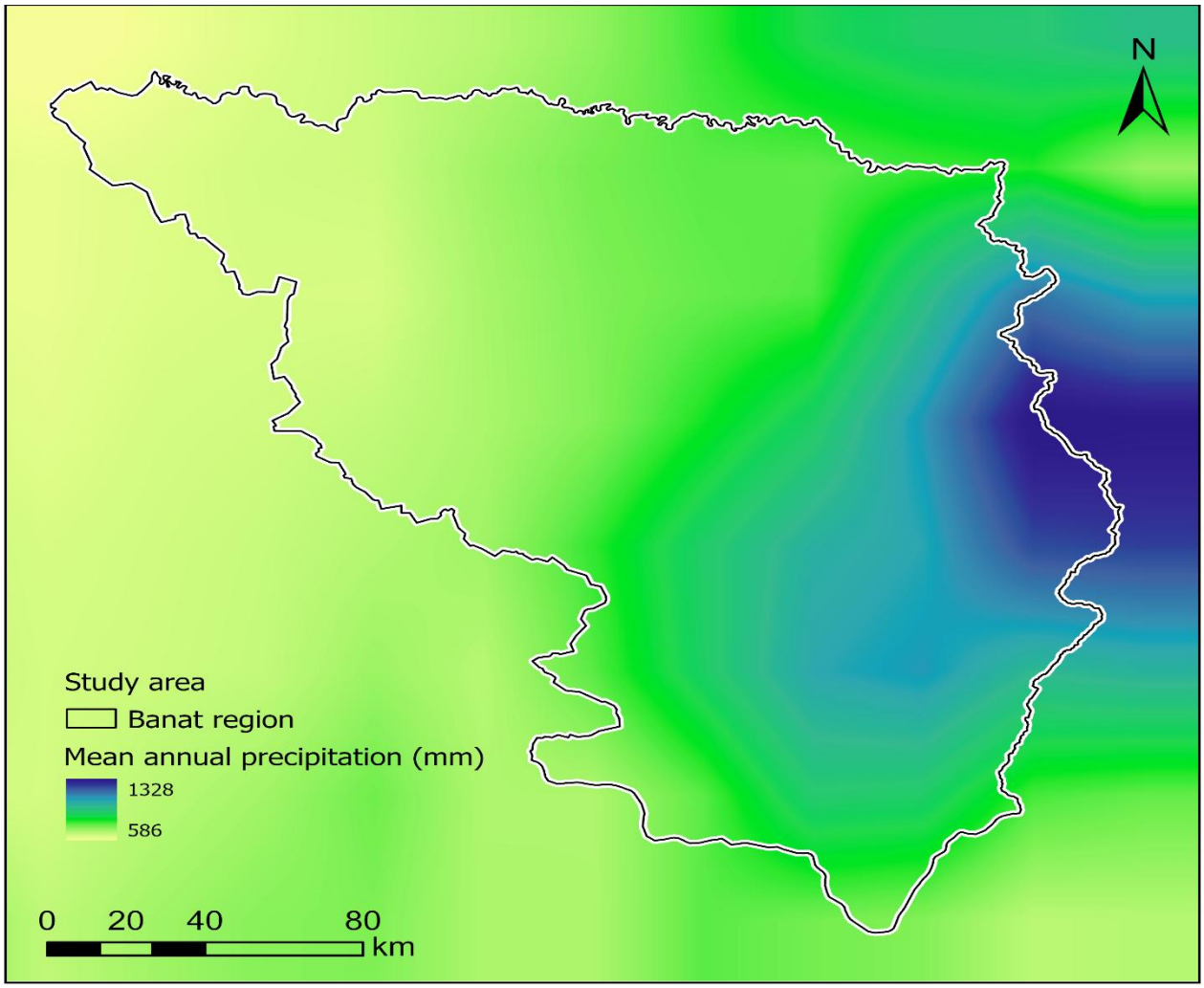


Map 1. Study area: the historical Banat region of Romania
Source: authors' own processing in ArcGIS Pro based on elevation and hydrographic spatial data; study area boundary digitized by the authors.

RESULTS AND DISCUSSIONS

Evolution of climate parameters in the Banat region. The analysis of the climate series for the period 1990–2023 highlights significant changes in the main climate parameters in the Banat region. Data obtained from the Copernicus Climate Change Service program indicate a trend of increasing average annual temperature, in line with trends observed at the European level. The increase in average temperature is associated with the intensification of evapotranspiration, which reduces soil water availability, especially during the vegetation season. At the same time, the analysis of precipitation indicates sharp variability in annual quantities, with periods characterized by significant water

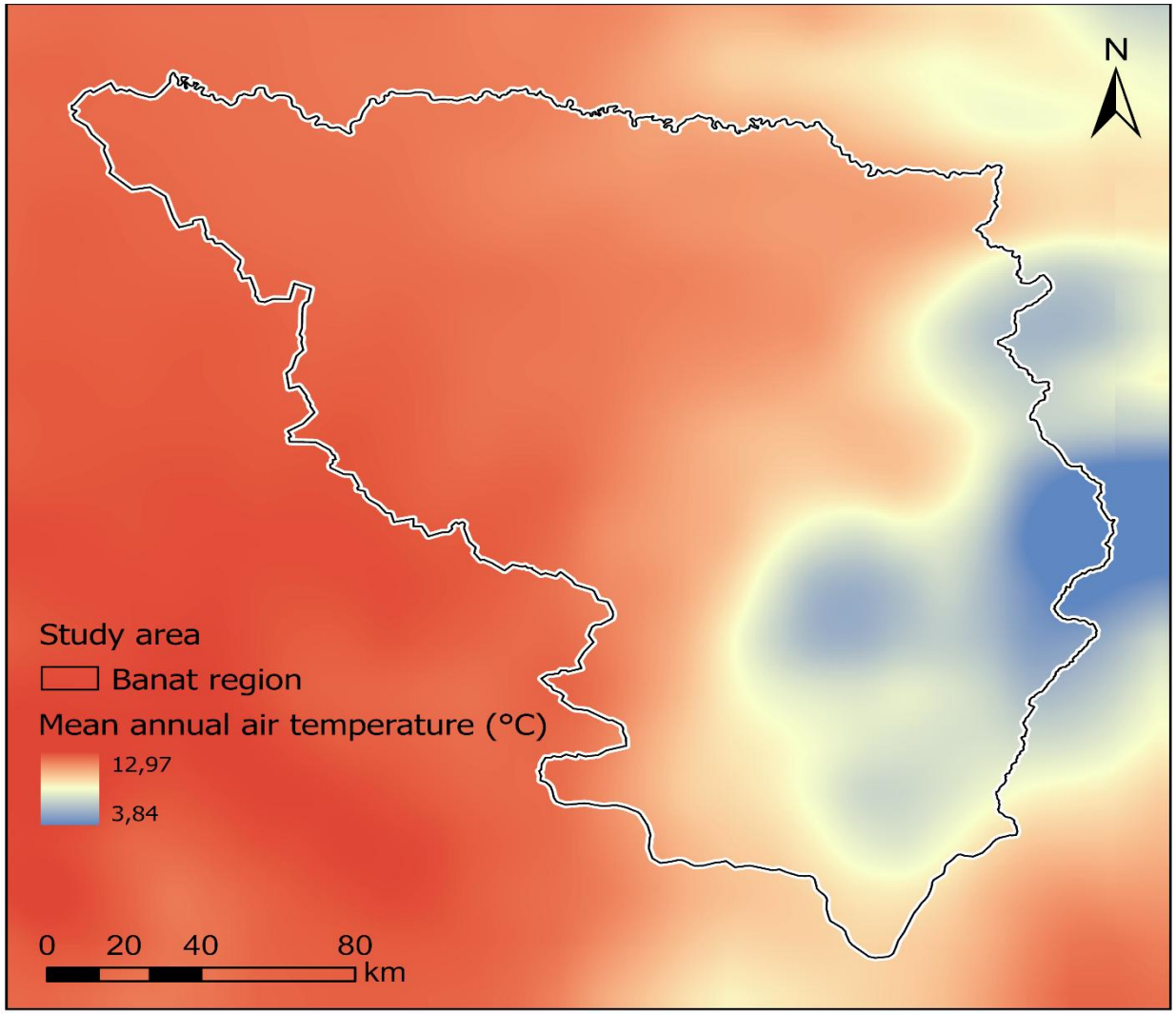
deficits. The climate maps generated from Copernicus data highlight the spatial distribution of precipitation and temperature in the Banat region, confirming regional differences that may influence agricultural productivity. In certain areas of the region, precipitation levels are lower in the spring and summer, a critical period for the development of agricultural crops. Regarding the annual precipitation contribution, the results indicate a multiannual average of precipitation of approximately 865.7 mm/year, reflecting the combined influence of the varied relief of the Banat region, which includes plains, hills, and mountains (Map 2). The interannual variability is pronounced, with minimum values recorded in 2011 (approx. 586 mm) and maximum values in 2005 (approx. 1,225 mm). The analysis of anomalies reported to the multiannual average highlights the alternation of wet and dry periods, characteristic of the temperate-continental climate in western Romania. Especially after 2000, a greater amplitude of annual variability is observed, marked by the succession of years with excess and deficit precipitation.



Map 2. Spatial distribution of mean annual precipitation in the Banat region during 1990–2023 based on ERA5-Land reanalysis data
Source: authors' own processing in ArcGIS Pro based on ERA5-Land monthly averaged precipitation data retrieved from the Copernicus Climate Data Store (C3S), DOI: 10.24381/cds.68d2bb30

The annual mean air temperature at 2 m (t2m) for the Banat region was analyzed for the period 1990–2023, based on ERA5-Land data, by annual aggregation of monthly values and calculation of the spatial average over the entire study area (Map 3). After converting the values from Kelvin to degrees Celsius, the resulting series indicates a multiannual mean temperature of 10.76 °C, characterized by a moderate but clearly expressed interannual

variability. The annual values ranged from approximately 9.34 °C to 11.97 °C, indicating an interannual thermal amplitude of approximately 2.6 °C at the regional level. The coldest years of the series were 1996 and 1997, while the highest values were recorded in the recent period, with maxima in 2019 and 2023. The temporal distribution of the values suggests a progressive shift towards higher thermal conditions in the second part of the analyzed interval. The analysis of thermal anomalies reported to the multiannual average highlights the predominance of negative deviations in the first part of the series and a higher frequency of positive anomalies after 2007. In particular, the period 2014–2023 is characterized by a succession of years with temperatures generally above the reference average, indicating an increase in the regional thermal regime during this interval. The highest positive deviations exceed +1 °C, while the most pronounced negative anomalies are observed in 1996–1997. From a regional perspective, these results indicate a warming trend in the climate of Banat, as reflected in the increasing frequency of warm years and the decreasing share of years with temperatures below the multiannual average. In the context of the integrated temperature–precipitation analysis, this evolution is relevant for assessing climate pressure on water resources, as higher temperatures can amplify potential evapotranspiration and, implicitly, vulnerability to water deficit.



Map 3. Spatial distribution of mean annual air temperature in the Banat region during 1990–2023 based on ERA5-Land reanalysis data
Source: authors' own processing in ArcGIS Pro based on ERA5-Land monthly averaged 2 m air temperature data retrieved from the Copernicus Climate Data Store (C3S), DOI: 10.24381/cds.68d2bb30

The analysis of the SPEI-3 time series for the period 1990–2023 highlights a pronounced variability of hydroclimatic conditions in the Banat region (Fig. 1). The index values frequently oscillate between periods of moisture surplus and episodes of water deficit, reflecting the variable nature of the regional climate. Several significant drought episodes can be identified in the analyzed interval, characterized by persistent negative SPEI values. Among the most pronounced episodes are the periods 1999–2000, 2007, 2012, 2015, and 2022–2023. In these intervals, the index values frequently drop below the threshold of −1, indicating moderate drought conditions, and in certain months even below −2, which signals severe drought episodes.

The most intense drought in the analyzed series occurs in the period 2022–2023, when SPEI values approach the threshold of −3, indicating extreme water-deficit conditions.

This episode coincides with high temperatures and low precipitation at the regional level, phenomena also reported in assessments carried out by the European Drought Observatory for South-Eastern Europe (Kireeva et al., 2025) [24].

In addition to drought episodes, the SPEI series also highlights periods with surplus moisture, characterized by positive index values. These are relatively evenly distributed throughout the analyzed period, without indicating a clear trend in their frequency.

Overall, the results indicate high climate variability in the Banat region, characterized by the frequent alternation of wet and dry episodes. However, the intensity of recent drought episodes suggests a possible amplification of water deficits under regional climate warming, a phenomenon also highlighted in other climate studies conducted for Central and Eastern Europe. The variability of hydroclimatic conditions in the Banat region was assessed using the SPEI-3 index, whose values are presented in Figure 4.

The analysis of the time series for the period 1990–2023 highlights a pronounced alternation between wet periods and drought episodes. Negative values of the index indicate the occurrence of water deficit episodes, the most pronounced of which are observed in 1999–2000, 2007, 2012, and 2022–2023, when the index reaches values corresponding to moderate or severe drought.

Numerous studies based on satellite data show that drought episodes characterized by negative SPEI values are generally associated with decreases in vegetation indices, including NDVI, reflecting water stress at the vegetation level. Thus, the observed SPEI variability in the Banat region suggests periods in which natural ecosystems and agricultural systems were exposed to unfavorable climatic conditions.

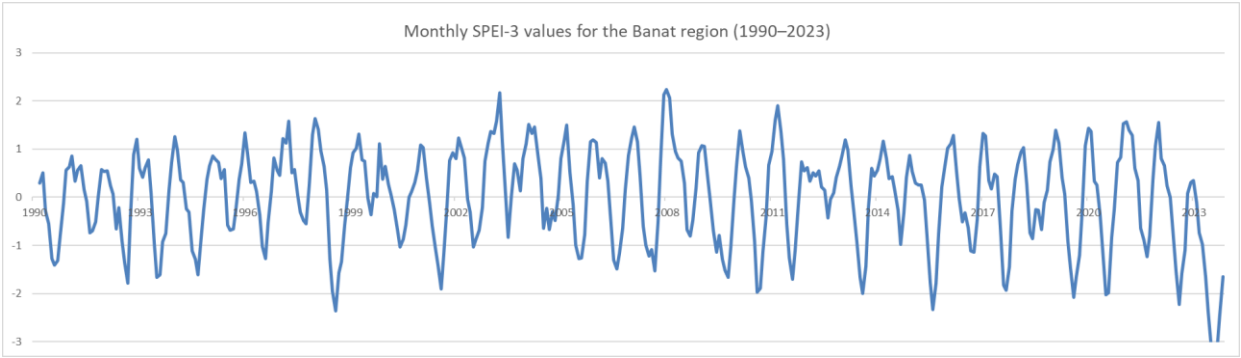


Fig. 1. Time series of the SPEI-3 index in the Banat region (1990–2023), calculated based on the climatic water balance (precipitation minus potential evapotranspiration)

Source: authors' own calculations based on ERA5-Land monthly averaged precipitation and 2 m air temperature data retrieved from the Copernicus Climate Data Store (C3S), with SPEI-3 computed following Vicente-Serrano et al. (2010) [40].

Spatial distribution of drought and water deficit

Analysis of drought indices, especially the Standardized Precipitation Evapotranspiration

Index (SPEI), indicates an increase in the frequency of drought episodes in recent decades. Data from the European Drought Observatory confirm that western Romania has experienced severe drought episodes in recent years. Maps generated from satellite data highlight the expansion of areas affected by water deficit during the summer, especially in years with low precipitation and high temperatures.

Over the years, soil moisture levels have decreased significantly, affecting crop development. Analysis of the NDVI (Normalized Difference Vegetation Index), derived from satellite data, highlights reduced vegetation activity in dry years. Low NDVI values are associated with water stress in vegetation and may indicate reduced agricultural productivity.

The relationship between climatic conditions and agricultural production

To assess the impact of climatic variability on agriculture, statistical data on agricultural production from the Statistical Yearbook of Romania, as well as data available in the Eurostat [12] and Food and Agriculture Organization databases, were analyzed. The comparative analysis of agricultural production indicates a significant correlation between precipitation during the vegetation period and the yields of the main agricultural crops. In years with sufficient precipitation, cereal production, such as wheat and corn, was high, whereas in dry years it was significantly reduced. For example, in years characterized by severe national-level drought, such as 2007, 2012, or 2020, the average yields per hectare for corn and wheat decreased significantly compared to years with favorable climatic conditions. This variation highlights the high dependence of agricultural production on climate and water availability.

Analysis of the statistical correlation between rainfall in the April–July period and wheat yields indicates a significant positive relationship, suggesting that rainfall deficits during this period can reduce crop yields. Similarly, maize production is strongly correlated with summer rainfall, when crop water requirements are high.

Discussions

Trends in agricultural productivity in the context of climate change. Analysis of the long-term evolution of agricultural production highlights a general increase in crop yields driven by technological progress and the adoption of more productive varieties and hybrids. However, climate variability continues to significantly influence annual agricultural production.

Years characterized by drought or water deficit determine significant decreases in agricultural production, even when modern agricultural technologies are used. This situation highlights the vulnerability of agricultural systems to climate change and emphasizes the importance of efficient water resource management.

In addition, rising temperatures and intensification of evapotranspiration can increase soil water deficit, affect crop development, and reduce agricultural land productivity in the long term.

In these conditions, the development of effective adaptation strategies becomes essential to maintain the sustainability of agricultural systems, while investments in resilience can reduce disaster-related losses affecting agriculture and food security (UNICEF, 2023) [39].

Implications for the sustainability of water resources

The increasing evolution of temperature values and the variability of the rainfall regime can lead to hydrological imbalances that negatively affect agriculture and regional ecosystems. In this context, the development of effective adaptation strategies becomes mandatory to ensure the sustainability of agricultural systems. Recommended measures include the restoration and modernization of irrigation systems, the application of adaptive agricultural practices and the integration of ecosystem-based solutions for the sustainable management of water resources.

The assessment of climate data reveals an upward trend in average temperatures and an increased variability of the rainfall regime, leading to an increase in evapotranspiration and a reduction in soil water reserves. The results obtained are consistent with European

climatological analyses, which indicate an intensification of the frequency of drought episodes in Central and South-Eastern Europe. The correlation highlighted between the rainfall regime and agricultural production confirms the significant dependence of the agricultural sector on water resources. The reduction of the rainfall regime in critical vegetation phases has led to significant decreases in agricultural production, especially for crops sensitive to water deficit, such as corn. At the same time, the results show that technological progress and the adoption of varieties and hybrids with high productive potential have contributed to the long-term increase in agricultural productivity.

However, climate variability remains a major limiting factor for agriculture in the Banat region. In this context, the development of effective strategies for adapting to climate change is a condition. Recommended measures include the modernization of irrigation infrastructure, the use of agricultural technologies with high water consumption efficiency and the integration of sustainable agricultural practices.

CONCLUSIONS

The results of the study reveal the major impact of climate variability on water resources and the performance of agricultural systems in the Banat region. The increases in temperature and precipitation variability observed in recent decades are consistent with climate trends identified at the European level.

The Banat region has experienced a clear trend of decreasing precipitation during the agricultural season and increasing evapotranspiration, resulting in a critical water-balance deficit during the period 1898–2019. Historical hydro-improvements and drainage accentuate this. To increase local climate resilience, integrative policies are needed — including infrastructure modernization, regional quantitative assessments of water availability, ecosystem-based solutions, and international collaboration - all adapted to the specifics of Banat.

The analysis of the correlation between climatic parameters and agricultural production demonstrates that agriculture in the region is strongly dependent on climatic conditions, particularly on precipitation during the vegetation period.

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RESEARCH ON ECONOMIC RESILIENCE THROUGH THE APPLICATION OF EFFICIENT TECHNOLOGIES TO SOYBEAN CULTURE IN THE REPUBLIC OF MOLDOVA

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Abstract

Our comparative research refers to soybean cultivation in the Republic of Moldova, as an efficient crop in agroeconomic, financial and ecological terms, valuable that combines in its composition a high amount of protein on average 40% and oil 20%. Productivity of 2,000 kg of grains per hectare ensures the obtaining of about 700 kg of crude protein and 400 kg of oil, synthesized in major quantities within 3-4 years of intensive cultivation. Through economic analyses and calculations, the estimated profitability of soybean production starts from about 1.0-1.2 t/ha, and that significant economic growth in the conditions of the Republic of Moldova for this crop can be achieved only by applying an intensive technological management through the application of an integrated protection system with effective and complex remedies, which allow to reduce production costs and obtain a stable income from sales. These systems are essential in integrated pest and disease management, by interrupting the life cycle and preventing the accumulation of specific diseases and pests, reducing their abundance and adaptability. Economically efficient are reducing the consumption of chemicals, improving soil properties, increasing profit, diversity and sustainability of legume production, including soybean.

Key words**:** *soybean, global production, global harvest, integrated management, cultivation technologies*

INTRODUCTION

Soybean is a very important crop (Du et al., 2024; Bîlteanu, 2003) for several industries, recognized worldwide (Pindit K. Et al., 2021) for proteins (Starodub, 2015; Constantinescu & Sinulescu, 2014; Yang et al., 2016;), which accumulate up to 45% (Nekrasov, 2020) and fats with 28% of its chemical content [5, 18, 24, 8, 28, 15].

The European Union, (Debaeke et al., 2022) [11] focuses primarily on soybean production, to raise its production potential and reduce protein imports by 2050.

Climate change in recent years (Raza et al, 2019) [19] has led to a significant increase in the frequency and intensity of extreme phenomena (Ashraf, et al. 2018) [1], such as prolonged droughts (Benevenuto et al., 2017) [4] and massive invasions of harmful organisms, increasingly affecting anthropized agrobioecosystems. These processes are also visible in the agriculture of the Republic of Moldova, where high climate variability negatively influences the stability of agricultural production, including soybean. Recent studies show that water stress is one of the main limiting factors of soybean production, significantly reducing plant growth and crop yield.

Research (Nguyen et al. 2023) [16] indicates that drought can reduce soybean production by up to 25% under moderate water deficit conditions and even by over 80% under extreme conditions, especially during the plant's reproductive phases. In addition, changes in temperature and rainfall patterns (Sharma et al., 2022) [23] directly influence crop productivity, with some studies showing that a 1°C increase in maximum temperature

can reduce soybean yield by approximately 25%.

For these reasons, in the agroeconomy of the Republic of Moldova, soybean cultivation and testing of soybean varieties under local pedoclimatic conditions (Leonte et al., 2025) [13] occupy an important place due to its high nutritional and economic value. At the same time, studies mention (Bădărău, 2016; Croitoru & Panută, 2017) [3, 9] that soybean crops face significant losses of 25-30% annually because of pests and invasive organisms. Thus, the implementation of efficient innovative agricultural technologies (Șhabalchin & Dubinchina, 2022) [22] and adapted to local pedoclimatic conditions can become essential for maintaining the competitiveness of agricultural producers on domestic and foreign markets. At the same time, soybean crop contributes to maintaining soil fertility through the biological fixation of atmospheric nitrogen, which makes it an essential component of crop rotation (Starodub, 2008; Yakovleva et al, 2022) [25, 27] and sustainable agricultural systems.

In this context, we can say that soybean production represents one of the main legume crops cultivated mainly for its high economic and nutritional value, and the application of sustainable management systems will ensure soybean production also has strategic value for the agricultural sector.

In the Republic of Moldova, the cultivation technologies are those applied in the conventional conservative system as well as in the No-Till system in relation to climate change-drought, invasive organisms, high crop demands, excessive temperatures, degraded soils, etc.

The article presents the integrated protection management in cultivation technologies, especially the key links in protecting plants from weeds, diseases and pests, with the current direction adapted to the climate, according to the economic damage threshold, the works of some rules for creating good conditions for crop formation.

The paper reflects comparative: analysis of production and income by year, as well as the estimation of protection links in the application of integrated management, with emphasis on climate change and the invasive impact of the mentioned harmful organisms.

MATERIALS AND METHODS

The research of the team of co-authors representing different research institutions in the Republic of Moldova focused on an inter-institutional collaboration agreement between the National Institute of Economic Research of the Academy of Economic Studies of Moldova with the laboratories of the Institute of Zoology and the National Botanical Garden "Alexandru Ciubotaru" of the State University of Moldova. The experimental part consisted of the soybean sectors in the Florești, Rîșcani districts, the Center for Production and Selection of Seeds from the North, Balți Municipality, which were subject to monitoring during the application of the integrated management system. Periodic records made by field observers, the application of surveys of owners of associations in the studied areas and the collection of soil samples for laboratory determinations were the basis for formulating the conclusions and recommendations of the integrated management system. The analysis of economic indicators was possible with the help of data taken from the database of the National Bureau of Statistics and the international databases FAOSTAT and Eurostat. At the same time, the government platforms of the relevant ministries and subordinate agencies were also consulted.

First, the bibliographic analysis method was used, which involved examining specialized scientific literature, publications indexed in international databases (Web of Science and Scopus), as well as technological guides on soybean cultivation. This method allowed the identification of the main modern phytosanitary protection technologies and effective agricultural practices applied in different production systems.

Second, the phytosanitary observation and monitoring method in the field was applied, used to identify the main diseases and pests specific to soybean crops and to assess the degree of attack on plants. Monitoring allowed the collection of data on the dynamics

of the appearance of pathogens and their impact on crop development.

Also, the comparative method was used, through which various plant protection technologies and their efficiency in reducing phytosanitary pressure and increasing production yield were analysed. This approach allowed highlighting the most efficient technological practices adapted to the pedoclimatic conditions of the Republic of Moldova. At the same time, the method of statistical analysis and interpretation of experimental data was used to evaluate the results obtained and to determine the influence of the applied technologies on the productivity of soybean crop. Data analysis allowed formulating substantiated conclusions regarding the efficiency of the studied technologies.

RESULTS AND DISCUSSIONS

Economic analysis of soybean cultivation in the Republic of Moldova

The analysis of soybean production in temporal and spatial dynamics is an essential stage in the research, as it allows highlighting the trends in the evolution of this crop in the specific pedoclimatic conditions of the Republic of Moldova. The examination of statistical data on production carried out in the period 2017–2024 provides a relevant picture of the level of development of soybean cultivation, the variability of yields and the influence of climatic and technological factors on the results obtained in the agricultural sector. The need to carry out this analysis derives from the fact that global production is one of the main indicators that reflect the efficiency of applied agricultural technologies and the degree of adaptation of soybean cultivation to environmental conditions. By assessing the evolution of production at the regional level, it is possible to identify both areas with high productive potential and those characterized by significant fluctuations in production, determined by climatic stress, the pressure of diseases and pests or the different level of application of agricultural technologies.

The information presented in Table 1 highlights a different structure for the Northern region of the Republic of Moldova regarding the evolution of soybean production in the analyzed period from 2017 to 2024. The figures show a fluctuating dynamics of the cultivated areas determined by factors generally created by pseudoclimatic conditions and applied technologies. These factors cause an instability of soybean production, classifying the period into years with favorable production and years with a significant reduction in the harvest.

Table 1. Evolution of total soybean production in the period 2017-2024 in the Republic of Moldova in the North, in quintals

	2017	2018	2019	2020	2021	2022	2023	2024
Balti Municipality	479	500	313	-	-	38	-	-
..Briceni	65,978	87,868	95,394	82,250	77,840	75,473	73,023	86,923
..Donduseni	44,777	33,972	51,697	17,659	60,639	18,677	31,857	23,452
..Drochia	60,160	69,092	50,051	12,261	42,163	12,331	18,255	6,883
..Edinet	47,627	52,374	52,403	17,415	21,972	23,393	30,266	21,972
..Falesti	17,439	14,222	19,862	3,582	7,236	2,450	1,881	1,028
..Floresti	364	892	1,239	1,101	4,530	658	-	1,333
..Glodeni	23,502	19,901	22,449	3,849	4,162	2,061	3,280	1,137
..Ocnita	18,065	26,010	24,643	12,759	22,056	14,399	15,671	13,737
..Riscani	50,534	58,050	53,725	21,791	46,146	24,976	25,743	13,330
..Singerei	9,977	16,031	13,678	1,317	9,612	2,793	3,211	1,244
..Soroca	9,503	12,136	7,855	2,054	6,889	3,256	5,670	1,645

Source: developed by the authors based on data from the National Bureau of Statistics [14].

During the analysed period, the highest levels of soybean production are recorded in the districts of Briceni, Rîșcani, Edineț and Dondușeni, which are constantly highlighted by higher volumes of overall production. For example, Briceni district recorded high values throughout the period, reaching a maximum of over 95 thousand quintals in 2019 and maintaining a high level in 2024 (86,923 quintals). Rîșcani district also presents significant production values, with a maximum of over 58 thousand quintals in 2018 and maintaining a relatively stable volume until the following years, although in 2024 a decrease in production is observed.

On the other hand, some districts, such as Drochia, Fălești, Glodeni or Sîngerei, record more pronounced variations in production, which reflects a higher vulnerability to climatic factors and the technological level applied in agricultural holdings. For example, in Drochia district, production decreases from over 60 thousand quintals in 2017 to approximately 6,8 thousand quintals in 2024, which indicates a significant reduction in production in recent years. At the same time, 2020 highlights a pronounced decline in production in most of the analysed districts, a phenomenon that can be associated with unfavourable climatic conditions, especially with the deficit of precipitation and episodes of severe drought. Subsequently, in the period 2021–2023, a certain recovery of production is observed in some districts, but without reaching in all cases the maximum levels previously recorded.

The analysis of global soybean production creates the empirical framework necessary to substantiate the research objectives. Thus, the identification of significant variations in production in different periods and regions justifies the need to investigate efficient agricultural technologies, especially those related to disease and pest management, which can contribute to stabilizing and increasing crop yields. Correlating data on production evolution with applied technologies allows highlighting the relationship between the technological level of agricultural holdings and the productive performance of soybean crops.

The analysis of the area sown with soybeans in the period 2016–2024 highlights a fluctuating evolution of the expansion of this crop in the Republic of Moldova, determined by climatic conditions, the agricultural market situation and the level of technologies applied in agricultural holdings. The total area cultivated with soybeans in households of all categories registered a downward trend in the first part of the analysed period, from approximately 39,9 thousand hectares in 2016 to 28.0 thousand hectares in 2018, which reflects a reduction in interest in this crop in the context of less favourable agro-climatic conditions or the orientation of farmers towards other more profitable crops (Table 2, Figure 1).

Table 2. Analysis of the evolution of sown areas, production and average yield per hectare of soybean calculated for households of all categories during the period 2017-2024

	2016	2017	2018	2019	2020	2021	2022	2023	2024
Sown area, thousand hectares	39.9	34.0	28.0	37.7	29.0	22.8	25.3	25.0	26.9
Global harvest, thousand tons	42.1	46.5	57.7	64.2	33.3	50.5	32.4	38.4	31.6
Average yield per hectare, quintals	11.7	14.0	21.2	17.3	12.3	23.7	13.9	15.5	12.2

Source: developed by the authors based on data from the National Bureau of Statistics [14].

Subsequently, in 2019, a significant increase in the cultivated area was observed, up to 37.7 thousand hectares, indicating a resurgence of interest in soybean cultivation, driven both by the increased demand for plant sources of protein and by the agronomic advantages of this legume in crop rotation. In the following years, however, the sown area continued to fluctuate, registering 29.0 thousand hectares in 2020 and 22.8 thousand hectares in 2021, which can be explained by the impact of unfavourable climatic conditions, especially

the severe drought that affected the agriculture of the Republic of Moldova during this period. In the structure of the cultivated area, a dominant share of agricultural enterprises is observed, which manage most of the land cultivated with soybeans.

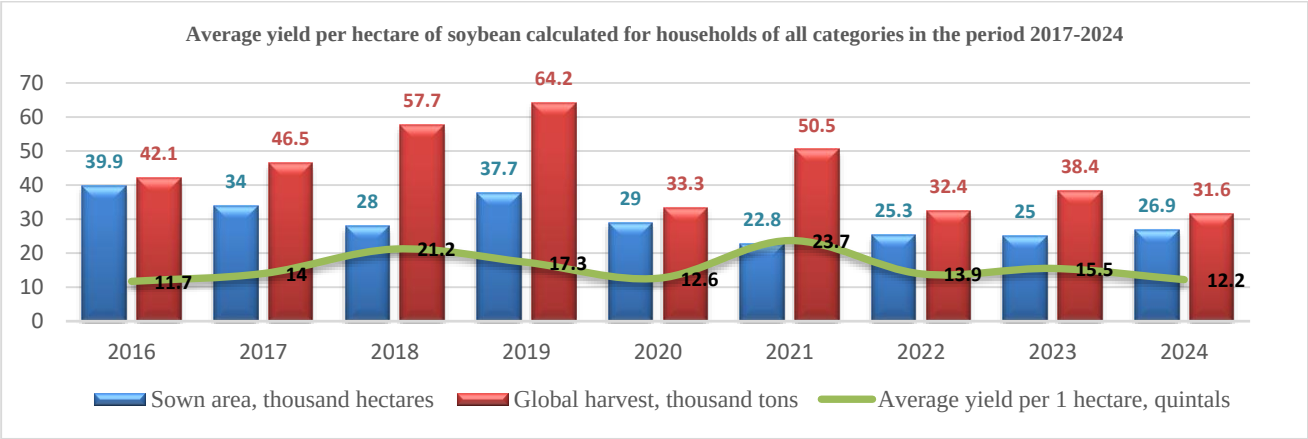

Fig. 1. Evolution of sown areas, production and average yield per hectare of soybean calculated for households of all categories during the period 2017-2024
Source: developed by the authors based on data from the National Bureau of Statistics [14].

The global soybean harvest also shows an oscillating evolution. In the period 2016–2019, a significant increase in the volume of production is observed, from 42,1 thousand tons to 64,2 thousand tons, the maximum level recorded in 2019. This evolution is determined both by the expansion of the cultivated area and by the increase in the productivity of the crop. However, in 2020 a pronounced reduction in production to 33,3 thousand tons is observed, a phenomenon largely associated with unfavourable climatic conditions, especially with severe drought episodes. In the following years, production remains at a relatively moderate level, ranging between 31,6 and 50,5 thousand tons. An important indicator for assessing the efficiency of applied agricultural technologies is the average yield per hectare, which reflects the level of crop productivity. During the analysed period, this indicator shows considerable variations, from 11.7 quintals/ha in 2016 to a maximum of 23.7 quintals/ha in 2021. Higher levels of productivity are recorded in years with favourable agro-climatic conditions and the application of more efficient agricultural technologies. Conversely, in years marked by water deficit or pressure from biotic factors, productivity decreases significantly, reaching 12–15 quintals/ha.

The analysis of these indicators confirms that soybean production in the Republic of Moldova is strongly influenced by the variability of climatic conditions and the technological level applied in the cultivation process. In this context, the implementation of efficient agricultural technologies, including modern disease and pest management systems, becomes essential for increasing production stability and capitalizing on the productive potential of soybean crop.

The producer price for soybeans has experienced significant variations during the analysed period. If in 2017–2019 the price ranged between approximately 284–334 USD/ton, in 2021–2022 a sharp increase is recorded, with the price reaching 500,7 USD/ton in 2021 and 497,4 USD/ton in 2022. This increase is determined by the increase in demand on the global market, the increase in the costs of agricultural inputs and the disruptions of supply chains at the international level. In the period 2023–2024, a relative reduction in prices is observed, stabilizing in the range of 367–389 USD/ton.

The evolution of the Producer Price Index (PPI) for soybeans in the Republic of Moldova during 2017–2025 reflects the cyclical changes in the agricultural market, influenced both by internal production factors

and by the dynamics of the international agricultural market (Figure 2).

The index, calculated with the base 2014–2016 = 100, highlights significant variations in the price level at the level of agricultural producers. In the first years of the analysed period, a downward trend of the index is observed. Thus, in 2017 the index recorded a value of 103.55, which indicates a level relatively close to the reference period. In 2018 it drops to 98,56 and in 2019 it is significantly reduced to 87,74 reflecting a decrease in producer prices for soybeans. This evolution can be associated both with the increase in supply on the regional market and with price fluctuations on the international oilseed market.

Since 2020, the producer price index has been recording a sharp increase, reaching 107,05 indicating a recovery in prices at the level of agricultural producers. The upward trend is accentuated in 2021, when the index reaches 155,54 and in 2022 the maximum level of the analysed period is recorded, at 165,17. This significant increase can be explained by the increase in demand for agricultural products on the global market, the increase in production costs (agricultural inputs, energy, fertilizers) and the disruptions of supply chains at the international level.

In the period 2023–2025, a price correction trend is observed, with the index decreasing to 117,34 in 2023, increasing slightly to 120.80 in 2024 and reaching 115,52 in 2025. This evolution suggests a relative stabilization of the market after the sharp increases in previous years, but the index level remains higher than in the period 2017–2019.

	2017	2018	2019	2020	2021	2022	2023	2024
Producer price (USD/ton)	318.6	333.8	284.1	351.7	500.7	497.4	367.7	388.9
Producer Price Index	103.55	98.56	87.74	107.05	155.54	165.17	117.34	120.8

Fig. 2. Evolution of the producer price and the Producer Price Index for soybeans in the Republic of Moldova for the period (2017–2025)
Source: developed by the authors based on data from the National Bureau of Statistics [14].

The correlation of these indicators highlights the fact that the soybean market in the Republic of Moldova is characterized by a high degree of volatility, determined by the interaction between climatic factors, agricultural productivity and price dynamics on the international market. Under these conditions, the profitability of the crop depends largely on the ability of agricultural producers to apply efficient cultivation technologies and manage the risks associated with climate change and market fluctuations.

Therefore, the results of the economic and statistical analysis confirm the importance of implementing high-performance agricultural technologies and modern crop management practices, including diseases and pests, which would contribute to increasing productivity and stabilizing soybean production in the Republic of Moldova. This approach is essential for strengthening the competitiveness of agricultural producers and for the sustainable development of the agri-food sector.

The evolution of foreign trade in soybeans from a quantitative point of view in the Republic of Moldova in the period 2017–2024 reflects the dynamics of domestic production, fluctuations in demand on the international market and structural changes in the agricultural sector (Figure 3).

The volume of exports and imports highlights the fact that the Republic of Moldova has traditionally been a net exporter of soybeans, but in recent years there has been a significant increase in imports, which indicates changes in the structure of the domestic market and supply chains.

During 2017–2020, soybean exports had a dominant share in the foreign trade of this crop. The volume of exports ranged between 12,8 thousand tons and almost 28 thousand tons, with the maximum level being recorded in 2019, when exports reached 27,986 tons, with a value of approximately 9,9 million USD. This evolution can be explained by the relatively high level of domestic production and the constant demand for soybeans on foreign markets.

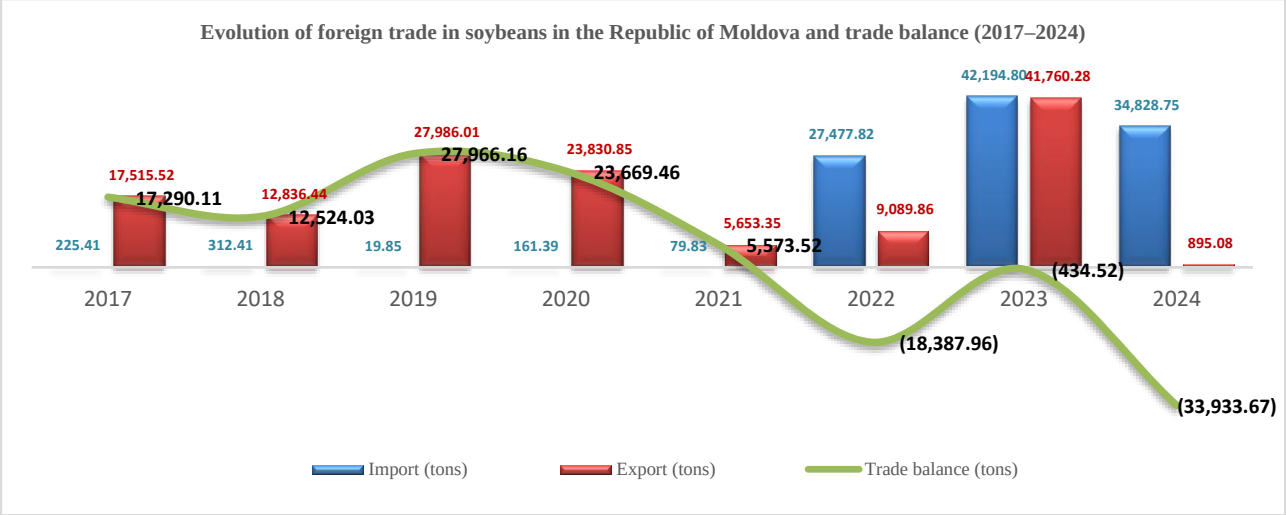

Fig. 3. Analysis of the evolution of the quantitative foreign trade in soybeans in the Republic of Moldova and the trade balance (2017–2024) in tons

Source: developed by the authors based on data from the National Bureau of Statistics [14].

During the same period, imports were insignificant, ranging between approximately 20 and 312 tons, which confirms the predominant orientation of the sector towards exports. In 2021, a sharp decrease in exports is observed, which decrease to 5,653 tons, and their value decreases to approximately 3,4 million USD. This evolution can be associated with the reduction in agricultural production in the context of unfavourable climatic conditions and increased uncertainty in agricultural markets.

At the same time, imports remain low, staying below 100 tons, indicating a relatively low dependence on the external market for domestic supply.

A significant change occurs starting in 2022, when soybean imports increase sharply to approximately 27.5 thousand tons, with a value of over 11.6 million USD. This trend is accentuated in 2023, when imports reach 42.2 thousand tons, worth almost 20 million USD, reflecting a significant increase in domestic demand for raw materials for the food industry and the livestock sector. In the same year, exports increase considerably, reaching 41.8 thousand tons, indicating an intensification of trade flows and a more pronounced integration of the Republic of Moldova in the regional oilseed trade. In 2024, a drastic reduction in exports is observed, which decrease to approximately 895 tons, while imports remain at a relatively high level of over 34.8 thousand tons. This evolution suggests a reorientation of trade flows, possibly determined by the decrease in domestic production or the increase in domestic demand for soybean processing.

The analysis identifies 2 periods of the evolution of the trade balance in which the first period between 2017–2021, the Republic of Moldova is a net exporter of soybeans, the trade balance being positive, and in the second period between 2022–2024, a structural change is observed, with imports exceeding exports, which indicates an increase in domestic demand (Fig. 4).

For these reasons, we need to apply an integrated management based on modern soybean cultivation technologies at the protection phase.

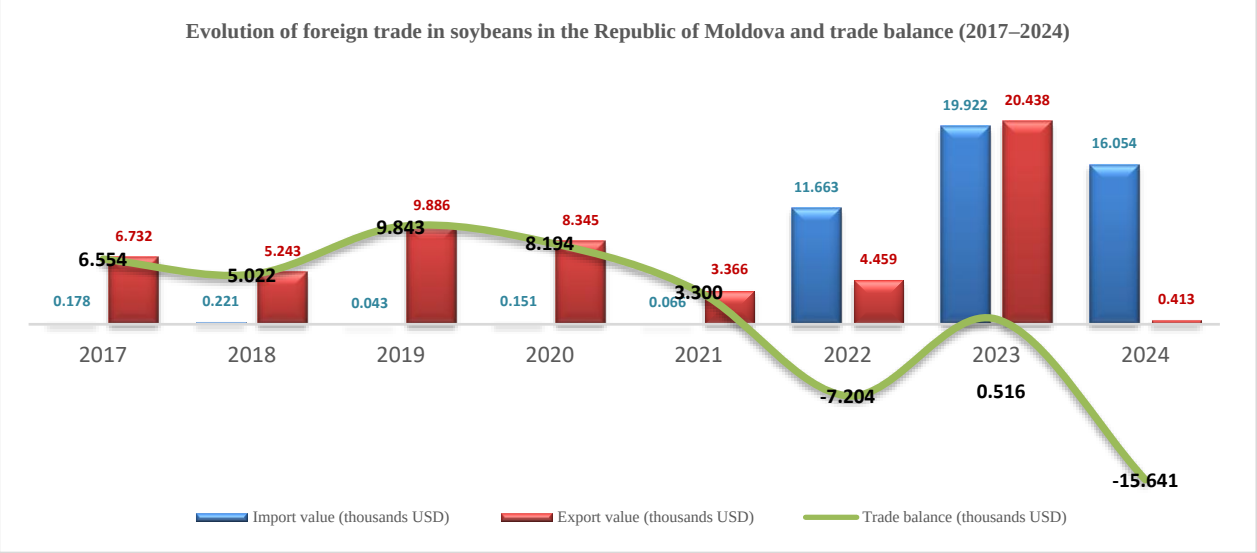

Fig. 4. Analysis of the evolution of the value of foreign trade in soybeans in the Republic of Moldova and the trade balance (2017–2024) in USD
Source: developed by the authors based on data from the National Bureau of Statistics [14].

Integrated management of harmful organisms in soybean production

To obtain high soybean yields and to react in a timely manner to various situations that may influence production, periodic and well-planned records are necessary. During the vegetation period, when various works are carried out on the plots and field visits are frequent. However, after covering the interval between the rows, the soybean sectors were periodically investigated. Control of soybean crops and recording observations should be implemented according to the following periodicity and scheme:

• weekly control to note potential problems and make decisions on interventions that are required to solve them in the phases of plant development;
• after sudden climate changes, storms, heavy rains, droughts, hail, frequent controls;
• maintaining and evaluating records of all works during the soybean crop vegetation period is an effective long-term method for detailed adaptations of agronomic practices and cost control;
• weekly control is performed for each plot and variety separately;
• control of soybean crops must ensure a detailed adaptation of agricultural practices and ensure the application of the most efficient and economical agronomic practices, suitable for a particular plot;
• regardless of the costs and prices for inputs to soybean cultivation, it is necessary to optimize agronomic practices and costs, which can ensure maximum profit;
• it is recommended to keep records for each plot on the preceding crop, period, plowing depth, herbicides, harvest period, production, marketing, etc. It is also required to keep records of all expenses with inputs for soybean crops, receipts of income from sales of the basic product (grains) and secondary products (weeds and straw) (Oancea, 2010; Starodub, 2008; Gherciu & Dima, Manual, 2020; Timuș &Fala, 2021) [17, 25, 12, 26].

A significant link in the integrated management of soybean crops are invasive weeds. The main source of weeding in soybean plantations is organic weed residues and seeds in the soil, and another source is the wind that disperses weed seeds. Integrated weed control management is methods of managing weeds on a more sustainable basis by combining biological, cultural, physical and chemical means, so as to minimize economic, health and environmental risks (Constantinescu & Sinulescu, 2014) [8].

Weed control is applied through a complex of measures framed in an economic system that provides for some preventive methods, agrotechnical prophylaxis and finally, as an exception, chemical protection management intervenes. The complex of measures includes the methods in the order in which they are applied and the execution indices of each method. The application of preventive methods of weed control provides for the implementation of:

• sowing with conditioned seeds;
• use of composted organic fertilizers, with a low degree of infestation with weed seeds;
• destruction of weed outbreaks on uncultivated areas;
• cleaning irrigation water from weed seeds;
• timely and qualitative performance of soil work;
• timely and correct harvesting of crops. The application of agrotechnical methods of weed control provides for the implementation and observance of:
• crop rotation, so that crop plants ensure a significantly superior competition to weeds for vegetation factors;
• soil work, by destroying weeds before sowing and during vegetation;
• plant nutrition regime, through randomized and reasoned use of fertilizers;
• conditioning the seed material, by cleaning it of weed seeds.
• mapping weeds in the fields by species, number and mass.

At the same time, in the application of effective management, important in soybean are the invasive insect complexes. The respective transactions demonstrate the capacity of the Republic of Moldova to function as a logistic hub. About 180 harmful organisms can damage soybean plants, of which 150 belong to the insect class, and 30 to other classes, and only 25 of these species can be considered agro-economically important for soybean plants in the environmental conditions of the Republic of Moldova (Busuioc, 2002; 2006) [7, 6]. The vast majority of these pests are polyphagous and oligophagous, and only a small number of 10-13 of them are associated only with soybean plants. However, Integrated Pest Management (IPM) plays an important role in the protection of soybean plants, as it represents a limiting factor in soybean production (Croitoru and Panuta, 2017; Timuș, A and Fala, 2021) [9, 26].

At the same time, having good experience especially in crop rotation, timely and qualitative sowing, fertilization, plowing, compliance with maintenance work, invasive weed control, irrigation and harvesting in optimal terms, all of these have an important role in Integrated Pest Management. As for the high plant density per hectare, soybean is less dangerous compared to other phytotechnical crops such as: sugar beet, maize, rapeseed and sunflower. All procedures that lead to the rapid and healthy development of soybean plants are considered beneficial in reducing the damage caused by invasive organisms. To combat all invasive organisms in soybean crops, the following measures must be observed:

• regular and systematic phytosanitary monitoring in the detection of invasive species;
• carrying out control measures when pest populations threaten the “economic damage” threshold, in which case the costs of applying a chemical treatment remedy need to be justified;
• when chemical management is necessary, the lowest effective amount of pesticide product is applied using the appropriate equipment, which is well calibrated.

In the Republic of Moldova, the most dangerous pests established in soybean crops are: wireworm (*Agriotis sputator* L.), fruit borer (*Heliocoverpa armigera* Hbn), pod moth (*Etiella zinckenella*) and mites (*Acaridae* sp.). Against pod moth, spraying of seeds with approved insecticide preparations in biologically effective doses, recommended by agricultural specialists, is applied. Entomoparasitic evidence carried out simultaneously in soybean crops highlighted the presence of 13 species of harmful insects from 4 orders of Coleoptera, Lepidoptera, Hymenoptera and Diptera with oligo-polyphagous trophic, specialized as invasive pests of soybean plants as well as other species of Fabaceae, cereals, field technical.

Integrated disease management. Diseases in soybean crops are associated with plant germination and significantly affect plants annually and cause significant damage. More than 100 different pathogens can cause various diseases in soybean. Fortunately, (Staradub 2008; Roșca et al, 2011; Roșca, 2017; Bădărău & Bivol, 2013) [23, 20, 21, 2] in the Republic of Moldova, diseases also cause major production losses, especially in years with abundant rainfall and temperatures specific to disease development. Some effective measures currently applied to soybean crops to prevent infection are:

• crop rotation, especially if there have been intense disease attacks in previous years;
• the use of healthy seeds for sowing prevents the introduction of diseases into the plots;
• too dense crops are prone to falling and create a favourable microclimate for certain diseases;
• the application of fungicides for disease control is not a common practice, but only an exception.

The most numerous and harmful diseases are pathogenic fungi, followed by bacteria and viruses. Several types of diseases in soybean plants appear more intensely in certain poorly maintained sectors, while others are not encountered or appear sporadically. In river meadows and water basins, the most widespread foliar diseases in soybean plants are soybean blight and bacterial blight (*Pseudomonas syringae* pv. Glycinea), and the main stem diseases are white rot (*Sclerotinia sclerotiorum*) and stem canker (*Diaporthe phaseolorum* var. *glycinea*). As a result of our investigations in recent years, the most widespread diseases in soybean culture throughout the territory of the Republic of Moldova have been reported practically in all sectors detected, such as: blight (*Peronospora manshurica*), bacterial blight (*Pseudomonus glycinea*), soybean mosaic caused by the virus belonging to the Soja virus species. In recent years, rot infections, called Fusarium wilt caused by the pathogen (*Fusarium* spp.), are increasingly associated. Route surveys and laboratory analyses of soybean samples and plants in the dynamics of growth and development phases, we found the presence, diversity and the invasive impact of 11 key diseases on soybean crops, established practically in all investigated sectors with differences in the frequency and intensity of attack values. More frequently and extensively manifested the pathogens that caused more serious the following diseases: root rot - *Fusarium* sp., downy mildew - *Phytophthora sojae*, ascochyta - *Ascochyta soyaecola*, powdery mildew - *Erysiphe communis*, rust - Uromyces sojae Syd., which reached attack values from 7 to 45%, both in the first vegetation period and in the second period, favoured by the alternations of precipitation and daily and monthly temperatures. The presence of diseases in lower values was established such as: cercospora - *Cercospora sojina*, bacterial blight - *Pseudomonas glycinea*, bacterial wilt - *Pseudomonas solanacearum*, also conditioned by environmental factors and advanced cultivation technologies.

Currently, soybean diseases are controlled and managed by cultivation practices and methods such as: the use of resistant or less resistant varieties, crop rotation, healthy and quality seed material. These practices reduce the costs of soybean cultivation and are more environmentally friendly. If considered as indirect measures, pesticides should not be used to manage and control soybean diseases, as they reduce the costs of cultivation and are more environmentally friendly. Thus, the control and management of soybean diseases will be based on the application of the following preventive measures:

• creation and cultivation of resistant or tolerant varieties to specific diseases;
• cultivation of resistant varieties allows the prevention of soybean disease;
• cultivation of late varieties, which are mostly less sensitive than early ones, allows the avoidance of bacterial blight;
• soybean genotypes with a short vegetation period can avoid white rot and stem canker infections, which have a high potential for damage to plants;
• the intensity of white rot and stem canker damage to crops can be managed or controlled by applying cultivation methods: such as early

sowing, but on the other hand early sowing favours grey rot;
• the optimal sowing time is recommended for each zone or microzone, where soybean is grown in order to hasten the rapid and uniform emergence of soybean plants, to avoid seed rot due to prolonged seed germination periods;
• crop rotation is an important practice in the management and control of diseases in soybean plants, because many disease pathogens survive on plant debris in the soil;
• growing soybeans in the same field is not recommended for at least 3-5 years;
• it is preferable that the preceding crops for soybeans are small-seeded crops, such as corn and sugar beet;
• early-maturing varieties are less branched and thus can tolerate higher density, while later-maturing soybean varieties are more robust and require lower plant density;
• high density of soybean plants makes plants weak and prone to falling, which ultimately favours the outbreak and spread of disease infection;
• healthy, certified and high-quality seeds are considered some of the best disease management practices;
• the use of own-produced and uncertified seeds, with an unknown health status, significantly increases the risk and strength of specific disease infection.

CONCLUSIONS

The analysis of the evolution of soybean production in the period 2017–2024 demonstrates that this crop is highly sensitive to the variability of climatic conditions and the level of applied agricultural technologies. Under these conditions, the implementation of efficient cultivation technologies, including modern disease and pest management systems, as well as the adaptation of technologies to climate change, are essential factors for stabilizing and increasing soybean production in the Republic of Moldova.
In the last years of the analysed period, a relative stabilization of the cultivated area is observed, standing at around 25–27 thousand hectares, which reflects a gradual adaptation of agricultural producers to market conditions and technological requirements of this crop. Thus, the analysis of the sown area confirms the importance of soybean in the structure of agricultural crops in the Republic of Moldova and highlights the need to apply efficient agricultural technologies to increase productivity and production stability in conditions of climate variability.
The analysis of the producer price index for soybean highlights a relatively high volatility of prices on the agricultural market, determined by the interaction between climatic factors, the level of agricultural production and the dynamics of international markets. For agricultural producers in the Republic of Moldova, these price fluctuations directly influence the profitability of soybean cultivation and decisions on the expansion or reduction of cultivated areas. In this context, the adoption of efficient agricultural technologies and increasing crop productivity become essential factors for maintaining the competitiveness of soybean production on the agricultural market.
The analysis of foreign trade in soybeans highlights a significant volatility of trade flows, determined by the interaction between domestic agricultural production, the level of prices on the international market and the demand of the agro-industrial sector. The increase in imports in recent years indicates a trend of deeper integration into regional trade chains and emphasizes the need to consolidate domestic production by applying efficient agricultural technologies. In this context, increasing soybean productivity and stabilizing production become essential factors for maintaining the competitiveness of the agricultural sector and reducing dependence on imports.
The integrated protection management estimates the remedial invasive impact on 11 key diseases in soybeans established practically in all investigated sectors with differences in the frequency and intensity of attack values. More frequently and extensively, pathogens that caused more serious diseases were manifested: root rot - *Fusarium* sp., downy mildew - *Phytophthora sojae*, ascochyta - *Ascochyta soyaecola*,

powdery mildew - *Erysiphe communis*, rust - *Uromyces sojae* Syd., cercospora - *Cercospora sojina* Hara, bacterial blight - *Pseudomonas glycinea* (Coerper) Stapp, bacterial wilt - *Pseudomonas solanacearum* Smith., conditioned equally by environmental factors and advanced cultivation technologies.

The results of the survey conducted on the invasive insect complexes established in the soybean crop have highlighted the presence of 13 species of parasitic insects, with oligo-polyphagous trophic, specialized as invasive pests of soybean plants as well as other species of Fabaceae, cereals, field crops. More dangerous complexes associated consecutively throughout the vegetation period such as: wireworm species of the genus *Agriotis* sp., leaf weevils belonging to the genus *Tanymecus* sp, followed by the larvae-caterpillars of the noctuid lepidopterans of the bull, *Helicoverpa armigera*, Seedworm - *Delia platura*, Tobacco thrips - *Thrips tabaci*, Pod moth - *Etiella zinckenella*, various species of aphids, especially colonies belonging to the species *Aphis glycine*, which also act as vectors of pathogenic diseases of root and stem rot.

We suggest that these results of our research are used by some economic agents in the cultivation of soybean production as a significant and applicable link in the integrated protection management specific to soybean cultivation, effective in reducing the density of the numerical population, frequency and intensity of parasitic-pathological attack, by applying and adjusting mixed procedures and remedies, through control, prevention, prophylaxis, with preventive phytosanitary monitoring and specific complex records in the conditions of the Republic of Moldova.

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THE ROLE OF PUBLIC POLICIES IN STRENGTHENING THE RESILIENCE AND COOPERATION OF AGRICULTURAL PRODUCERS IN THE CIS REGION

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Abstract

Cooperation is widely recognized as one of the key solutions to the multiple challenges faced by agricultural producers, including limited market access, low bargaining power, and vulnerability to economic shocks. The establishment and development of agricultural cooperatives and other forms of producer associations can be viewed as an evolutionary process, motivationally driven by the socio-economic interests of agricultural producers. The purpose of this article is to assess how public policies have influenced the formation, development, and effectiveness of agricultural producer cooperation in selected post-Soviet countries, with particular attention to their role in supporting resilience, market integration, and sustainable agricultural development. This article analyses the impact of relevant public policies on the development of agricultural producer cooperation in the post-Soviet period in Armenia, Georgia, the Republic of Moldova, and Kazakhstan. Using a comparative analytical approach, the study evaluates the role of various state policies in shaping cooperative development and examines both the similarities and differences in policy design and implementation across the selected countries. The findings highlight that while institutional frameworks and support instruments differ across national contexts, public policies play a decisive role in strengthening cooperative structures, enhancing producers' resilience, and fostering sustainable agricultural development. The article contributes to the academic debate on agricultural cooperation and public policy in transition economies and provides insights relevant for policymakers seeking to promote inclusive and resilient agricultural systems.

Key words**:** *cooperative, cooperation of agricultural producers, public policies*

INTRODUCTION

The post-Soviet countries, whether located in Eastern Europe, the Caucasus or Central Asia, share similarities stemming from common economic realities shaped by the Soviet legacy.

Agriculture plays an important role in ensuring the socio-economic development of rural areas, as well as in the overall economy of a major part of the post-soviet countries. The development of agriculture and rural areas is affected by a series of similar challenges, such as excessive fragmentation of agricultural land, low productivity and product quality, limited access to financing resources, inputs and markets etc.

Challenges in the development of agriculture and rural areas highlight the relevance of promoting cooperation of agricultural producers, as one of the most efficient and feasible solutions. All four states have recorded certain progress in the development and implementation of policies aimed at promoting cooperation among agricultural producers. The comparative analysis of these specific experiences contributes to the development of a broader analytical perspective and the identification of alternative criteria and solutions for the evaluation and identification of measures and criteria for evaluating and improving the effectiveness of such policies.

In the Eurasian space, significant differences can be observed in the development of agricultural cooperatives, starting with the experience of agricultural cooperatives in Europe, including in the member states of the European Union on the one hand, and ending with the post-socialist and post-communist states on the other. There is a significant gap regarding the level of development and spread

of agricultural cooperatives, the quality of government policies and the extent to which a favourable legislative framework has been established. These differences are both conceptual and empirical, being rooted in the Soviet period and continuing in some forms to the present day (Lerman & Sedik, 2014), (Lerman, 2013), (Altshul, 2001), (Groeneveld, 2016), (Kim et al., 2018) [20, 21, 19, 1, 6, 17]. Since the 1990s, the countries under review have been in a process of transition from a planned economy to a market economy. Economic and institutional reforms have involved the abolition of centralized control and planning, the privatization of the means of production and agricultural land, the reduction of government intervention in the domestic market, and the liberalization of trade (Droždz & Jurkėnaitė, 2017), (ILO, 2001), (Kim et al., 2018), (Lerman & Sedik, 2014a) [4, 15, 17, 20].

The role of the agricultural sector in these countries is quite important and is determined by the share of the rural population, the population employed in agriculture, and the contribution of the sector to GDP. Following the decline in agricultural production, governments have launched reforms to stimulate the development of the agricultural sector and increase productivity, in order to maintain the sector as an important field of activity for engaging the rural workforce (Ignat at al., 2017), (Altshul, 2001), (Droždz & Jurkėnaitė, 2017), (Kim et al., 2018) [14, 1, 4, 17].

Although the policy models applied have shown some important differences, the priorities contained in the policy documents of these states are very close, focusing on increasing production and ensuring food security, enhancing competitiveness and productivity, and diversifying markets. Challenges that the governments of these states still need to address include a series of phenomena affecting stability and development, such as high rate of poverty in rural areas, the large number of small producers, low productivity and product quality, limited access to financing resources, inputs markets (Ignat at al., 2017), (Altshul, 2001), (Droždz & Jurkėnaitė, 2017), (Kim et al., 2018), (Lerman & Sedik, 2014a) [12, 1, 4, 20].

Cooperation among agricultural producers is recognized as one of the effective ways of addressing socio-economic challenges in rural areas and ensuring the development rural areas and agriculture. Policies and regulatory frameworks represent, along with historical, cultural, social and economic elements, important contextual factors for the promotion and activity of agricultural cooperatives (Ortmann & King, 2007), (LEI Wageningen UR, 2012) (IFAD, 2016), (Sauer et al., 2011) (IFAD, 2013), (Birchall, 2004), (COPAC, 1999) [23, 18, 10, 26, 8, 2, 3].

From a theoretical perspective, the analysis combines cooperative theory with collective action theory and an institutional perspective on post-socialist transformation. It considers the complexity of the factors impacting the collective actions, including economic rationale of agricultural cooperatives as member-based institutions, their viability through the alignment of the individual interest and collective objectives (Ostrom, 1990), (Ortmann and King, 2007) [24, 23]. In post-Soviet agricultural systems, public policy plays an extended role representing an important structural factor for shaping the broader process of agricultural restructuring (Petrick, 2021), [25]. It influences land relations, patterns of farm organization, access to capital, and the institutional conditions under which agricultural cooperation may re-emerge (Lerman and Sedik, 2014), [20]. Weak policy making capacity, lack of coherent sequence in the promotion of cooperatives may interact with existing asymmetries in access to land, capital, information and administrative resources. Support policies may become oriented toward short-term incentives, ensure a partial compliance with the objectives or the concentration of benefits among stronger actors, instead of evolving into durable collective action based on functional governance and shared economic interests (Howlett, 2004), (Schneider and Ingram, 1993), [9, 27].

Policies and legislation on agricultural producer cooperation adopted in the examined

countries show both similarities and important differences. Therefore, their analysis should pay particular attention to the way in which they interact with contextual factors and influence structural changes, as well as to the extent to which the promotion of agricultural producers' cooperation is carried out in accordance with internationally recognized cooperative values and principles (Münkner, 2002), (LEI Wageningen UR, 2012), (ILO, 2001), (IFAD, 2013), (Henrÿ, 2012), (Groeneveld, 2016), (COPAC, 1999), (Birchall, 2004) [22, 18, 15, 8, 7, 6, 3, 2].

The aim of the paper is to comparatively analyze how public policies, legislative and institutional frameworks and support interventions have shaped the evolution of agricultural producer cooperation in Armenia, Georgia, the Republic of Moldova and Kazakhstan in the post-Soviet period. The study starts from the idea that the development of cooperation should not be interpreted only as a response to common structural constraints, but also as an effect of the way in which cooperation was promoted, regulated and supported through public interventions. Through the comparative perspective, the paper aims to identify common patterns, the main constraints and the relationship between the types of intervention and the results recorded, in order to deepen the understanding of the conditions necessary for rethinking and improving measures to promote agricultural producer cooperation, so that it develops as a viable economic and institutional solution and supports the formation of functional and sustainable associative structures.

MATERIALS AND METHODS

The research examines the impact of relevant public policies on the development of agricultural producer cooperation in Armenia, Georgia, the Republic of Moldova and Kazakhstan in the post-Soviet period. In the case of Kazakhstan, the analysis focuses on the southern region of the country, where pedoclimatic and economic conditions are more comparable to those in Georgia, Armenia and the Republic of Moldova.

The research applies a comparative qualitative design, aimed at assessing the role of state policies in shaping the development of agricultural producer cooperation in selected cases. Methodologically, the study combines comparative policy analysis, review of legal and institutional frameworks and qualitative assessment of socio-economic and political factors influencing cooperation. This approach makes it possible to identify both country-specific trajectories and common patterns in the design, implementation and outcomes of cooperation support policies.

The analysis builds on findings generated within the project "Promoting Inclusive Horticultural Value Chains in Armenia, Georgia, Kazakhstan and Moldova", funded by the International Fund for Agricultural Development (IFAD), while expanding the assessment of subsequent developments and incorporating a prospective perspective. This combination of project-based empirical evidence and broader comparative interpretation allows for a more comprehensive understanding of how public policies, structural conditions and institutional configurations shape the development of agricultural producer cooperation.

The selection of the countries was based on their common post-Soviet background and comparable transformation processes, including the transition to market economies, agrarian reforms and farm fragmentation, the large number of small agricultural producers and experience of implementation of initiatives aimed at promoting producer cooperation. The focus was placed on countries or regions with relatively high value-added horticultural value chains, where joint investments may create stronger interest for cooperation.

The analysis is based on qualitative analytical framework structured around common dimensions such as legal and regulatory framework, policies and support measures, institutional arrangements, donor involvement and observed outcomes, including the impact on functionality, sustainability, inactivity or dissolution of cooperative structures. The article uses as reference for interpretation, contextual and impact evaluation analytical

data generated by broader project research, in particular referring to producer level and organizational factors influencing collective action, including subjective, internal governance and economic factors.

RESULTS AND DISCUSSIONS

Comparative context of agricultural producer cooperation development

The states analyzed present a series of structural characteristics that influence the development of agricultural producer cooperation. These include the disruption of cooperative development during the Soviet period, similar land reform processes, the prevalence of small and highly fragmented farms, limited access of small producers to markets, financial resources and post-harvest infrastructure, as well as high levels of rural poverty (Lerman & Sedik, 2014a) [20]. Accelerated transformations of the agricultural sector, migration and aging of the rural population, land abandonment, and the consolidation of large agricultural holdings tend to become dominant contextual factors.

The comparative analysis shows that these common structural features are manifested under different national conditions, shaped by variations in land consolidation, regional development patterns, economic resilience strategies of the rural population, support measures for agriculture and rural development, access to inputs and machinery, post-harvest and marketing infrastructure, cultural particularities, and the relief conditions in the areas where producers are located.

In all four countries, during the post-Soviet period was gained relevant experience necessary to improve measures and actions to support the development of agricultural cooperatives. The association of the image of former Soviet-style collective farms with modern cooperatives is no longer a significant barrier to their establishment and development. Information and promotion activities carried out by governments and donor organizations have contributed to increasing the level of awarnes and knowledge of the principles of cooperation among agricultural producers.

The factors that can influence the success or failure in the development of cooperatives can be identified to a greater extent at the level of objective factors, such as state policies, pedoclimatic conditions, the economic situation of farmers and the interventions of donor organizations, and to a relatively lesser extent at the level of subjective factors, such as mentality and cultural models. This applies to all four countries analyzed, without excluding the fact that cultural factors can influence the concrete way in which structural and institutional constraints are perceived and managed.

The size and homogeneity of agricultural holdings represent a significant determinant for the formation of cooperatives. Members of cooperatives tend to be agricultural producers who own larger land areas than the average of farmers who do not participate in such forms of association, except the cases where a large producer serves as the nucleus for the cooperative, which in most cases proven to be a simulation of cooperation process to ensure access to dedicated support.

The analyzed experiences indicates that the optimal number of cooperative members appreciated to be efficient is relatively small. In the Republic of Moldova, cooperatives operate efficiently with approximately 5–6 members, in Georgia with approximately 8 members, and in Armenia with approximately 30 members. At the same time, perceptions regarding the expansion of cooperatives in the near future differ between the analyzed countries, with a higher level of skepticism being observed in the Republic of Moldova and Georgia, compared to Armenia. (Ignat A. Țirigan S., 2016; Sirbiladze G., Memarnishvili N., 2016; Shen NGO, 2016) [11, 29, 28].

Over a longer period, cooperation in the Republic of Moldova and Western region of Georgia was driven primarily by the need for joint investments in specialized equipment, post-harvest infrastructure, and the joint organization of sales, while informal cooperation in activities such as input purchasing and joint cultivation was relatively

common. These forms of informal cooperation were generally not perceived as a sufficient basis for the formalization of cooperatives. In central and eastern Georgia, Armenia, and southern Kazakhstan, cooperation was more often associated with the need for shared access to means of production, inputs, transport, and production organization, which were considered sufficient for establishment of cooperatives. (Ignat A., Țirigan S., 2016, 2017; Sirbiladze G., Memarnishvili N., 2016; Shen NGO, 2016; Kazakh Research Institute of Economics, Agribusiness and Rural Development, 2016; Lerman & Sedik, 2014b) [11, 12, 29, 28, 16, 20].

The process of forming cooperatives is slower among subsistence agricultural producers, who show a higher level of reluctance. The main challenge is to ensure the functionality of the cooperative, as this category of producers frequently faces limited access to the equipment necessary for cultivating the land. The interest in establishing cooperatives is significantly influenced by the availability of support programs offered by the state and donor organizations, especially in the form of financial support or access to agricultural machinery and equipment. The dependence on external support indicates that the initiative for cooperation is often determined by the incentives offered by support programs rather than by an autonomous economic motivation of agricultural producers.

Another set of challenges is related to farmers' concerns regarding the ownership regime of agricultural land and cooperative assets, as well as the level of understanding of how cooperatives can contribute to economic development at both, the individual farm and rural community levels.

Advisory support, including the facilitation of the dialogue and mediditation of the relations between cooperative members in difficult situations, is one of the needs identified in all the countries analyzed. The need for such support is mentioned both at the stage of establishing cooperatives and during their operation, being essential for managing legal procedures, organizing activities, understanding specific challenges and defining the vision and development objectives of the cooperative, as well as for ensuring the option of mediation in case of divergences between cooperative members. (Ignat A., Țirigan S., 2018) [13].

The esential challenges in promoting the formation of agricultural cooperatives are less determined by insufficient level of general knowledge about cooperation, a more from the lack of motivation and expectations of farmers regarding the results of such activity. A common trend observed in all four countries analyzed is the predominant orientation of agricultural producers towards obtaining immediate benefits, especially in the form of subsidies, rather than engaging in long-term collective activities, characterized by uncertainty and risk.

Cultural barriers such as low levels of interpersonal trust, difficulties in identifying and fromation ot the leaders, ensuring their integrity, and effectively organizing internal communication and democratic processes are common systemic factors for all countries examined. Advisory assistance tailored to specific conditions on the ground has the potential to play a key role in overcoming these constraints and strengthening the functionality of cooperatives (Ignat A., Țirigan S, 2018) [13].

Support policies and donor involvement

Fragmentation and discontinuous nature of support mechanisms represent one of the main structural constraints in the development of agricultural cooperatives in case of all analyzed countries. In the absence of stable policy frameworks, dedicated functional institutions and effective coordination between interventions, support was provided mainly through temporary programs and projects, which limits the accumulation of institutional capacity and the sustainability of results. In Armenia, this problem was accentuated by the involvement of multiple donor organizations applying their own methodologies, which in some cases leads to partial implementation of planned activities (Shen NGO, 2016) [28]. In Georgia and Kazakhstan support tend to be provided through short-term programs, poorly correlated and without guarantees of

continuity (Gigauri M., 2017; Kazakh Research Institute of Economics, Agribusiness and Rural Development, 2016) [5, 16]. In the Republic of Moldova, field intervention functions were largely carried out through projects, while state policy was focused mainly on applying of certain schemes of financial support that demonstrates their inefficiency to stimulate cooperation without a combined approach previously covered through the involvement of donor organizations (Ignat A., Țirigan S., 2017) [12].

The promotion of cooperation is perceived, in all four countries analyzed, as a public policy instrument aimed at facilitating the integration of agricultural holdings, in order to achieve economies of scale, increase competitiveness, improve access to markets and reduce rural poverty. In this sense, cooperation is formally reflected in the national agricultural and rural development strategies.

Only in the case of Kazakhstan is there a long-standing public policy, which provides mechanisms for access to financial resources to subsidize the costs of establishing cooperatives, implementing pilot programs and conducting information and promotion campaigns. Despite this relatively developed framework, its predominantly formal character and low efficiency in implementation limit the real impact on the development of agricultural cooperatives (Kazakh Research Institute of Economics, Agribusiness and Rural Development, 2016) [16].

In the case of the Republic of Moldova, the long-term approach to supporting producer groups is based on providing financial support ranging from 1% to 15% of the value of sales, for a period of up to 5 years from their establishment. However, the support model remains focused mainly on the initial stage of operation, while after this period the groups tend to disappear from the authorities' attention, especially when they do not initiate investments to access increased support ensured through invement support measures (Ignat A., Țirigan S., 2017) [12].

In the case of Georgia, the policy framework applied covers a broader range of instruments, including financing, advice and institutional support. However, its effectiveness and sustainability are limited by its temporary nature and significant dependence on the European Union-funded ENPARD programme (Gigauri, 2017) [5]. International donor support plays an important role in ensuring access to expertise and promotion in all four countries. Support is provided for the design and implementation of projects, as well as their financing (Ignat A., Țirigan S., 2018) [13].

Donor support plays a key role in promoting cooperation between agricultural producers at all levels of intervention, including advocacy, policy development, knowledge and know-how transfer, grassroots activities, and financial support measures. The involvement of non-governmental organizations has contributed to strengthening a representation and lobbying framework for promoting the interests of agricultural producers. (Ignat A., Țirigan S., 2017) [12].

The role of the Government in relation to donor organizations differs significantly between the analyzed countries. In Armenia, donor organizations continue to play a predominant role, with initiatives and decisions on interventions being largely influenced by them. The adoption of the Law on Cooperatives (2015), developed with the support of the European Union, established a legal framework for the development of agricultural cooperation and created premises for strengthening the role of the state in coordinating policies in the field. However, despite the existence of the regulatory framework and the continuous support of international programs, implementation remains dependent on external initiatives, and the institutional role of the state in integrating and coordinating these interventions is still limited (Shen NGO, 2016) [28].

In Georgia, a relatively advanced integration of the activities of donor organizations with those of the Government is ensured, allowing for more efficient coordination of interventions in the field of rural development and agricultural cooperation (Sirbiladze G., Memarnishvili N., 2016) [29].

A disadvantage of this model is the correlation of the implementation deadlines of national policies and programs with the funding cycles of external programs and projects, which affects the continuity of interventions and the sustainability of long-term results. Only in the case of Georgia, a specialized institutional structure was initially established for the implementation of government policies in the field of agricultural producer cooperation, namely the Agency for the Development of Agricultural Cooperatives. Later, this structure was integrated into a broader institution responsible for rural development, with cooperation being treated as part of an integrated framework of agricultural and rural policies. In the Republic of Moldova and Armenia, the existing institutional framework is used, complemented from time to time by implementation units and/or coordination teams related to programs implemented with the support of donor organizations (Ignat A., Țirigan S., 2018) [13].

In the case of the Republic of Moldova, although a certain synergy with donor organizations was ensured, state policies also manifest elements of autonomy, especially through the agricultural payment system (Ignat & Țirigan, 2016) [11]. In the case of Kazakhstan, access to expertise provided by donor organizations plays an important role in the process of developing cooperation policies. However, implementation and financing are mainly carried out through state programs. At the same time, inefficient coordination of actions, institutional fragmentation, as well as limitations in the allocation of financial resources are the main barriers to achieving the proposed objectives (Kazakh Research Institute of Economics, Agribusiness and Rural Development, 2016) [16].

Table 1. Comparative policy and institutional framework for agricultural producer cooperation

Analytical dimension	Armenia	Georgia	Republic of Moldova	Kazakhstan
Legal and regulatory framework	Law on Agricultural Cooperatives adopted in 2015; further harmonisation with fiscal and support policies remains necessary.	Law on Agricultural Cooperatives adopted in 2013; legal development strongly linked to ENPARD-supported reforms.	Dynamic legal evolution; separate producer group regime introduced since 2013; fiscal and implementation barriers persist.	Fragmented framework until 2015; unified Law on Agricultural Cooperatives implemented since 2016.
Institutional arrangements	State coordination remains limited; implementation strongly influenced by donor-supported initiatives.	Initially had a specialized agency for cooperative development; later integrated into a broader rural development institution.	Existing institutional framework is used; support based on payment/subsidy mechanisms, advisory component ensured only within donor supported initiatives.	State-led implementation through public programmes; fragmented and underfunded mandates.
Main support model	Predominantly donor-driven; support often linked to equipment, training and project-based interventions.	Mixed model combining donor support, financing, advisory assistance and institutional development, especially through ENPARD.	Financial support for producer groups linked to sales value; investment support available, but limited post recognition consolidation.	Public policy and state programmes focused on establishment, pilot initiatives, machinery, procurement and promotion.
Role of donors	Donors play a predominant role in initiating, financing and shaping interventions.	Donor support is relatively well integrated with government policies, but sustainability depends on external funding cycles.	Donor projects are important for field interventions. State maintains a more autonomous role through the agricultural payment system.	Donor expertise contributes to policy development, while financing and implementation are mainly ensured by the state.
Main institutional weakness	Limited state coordination and dependence on external initiatives.	Continuity of support is affected by donor programme cycles and limited long-term advisory mechanisms.	Weak post-recognition support and insufficient institutional follow-up after initial support periods.	Implementation affected by coordination challenges and limited operational effectiveness of support

Source: Authors' synthesis.

The analysis of the evolution of the legislative framework in the four countries highlights the existence of two distinct stages, which can serve as a central reference point for understanding the transformations in the field of agricultural cooperation. The first stage was dominated by the persistence and partial adaptation of the Soviet model, and the second by its gradual revision, under the influence of international practices and new economic needs. However, the transition to a coherent legislative and institutional model remains incomplete in all the countries examined, as a result of both a reduced institutional capacity and a lack of political will.

In all the countries analyzed, the development of the legal framework in the field of

cooperation faces similar challenges, especially in terms of overcoming the institutional and conceptual legacy of the Soviet period, as well as integrating the lessons learned from post-independence agricultural reforms. Common deficiencies are also manifested in other dimensions, such as: the difficulty of adapting legislation to the specific environmental conditions and structure of the agricultural sector; the slow pace of adopting legislative amendments; the lack of a strategic approach to the development of cooperatives; the insufficiency of economic incentives as well as the difficulties in ensuring a continuous adjustment of the legal framework.

Influenced by the region's historical model, the legislative framework has maintained the distinction between production and service cooperatives. This distinction separates cooperatives focused on joint agricultural production from those focused on providing inputs, mechanization, processing, storage or marketing for members. In all the countries analyzed, agricultural cooperation is mainly designed around the direct participation of farmers, especially individuals. In Georgia, this logic is maintained at the level of basic cooperation, even though the law also allows the participation of other agricultural cooperatives as members, and legal entities as associate members (Gigauri, 2017) [5].

At the same time, in countries where access to agricultural machinery and equipment is a major constraint (Armenia, Georgia, Kazakhstan), maintaining the status of non-profit organizations for technical service cooperatives has limited their development, despite the financial support provided through various programs. (Ignat A., Țirigan S., 2018) [13].

The legislative framework on agricultural cooperatives in the four countries highlights both structural convergences and relevant differences in the pace and depth of reforms. In the Republic of Moldova, the regulatory evolution has been one of the most dynamic, from the general regulations introduced in the 1990s to the specific laws adopted in the period 2000–2002, later complemented, since 2013, by establishing a distinct regime for producer groups. This evolution has allowed for a functional separation between the legal regulation of cooperatives and the support policies addressed to market-oriented associative structures. However, the sophistication of the regulatory framework has not been accompanied by a similar capacity for implementation. Including in the fiscal plan, the adjustments made have not led to the effective elimination of barriers, and persistent difficulties in interpretation and application have continued to affect economic efficiences of the cooperatives. (Ignat A., Țirigan S., 2016; Ignat A., Țirigan S., 2017) [11, 12].

In Armenia, the adoption of the Law on Agricultural Cooperatives in 2015 created the necessary legal basis for the development of cooperation, but the regulatory framework continues to be affected by fragmentation and incomplete harmonisation with other relevant regulations, particularly in the area of iscal and support policies. Consequently, the central problem is no longer the absence of the legal framework as such, but its limited capacity to provide a sufficiently coherent legal and economic regime for the functioning of cooperatives as viable entities. (Urutyan V., 2017) [30].

In the case of Georgia, the legal framework on agricultural cooperatives is regulated by a combination of general and specific normative acts. The Law on Entrepreneurship continues to establish the general rules for the establishment and operation of economic entities, including cooperatives, but their activity is specifically regulated by the Law on Agricultural Cooperatives adopted in 2013. Although there is a formal delimitation between the legislative framework and the supporting policies, in practice they are closely interconnected. Certain provisions of the normative framework remain relatively general and do not fully reflect the current economic needs of cooperatives. Its development has remained closely linked to the impetus of externally supported programmes, in particular in the context of ENPARD. From this perspective, the Georgian case highlights the risk that the modernization of the normative framework

remains dependent on external priorities and resources, without being fully anchored in an internal logic of institutional continuity. (Gigauri M., 2017; Ignat A., Țirigan S., 2018) [5, 13].

In Kazakhstan, until 2015, the legislative framework for agricultural cooperatives was fragmented, consisting of several normative acts regulating different forms of association. This approach generated inconsistencies and limitations, including restrictions on income distribution and the lack of effective economic incentives. The adoption of the Law on Agricultural Cooperatives, implemented since 2016, unified the regulatory framework and introduced the status of commercial entities for cooperatives, allowing for the distribution of income to members and strengthening the role of the state in their development. (Kazakh Research Institute of Economics, Agribusiness and Rural Development, 2016) [16]. However, the impact of the legislative reform remains limited, due to the low institutional capacity and low efficiency of the implementation mechanisms.

Overall, the comparative analysis suggests that the differences between the states do not lie only in the timing of the adoption of laws or in the number of relevant normative acts, but especially in the degree of correlation of the legal framework with the supporting policies, the fiscal regime and the institutional mechanisms of implementation. From this perspective, the main common limit of the four cases is not the lack of legislative reform, but its incomplete nature and the reduced capacity to transform formal regulation into a functional framework for the development of agricultural cooperatives.

The gap between policy objectives and actual outcomes

The analysis of the divergence between the declared objectives and the observed results is essential for the evaluation of policies supporting agricultural cooperatives, as it allows the identification of the gap between the normative logic of the interventions and their practical effects. This gap reveals not only implementation limits, but also potential problems in policy design, the adequacy of the instruments used and their correlation with the real needs of agricultural producers.

A major problem for the analyzed countries is the orientation and focus of public policies. Measures implemented in the Republic of Moldova and Kazakhstan in the first decade of the 21st century, which, at a declarative level, aimed to stimulate cooperation among agricultural producers, generated results that diverged from the assumed objectives.

In the case of the Republic of Moldova, due to deficiencies in ensuring internal democracy and the persistence of organizational practices inherited from the Soviet period, some of the cooperatives established on the basis of former collective farms (kolkhozes) operated de facto as enterprises managing agricultural land under lease contracts. Financial allocations intended for the creation of so-called "technical service stations" in a cooperative format contributed to the technological modernization of agriculture, but failed to strengthen cooperation between producers. In practice, these mechanisms favored the capitalization of large producers, either by transforming the respective structures into limited liability companies or by transferring assets to such entities. (Ignat A. Țirigan S., 2016) [11].

In Kazakhstan, a similar set of measures was implemented starting in 2006, through the creation of technical service and procurement centers. The predominantly top-down approach proved ineffective, in the context of setting high tariffs and failing to develop functional long-term procurement mechanisms. Although these interventions contributed to the mechanization of agriculture and the development of local infrastructure, they deviated from the original objective of promoting cooperation. Moreover, in the absence of viable alternatives, farmers' dependence on these centers led to increased indebtedness and, in some cases, the bankruptcy of small farms, favoring the concentration of land in favor of large producers. (Kazakh Research Institute of Economics, Agribusiness and Rural Development, 2016) [16].

Striking a balance between public policy instruments and regulatory measures is a

major challenge for the countries under review. In an attempt to control financial flows and prevent the misuse of associative forms, the policies adopted have led, in some cases, to limiting the ability of cooperatives to provide services to third parties, as well as to restricting the possibilities of accumulating and distributing profits to their members (Armenia, Georgia, Kazakhstan). In institutional and normative terms, the Republic of Moldova stands out for a clearer separation between the legal regulation of cooperatives and the support policies applicable to them, while in the other countries this delimitation remains partial or insufficiently explicit, reducing the flexibility of the regulatory framework and the capacity to adjust policies to the needs of the sector (Ignat & Țirigan, 2017) [12].

A factor that negatively affects the development of cooperatives is the divergence between the objectives set in the framework of support policies and the real pace of their consolidation. Rapid quantitative expansion does not guarantee organizational sustainability. In the Republic of Moldova, out of approximately 180 cooperatives created in the early 2000s under a program financed by external assistance, only a very small number are still functional today. In Georgia, over 1,500 cooperatives were established in the first year of implementation of the ENPARD program, but subsequent evaluations showed that a significant part of them failed to maintain their status or activity in the medium term.

In the absence of real economic incentives and functional internal governance mechanisms, cooperatives established under support programs tend to remain fragile or ad hoc structures. In Armenia, a significant number of cooperatives established under donor-funded programs have subsequently disintegrated, some of which were created primarily to facilitate the transfer of equipment to beneficiaries. These developments suggest that achieving short-term quantitative targets, such as the number of cooperatives established, is not necessarily correlated with their long-term economic and institutional viability.

Table 2. Comparative outcomes, implementation gaps and policy lessons

Analytical dimension	Armenia	Georgia	Republic of Moldova	Kazakhstan
Observed outcome	Many cooperatives established through donor programmes later disintegrated, especially when created mainly around access to equipment or project benefits.	Rapid quantitative expansion of cooperatives was followed by inactivity, suspension or delisting of part of them.	Producer groups lose policy attention after the recognition/support period; no new groups registered in 2022-2025.	Technical service and procurement structures contributed to mechanization and infrastructure, but only partially achieved the objective of real cooperation.
Main implementation gap	Support stimulated creation, but did not always ensure long-term economic activity, governance and member commitment.	The policy model achieved rapid expansion, but continuity and consolidation remained dependent on donor-supported mechanisms.	Formal recognition and financial incentives not sufficiently connected to support for operational consolidation.	Top-down interventions created structures, but weak governance and implementation efficiency limited cooperative development.
Distortion risk	Cooperatives may be created to access equipment or donor-supported assets rather than to develop durable cooperation.	Quantitative targets may encourage formal establishment without sufficient economic base.	Risk of associative formulas dominated by large producers formally associated with smaller producers (redirection of the support toward stronger actors)	Service-based support mechanisms may increase dependency and distort cooperative objectives.
Factors limiting sustainability	Weak internal governance, limited state coordination and dependence on external support.	Donor-cycle dependence, insufficient continuity of advisory assistance and fragile economic anchoring.	Lack of post-recognition support, insufficient advisory system and weak mechanisms for balancing member participation.	Underfunded support, institutional instability and limited farmer control.
Main policy lesson	Strengthen state coordination and provide post-establishment advisory and governance support.	Ensure continuity beyond donor programmes and shift from quantitative creation to consolidation.	Develop maturation mechanisms, balanced membership criteria, advisory support and performance-based monitoring.	Move from top-down establishment toward functional cooperative governance, market integration and member-based control.

Source: Authors' synthesis.

Overall, these cases show that policies focused predominantly on the rapid creation of associative entities do not automatically produce viable cooperatives, unless they are accompanied by adequate economic incentives, market anchoring and organizational consolidation mechanisms. The assumption of a process of further

reorientation of policies from numerical stimulation of the establishment of cooperatives to more selective consolidation measures has been achieved with some success only in the case of Georgia, being as a rule followed by periods of exclusion of cooperation from priorities. The transfer of policy emphasis towards monitoring, co-financing of investments and support for the infrastructure and mechanization of cooperatives is affected in its effectiveness by the lack of institutional solutions to ensure the continuity of advisory assistance to cooperatives. (Ignat & Țirigan, 2016; Sirbiladze & Memarnishvili, 2016; Shen NGO, 2016; Kazakh Research Institute of Economics, Agribusiness and Rural Development, 2016) [11, 29, 28, 16].

A common problem in both Georgia and Armenia is the interference of the state and, in some cases, donor organizations, especially in Armenia, in the processes of establishment and development of cooperatives. In this regard, the achievement of quantitative indicators of policies or support has prevailed. This has been manifested by artificially stimulating the growth of membership or by encouraging the formation of secondary-level structures (level II cooperatives) in the absence of a solid economic base. In the case of Armenia, the experience of cooperatives established with the support of donor organizations highlights a significant difference between cooperatives that failed and those that remained functional: the former had, on average, a larger number of members than the latter. This finding does not suggest that larger size is, in itself, a factor of failure, but indicates that the artificial expansion of the membership base, in the absence of converging economic interests and functional internal governance, can affect the internal cohesion and economic efficiency of cooperatives. (Ignat A., Țirigan S., 2018) [13].

In the Republic of Moldova, the support provided to producer groups highlights the limits of a policy model partly taken from the European logic, but incompletely applied. The existing framework introduced formal recognition and financial incentives linked to sales volume, but is not accompanied by proactive consolidation measures, operational support and an efficient agricultural advisory system. The fact that no new producer group was registered in the period 2022–2025 shows that the existing support mechanism no longer functions as a tool to stimulate association. Some of the groups created capitalized on the shortcomings of the legislative framework, including the lack of sufficiently robust criteria regarding the balance between members, which allowed for associative formulas dominated by large producers, formally associated with small producers.

The fact that only two groups out of the total of forty-six requested the extension of recognition after the expiry of the five-year period is correlated with the lack of a mechanism to support the maturation of producer groups. Groups tend to disappear from the authorities' sights once they no longer pursue investment projects. This evolution is part of the same pattern observed in the other countries analyzed, where the rapid creation of associative structures did not guarantee their subsequent consolidation. In this regard, the case of the Republic of Moldova confirms that formal recognition and financial incentives, in the absence of an institutional ecosystem based on consultancy, monitoring and post-establishment consolidation measures, are not sufficient to transform associations into economically and organizationally viable structures.

CONCLUSIONS

The comparative analysis shows that the evolution of agricultural producer cooperation in the post-Soviet states examined was influenced not only by the existence of common structural constraints, but also by the nature, continuity and coherence of the interventions through which cooperation was promoted. The development of cooperation depended to a large extent on the capacity of public policies and support mechanisms to transform the idea of cooperation into a relevant economic and functional institutional framework.

An important result of the research is the highlighting of a common pattern regarding

the gap between the declared objectives of policies and the results actually obtained. In several cases, policies formally aimed at stimulating cooperation have produced limited, distorted or unsustainable effects, including the artificial expansion of the number of cooperatives, the establishment of structures motivated mainly by access to support, the consolidation of associative formulas dominated by large producers, the admission of forms of cooperation that resulted in the transfer of benefits to a limited group of beneficiaries. Distorted or unsuccessful support experiences have, in some cases, conducted to the formalization and deprioritization of cooperation as a policy objective. While cooperation remains in strategic documents and support frameworks, it is increasingly treated as a formal objective and not as an active policy direction, and attention is redirected toward other instruments.

The main obstacles to the development of cooperatives have been determined mainly by objective, structural and institutional factors, and to a lesser extent by cultural or subjective factors. Although barriers such as low levels of trust, difficulties in internal organization and leadership problems remain relevant, they operate within broader constraints, shaped by public policies, economic conditions and access to resources. Shifting the emphasis from general explanations based on "mentality" to institutional and economic conditions, structural changes and action of interest groups, policies and institutions increases the relevance in the analysis of real processes in relation to cooperation. The errors made in the implementation of support measures reinforced the fears of agricultural producers regarding integration into cooperatives and affected the cooperative movement to a much greater extent than the experience of Soviet collective farms, and should be considered paramount in the design of support measures or policies.

The efficiency of support policies was limited by the fragmentation of interventions, dependence on projects and donors, lack of institutional continuity and insufficient consultative support. In this context, cooperation was frequently treated as a formal policy objective rather than as a process requiring long-term institutional building. The predominance of short- and medium-term programmatic approaches ensured conditions for subordinating cooperation support to the achievement of short-term quantitative indicators, not aligned with the dynamics and pace of the cooperation process. Farmers' responsiveness to subsidies, a legitimate and potentially useful motivation for cooperation, was not efficiently valorised to be transformed into durable collective action and functional cooperative development.

The existence of a legislative framework, although necessary, is not sufficient in itself. Its effects depended on the correlation with support policies, the fiscal regime, implementation mechanisms and the institutional capacity of the state. From this perspective, the main common limitation identified in all four cases was not the lack of legislative reform, but the reduced capacity to transform formal regulation into a functional environment for the development of cooperation.

The outcomes of cooperation policies should not be interpreted only as governance failures or implementation shortcomings. In post-Soviet agricultural systems, the state acts within a specific institutional and social configuration, affected by continuous process of structural change, limited policy capacity, reshaping informal practices and changing the capacity and role of key actors and institutions. Policy interventions are not perceived only as technical support measures, but also as instruments integrated in broader processes of agricultural restructuring and institutional change. Their effects therefore depend on how different stakeholders interpret, adapt and use these measures according to their interests, capacities and access to resources.

Governments should move from policies focused mainly on formal initiatives and support for the establishment of cooperatives to policy frameworks that accompany cooperative development through all stages. It is required an audit and adjustment of the broader legal and regulatory framework

affecting cooperatives, including fiscal rules, organizational requirements, asset ownership and protection, correspondence between legal provisions and field realities. A long-term vision is also needed to integrate cooperative support into the agricultural advisory system, build permanent advisory capacity for pre and post establishment assistance and ensure predictable support policies. Support instruments should also encourage balanced member participation, prevent excessive dominance by stronger members and protect cooperative assets as common economic resources.

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STUDY ON THE RELATIONSHIP BETWEEN FOOD SECURITY, FOOD PRODUCTION AND RURAL AREAS IN BULGARIA

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Abstract

The relationship between food security, food production, and rural development reveals the interdependence of the so-called ''triangle of sustainability'', in which each component is essential and influences the others. The link between food production and rural areas is bidirectional: agriculture serves as a primary source of income and a guarantee of food security, while the absence of production and processing activities intensifies depopulation processes. The food industry occupies a strategic position in the Bulgarian economy, generating a significant share of the gross domestic product and contributing to sustainable development, public health, and quality of life. The article focuses on analyzing trends and challenges in food production and identifying directions for their development. The study applies statistical methods to analyze development trends and structural changes using data from the National Statistical Institute and Eurostat. It also analyzes the main economic indicators for the Food Production sector in Bulgaria for the period 2021–2024. The specific characteristics of individual subsectors are systematized, and potential pathways for their future development are outlined. The main results are expressed in the outlined guidelines for sustainable development of food production in Bulgaria. The study of the food production - food security - rural development interrelationships reveals a high degree of interdependence, in which the three components form the so-called "triangle of sustainability". The need for structural transformation and the implementation of a coordinated policy in the field of the food industry is put at the forefront. Ensuring national food security requires timely management decisions aimed at stimulating investment, enhancing competitiveness, developing domestic production, reducing dependence on imports, and adapting the legislative framework to contemporary dynamic conditions and long-term social stability.

Key words**:** *food security, food production, rural areas, sustainable development, relationship.*

INTRODUCTION

In the current conditions of global economic, social and environmental challenges, the issue of ensuring food security is gaining increasing importance. Food production is a fundamental element of the agrarian economy with a key role in ensuring sustainable food supply, economic development and social stability. The food and beverage industry as a processing activity of agricultural raw materials adds value to the chain and provides employment. Taken together, production and processing activities are characteristic and related to the development of rural areas and local economy. The lack of sufficient production and processing activities often leads to weaker economic development, strengthening demographic problems, with some regions experiencing a pronounced decline and aging of the population. Therefore, the study is aimed, on the one hand, at exploring the food security - food production - rural development relationship, as well as outlining possible directions for sustainable development of food production and for strengthening the relationship between agriculture, the processing industry and rural development. The food and beverage industry (FBI) is the largest sector of the processing industry in Europe and occupies a strategic place in the Bulgarian economy. It contributes significantly to the gross domestic product, employment and export potential of the country, while also influencing the quality of life, health and sustainable development. The sector includes processing of agricultural produce, production of food and beverages, packaging and specialized food supplements. The main raw material base is formed by Bulgarian agriculture and fishing.

Food security is a key element of the economic and social stability of any country. Within the European Union, ensuring food

security is among the main objectives of agricultural policy, implemented through the European Commission and its Common Agricultural Policy (CAP), which aims to ensure sustainable food production, stable incomes for farmers and development of rural areas.

Literature review

Rural areas are the subject of attention in a number of strategic European and national documents, as well as in many scientific publications. For example, in recent years, the trend of significant disparities in the socio-economic development of individual municipalities in Bulgaria has been highlighted (Nikolova, 2024) [12]. In addition, in the Strategic Plan of Bulgaria for the Development of Agriculture and Rural Areas for the period 2023-2027 (MAF, 2022) [9], a new national definition, "rural area" is defined as municipalities in which there is no settlement with a population of over 15,000 people. Thus, out of 231 municipalities (87.16) under the old definition (Regulation on the Definition of Settlements in Rural and Mountainous Areas, No. 14, 2003) [2, 10], 215 (81.13%) remain and 16 municipalities are eliminated. Considering that a large part of the territory of Bulgaria is agricultural territory and together with forests, the functional use of land is an important factor in supporting most municipalities, especially in rural areas. In this sense, the relationship between them and food production is mutually conditioned. It is an indisputable fact that, the lack of sufficient production and processing activities in them strengthens the processes of depopulation and the impossibility of a higher standard of living. In this direction are the efforts not only at the European, but also at the national level to achieve sustainable and competitive agriculture and vibrant rural areas. On the other hand, it is precisely these areas that have the potential for diversification of production activities outside of agriculture (e.g. alternative tourism) or the implementation of innovative production models (e.g. organic farming), which provide the opportunity to offer healthy food through direct deliveries or from one's own farm, local production.

For some of the regions, it is important to seek and implement mechanisms for the sustainability of the entire territory, since even large centres include a significant number of villages in their scope. For example, in Bulgaria there are 5,256 settlements – 257 cities and 4,999 villages by the end of 2024. There are 166 settlement formations, including 8 of national importance and 158 of local importance (NSI, 2024) [11]. Another scientific publication states that the choice of a model for increasing sustainability in a specific territory should be aimed at optimal utilization of regional resources, diversification in the functional use of the territory, optimal diversification of production and economic activities, environmentally friendly business practices and, above all, at effective interaction between institutions, local administration, businesses and local communities (Nikolova, M., P. Pavlov, 2023) [16]. Bulgarian authors from the University of National and World Economy - Sofia claim that entrepreneurial initiatives in rural areas inevitably lead to positive effects in the economic and social development of individual territories. (Harizanova-Bartos, H. et al., 2020) [8].

Another detailed study emphasizes the role of micro, small and medium-sized enterprises, whether they are traditional enterprises, family businesses, traders, social economy enterprises, crafts or liberal professions, as an essential part of the solution for a competitive, climate-neutral, circular and inclusive European economy (Angelova, 2023) [1]. The study by authors Sarov and Tsvyatkova (2021) [18] states that sustainable rural development is associated with both the survival of small farms and the promotion of diversification of the economy into activities other than agriculture, which, although remaining the main source of livelihood for the population, has a decreasing share in the overall economic profile. According to other scholars, such diversification means both the development of agricultural activities and the search for alternative solutions for entrepreneurial activities outside the scope of agriculture (Fan, S., & Rue, C., 2020) [5]. This explains the continuous search for opportunities to achieve a higher degree of sustainability in rural development. For example, Bulgarian scientists are implementing a large-scale project with the participation of experts from the main economic universities in Bulgaria, with an emphasis on rural territories

under the conditions of an economy transforming towards sustainability (Nikolova, M., Doychinova, Yu., Stoyanova, Z., Slaveva, K., Stanimirova, M., Krasteva, E., Pavlov, P., Kirechev, D., Velkovska, G., Velkovski, V., Markov Ts., 2024) [14]. The same team contributes new knowledge to the existing knowledge on the topic regarding innovations in managerial and environmental aspects for increasing sustainability in the regional development of rural areas in Bulgaria (Nikolova, M., Doychinova, Yu., Stoyanova, Z., Slaveva, K., Krasteva, E., Pavlov, P., Kirechev, D., Velkovska, G., Velkovski, V., Markov Ts., 2025) [13]. Foreign researchers are also implementing a large-scale project to systematize challenges and opportunities in the transformation of food systems and the well-being of rural areas (Woodhill J, Kishore A, Njuki J, Jones K, Hasnain S., 2022) [21]. Meeting national food needs is analyzed by the relationship between the three components "production-import-export" (Grozdanova, 2005) [7]. The contribution of organic and bio-food industries, which have a significant impact on rural economies by generating jobs and increasing farm incomes, is not small. Organic farming often promotes local supply chains, supporting small farmers and reducing dependence on global agribusiness corporations (Surya et al, 2021) [19]. Studies show that organic farms are larger and more often managed by younger farmers compared to conventional farms (EU, 2023) [3]. Furthermore, the organic food market has experienced significant growth, with the global sector estimated to be worth over $120 billion in 2022 (FiBL & IFOAM, 2023) [6]. Trends and patterns suggesting that the production of organic products and foods in our country can contribute significantly to increasing the sustainability of rural areas with multiple benefits are identified. (Tsonkov, N.; Borisov, P.; Slaveva, K., 2025) [20]. Bulgarian researchers emphasize the implementation of an innovative model of "organic farming" in order to increase the sustainability of rural development. They prove that organic production can increase the underutilized potential of rural territories in Bulgaria. (Petrova, M., Nikolova, M., Pavlov, P., 2023), (Nikolova, M., Slaveva, K., Pavlov, P., 2025) [17, 15].

Everything said so far speaks of the strong interrelation and interdependence between the three components of the food security - food production - rural development chain, or the so-called "triangle of sustainability", in which each component is essential and influences the others. The complex interrelationship finds expression in several directions: food production is a prerequisite for ensuring food security and rural development, by stimulating the local economy, jobs, income growth and structural transformation. On the other hand, the development of rural areas creates the need for investments in the food industry to increase the efficiency of production processes. This means that these territories, with good management, can provide sustainable food systems and minimize the possibility of insecurity in the food system. Ultimately, a sustainable ecosystem means that the three components of the triangle of sustainability must develop as a single system and the positive impact of each of them affects food production and its security. In Bulgaria, the relationship between food security, agricultural production and rural development is particularly important, as rural areas are the space in which the main part of food production is concentrated.

The aim of the study is to analyze the trends, problems and guidelines for sustainable development of food production in Bulgaria and their impact on food supply and rural development.

The main research thesis is that sustainable development of food production is an important factor in ensuring national food security and improving the socio-economic development of rural areas. To increase the efficiency of sector management, integrated policies are needed, including investment incentives, production modernization and reducing import dependence.

MATERIALS AND METHODS

The methodology of the study includes the use of scientific methods and approaches that allow for the analysis of the state and trends not only in production activities, but also their relationship with food security and their impact on the level of development of Bulgarian rural areas. The theoretical framework related to the research problem has

been studied. Statistical methods have been applied to analyze development trends and structural changes. The application of these methods creates an opportunity for a deeper study of the interrelationships between food production, food security and rural development. The main economic indicators for the food production sector in Bulgaria for the period 2021–2024 have been analyzed.

Limitations of the study. The limitations are reduced to an analysis of the peculiarities and specific characteristics of the food sector in Bulgaria, and specifically the production of products and its influence on ensuring the country's food policy, as well as its role in stabilizing the rural economy. The analysis is based primarily on available statistical data and published scientific sources, which does not allow for an exhaustive consideration of all regional features and specificities of the individual subsectors of the food industry. However, the information base used and the applied scientific methods allow for the outline of the main trends and to draw substantiated conclusions regarding the role of the sector for food supply and increasing the level of sustainability in the development of the local economy. The main data sources used are: National Statistical Institute, Ministry of Agriculture and Food, Eurostat, scientific publications, analytical reports and strategic documents related to the development of the food industry and agriculture.

RESULTS AND DISCUSSIONS

Analysis of the food production sector

In the context of global challenges and transformation towards a sustainable economy, food production is a key factor in the production of safe and high-quality food that supports a healthy lifestyle and environmental protection. The sector also plays a crucial role in the integration of Bulgaria into the European Union food chain and international markets. The food production sector covers a wide range of activities: Production and processing of meat and meat products (excluding prepared meals), Processing and preserving of fish and other aquatic animals, Processing and preserving of fruits and vegetables, Production of vegetable and animal oils and fats, Production of milk and dairy products, Production of flour milling products, starch, bread and pasta, Production of other food products and ready-made animal feeds. The food production shows the integration of the sector with agriculture and fishing, as the main raw material base depends on the development of Bulgarian agriculture. The food production sector has demonstrated stable growth and sustainability in recent years, despite challenges such as the COVID-19 pandemic and global economic crises, military conflicts, etc. The total output of the food production sector in Bulgaria increases from EUR 4,786 million in 2019 to EUR 7,383 million in 2023, with a growth of 54.26%. The number of enterprises in Bulgaria has recorded a minimal decrease from 5,280 in 2019 to 5,061 in 2024, with a decrease of 4.14%. The number of people employed in food production is also decreasing – from 81,172 people in 2019 to 77,585 people in 2024, with a decrease of 4.42%. The turnover of enterprises increases from 5,484 million euros in 2018 to 8,782 million euros in 2022, with a minimal decline in the following years and 8,474 million euros in 2024. The average two-year values confirm the sustainability of the sector, with an increase in production and turnover, despite fluctuations in global markets.

As a member of the European Union, Bulgarian producers have access to the single market and the instruments of the Common Agricultural Policy, but at the same time they face strong competition from countries with more developed food and beverage industries. Among the main competitive advantages of Bulgarian food products are traditional recipes and products, the availability of raw materials and relatively lower production costs. However, the limitations are related to the lower degree of processing, the limited recognition of Bulgarian products on international markets, the small size of enterprises and insufficient investment in innovation and research. In this context, the sustainable development of the food production sector is gaining strategic importance. The green transformation of the agri-food sector, including the development of organic production, improving food traceability and reducing the environmental footprint of production, is becoming an increasingly important factor for

competitiveness. Although these processes require significant investments, in the long term they create conditions for increasing added value and for better positioning of Bulgarian food products on international markets. From the point of view of food security, the development of the sector is of strategic importance, as it contributes to the stable supply of the population with quality food products, reducing dependence on imports and stimulating economic activity in rural areas. Expanding the production of processed foods, strengthening the ties between agricultural producers and the processing industry, as well as developing a national brand for Bulgarian food products can contribute to a more effective use of the available resource potential. It follows that Bulgaria has significant potential for the development of food production. The realization of this potential requires a transition to a development model based on a higher degree of processing, technological innovation and sustainable use of resources. Such a transformation would simultaneously contribute to increasing the competitiveness of the sector, strengthening national food security and stimulating the economic development of rural areas.

Analysis of the efficiency and competitiveness of the food production sector

The analysis of the main economic indicators for the period 2021–2024 shows a relatively stable development of the sector, accompanied by a gradual improvement in labour efficiency. The labour efficiency indicator per employee in relation to the output produced increases significantly between 2021 and 2022 from 73.18 thousand euros to 100.58 thousand euros, which reflects the strong growth in value production during this period. In 2023, a certain decrease was observed to 95.81 thousand euros, while in 2024 the value stabilized at a level of 96.28 thousand euros (Table 1).

A more pronounced positive trend is observed in labour efficiency in relation to the created added value. From EUR 14.8 thousand per employee in 2021, the indicator increases sequentially to EUR 18.15 thousand in 2022 and EUR 19.92 thousand in 2023, reaching EUR 23.85 thousand in 2024. This testifies to the increasing contribution of labour to the generation of added value and to the gradual increase in the economic efficiency of the sector. Similar dynamics are observed in labour efficiency relative to turnover. After a significant increase from EUR 84.8 thousand per employee in 2021 to EUR 115.18 thousand in 2022, a moderate decrease to EUR 109.16 thousand is reported in 2023

Table 1. Indicators for the food production sector

Indicators	2021	2022	2023	2024
Labour efficiency per 1 employee to output (thousand euros)	73.176	100.581	95.806	96.281
Labour efficiency per 1 employee to value added (thousand euros)	14.797	18.146	19.915	23.852
Labour efficiency per 1 employee to turnover (thousand euros)	84.803	115.179	109.161	110.419
FDI per 1 enterprise (thousand euros)	127.81	105.21	106.69	162.38
FDI per 1 employee (thousand euros)	8.81	7.29	7.35	11.23
FDI per unit of output (thousand euros)	0.06	0.04	0.04	0.06
FDI per unit of value added (thousand euros)	0.30	0.21	0.19	0.24
Share of exports in GDP, %	3.96	5.42	4.18	3.53
Share of imports in GDP, %	3.51	4.35	4.02	3.94
Coefficient of dependence of the sector on foreign trade, %	3.74	4.89	4.10	3.73

Source: NSI, Eurostat and authors' own calculations [11, 4].

However, in 2024, the indicator reaches EUR 140.42 thousand per employee, which is the highest value for the period under review and confirms the trend towards improving productivity. The increase in labour efficiency is closely related to investment activity in the sector. Although investments were characterized by certain fluctuations in the period 2021-2023, in 2024 a significant increase was observed in both investments per enterprise and investments per employee. This creates prerequisites for modernization of production capacities, implementation of new technologies and increased productivity. Such processes also have a broader economic significance, as they stimulate economic activity and create jobs in rural areas. An essential aspect of the development of the sector is its participation in

foreign trade. During the period under review, food exports showed significant dynamics. In 2021, it amounted to 2.83 billion euros, and in 2022 it increased sharply to 4.67 billion euros, which represents an increase of over 65%. In 2023 and 2024, a certain decrease was observed to 3.96 billion euros and 3.69 billion euros, respectively. The share of the sector in the country's total exports reached its highest value in 2022 – 9.82%, and in 2024 it decreased to 8.33%. At the same time, food imports follow a steady upward trend from EUR 2.5 billion in 2021 to EUR 4.13 billion in 2024. Its share in the country's total imports increases from 6.37% to 8.11%, indicating an increasing dependence on external supplies. As a result, the sector's trade balance also deteriorates from positive values in 2021 and 2022 to a negative balance in 2024.

These processes reveal the presence of structural challenges to the competitiveness of the Bulgarian food industry. Despite the presence of comparative advantages in the production of agricultural raw materials, especially in cereals and oilseeds, our country continues to lag behind in the production and export of processed food products with higher added value.

In terms of individual sectors within the food industry, two main groups stand out. The first group includes sectors with a sustainable export orientation and a positive trade balance throughout the period 2021-2024, such as "Production of flour milling products, starch and starch products", "Production of bread and pastry products" and "Production of vegetable and animal oils and fats" Their results are determined by the presence of comparative advantages, expressed in a well-developed raw material base, relatively competitive production costs and established positions in foreign markets. The second group includes sectors characterized by high dependence on imports, such as "Processing and preserving of fruits and vegetables", "Production of milk and dairy products", "Production, processing and preserving of meat", "Processing of fish and seafood" and "Production of other food products". The main factors for this dependence are insufficient domestic raw material supply, fragmented production structure, lower degree of technological modernization and strong competition from imported products. The analysis shows a clear distinction between export-oriented subsectors with comparative advantages and import-dependent subsectors. This requires the implementation of targeted policies aimed at increasing productivity and technological level, developing products with higher added value, diversifying export markets and strengthening the sustainability of supply chains. Such measures would contribute both to improving the foreign trade positions of the food industry and to strengthening national food security and the economic viability of rural areas.

Availability of raw materials Raw material security is a determining factor for the sustainability and competitiveness of the food production sector, as it affects the continuity of the production process, the degree of dependence on foreign markets and the opportunities for generating added value in the national economy. The analysis by subsectors shows that the raw material supply of the food industry in Bulgaria is unevenly distributed and is characterized by significant differences, which are determined both by the specifics of the raw materials used and by the level of development, specialization and efficiency of the relevant sectors in agriculture, which has a direct impact on the functioning and competitiveness of processing industries.

A relatively high level of availability of local raw materials is observed in the sectors related to grain production and oilseed crops. The sub-sectors "Production of flour milling products, starch and starch products", "Production of bread and pastry products" and "Production of vegetable oils and fats" are based primarily on the domestic production of grain and oilseed crops, which contributes to the formation of a sustainable raw material base and allows for effective utilization of production capacity. Sunflower processing is distinguished by its leading positions, generating significant export potential and having a positive impact on the trade balance. The situation is different in some other subsectors of the food production sector, where a lower degree of provision with local raw materials and a higher dependence on imports is observed. For example, the sectors "Production of meat and meat products" and "Production of milk and dairy products" rely on local livestock farming, but it does not provide enough raw materials, so the shortage is compensated by

importing raw materials and semi-finished products. This increases the sensitivity of enterprises to price fluctuations on international markets and creates additional risks for production stability. A similar dependence is also observed in the sectors "Processing of fish and seafood products" and "Production of other food products", where a significant part of the raw materials used, such as fish, cocoa, coffee, tea and some specialized ingredients, are supplied through imports. This limits development opportunities and increases the influence of external factors such as logistical difficulties, price volatility and climate changes. Of particular interest is the sector "Processing and preserving of fruits and vegetables", which is important for our country due to the favourable natural and climatic conditions and the traditions of local horticulture. However, domestic production of raw materials remains insufficient, which hinders the effective functioning of processing enterprises and leads to dependence on imports. This limits the creation of added value and weakens the links between agriculture and the processing industry. Data for 2024 show that the fruit produced in the country amounted to about 205 thousand tons, with approximately 40% of them used for processing, while the rest is sold on the fresh market.

Vegetable production reached 646 thousand tons, with growth observed in both field and greenhouse production. The dependence on imports of certain raw materials remains significant, which hinders the development of the processing sector and limits the creation of higher added value. The results of the analysis emphasize the key role of the provision of raw materials for the development of rural areas.

At the same time, the development of local agricultural production creates prerequisites for a closer connection between primary production and the processing industry, which is manifested in an increase in employment, an increase in income and the activation of economic processes in rural areas.

Increasing the provision of raw materials requires complex measures, including stimulating local agricultural production, diversification of supplies, modernization of storage facilities and processing enterprises, as well as strengthening coordination between producers and processors, thus reducing dependence on imports, increasing the competitiveness of the Bulgarian food industry and guaranteeing national food security.

Structure of enterprises and employment in the food production sector

The analysis of the distribution of enterprises by size in the food production sector reveals a dominant participation of micro enterprises and a relatively weak performance of medium-sized enterprises, which is an indicator of a high degree of fragmentation of production capacity in the sector. In the food production sector, micro enterprises form about 74% of all companies, small enterprises – about 20%, and medium-sized enterprises – about 6%.

The analyzed structure shows a dominant presence of enterprises with a small scale of activity, which implies limited opportunities for economies of scale, smaller investment opportunities, a low degree of automation and technological innovation, which makes them more sensitive to changes in the prices of raw materials, energy resources and the regulatory environment. (Table 2).

Table 2. Distribution of enterprises according to their size

Code	Name	Relative share of enterprises (%)		
		micro 0-9 people	small 10-49	medium 50-249
C 10	Food production	74.3	19.7	6.1
10.1	Production and processing of meat; production of meat products, excluding prepared meals	41.4	41.2	17.4
10.2	Processing and preserving of fish and other aquatic animals, excluding prepared meals	36.4	36.4	27.3
10.3	Processing and preserving of fruit and vegetables, excluding prepared meals	66	26	8
10.4	Production of vegetable and animal oils and fats	67.3	13.7	19
10.5	Production of milk and dairy products	50.2	35.8	14
10.6	Production of flour milling products, starch and starch products	65	21	14
10.7	Production of bread and pastry products	84	13.2	2.6
10.8	Production of other food products	79.6	15.7	4.8

Source: NSI, Eurostat and authors' own calculations [11, 4].

The most pronounced fragmentation is found in the subsectors "Production of bread and pastry products" and "Production of other food products", where micro enterprises form between 79% and 84% of the companies. The sectors that can be said to have a moderate concentration of micro enterprises between 55% and 70% are "Processing and preserving of fruit and vegetables", "Production of flour milling products, starch and starch products" and "Production of vegetable and animal oils and fats". Production capacity is more concentrated in the sectors "Production and processing of meat", "Production and preserving of fish" and "Production of milk and dairy products", where the share of micro enterprises is between 40% and 55%, which indicates a more efficient use of resources and a larger production scale.

The analysis of the distribution of employed persons reveals a clear disproportion to the structure of enterprises. Despite the dominant number of micro enterprises, the largest share of employment – about 49%, is concentrated in medium-sized enterprises. This shows that it is medium-sized enterprises that form the core of the production system, ensuring more efficient organization of activity, higher productivity and better adaptability to technological and quality requirements. The largest share of employed persons is concentrated in medium-sized enterprises in the sectors "Production of vegetable and animal oils and fats", "Processing and preserving of fish", "Production and processing of meat", "Production of flour milling products" and "Production of milk and dairy products". Sectors such as "Production of bread and pastry products" demonstrate an almost even distribution of employed persons between micro, small and medium-sized enterprises, while in "Production of other food products" medium-sized enterprises have a leading position in terms of employment (Table 3).

Table 3. Distribution of employed persons by enterprise size

Code	Name	Relative share of employed persons		
		micro 0-9 people	small 10-49	medium 50-249
C 10	Food production	17.2	34.2	48.5
10.1	Production and processing of meat; production of meat products, excluding prepared meals	5.3	33.2	61.5
10.2	Processing and preserving of fish and other aquatic animals, excluding prepared meals	3	31.8	65.2
10.3	Processing and preserving of fruit and vegetables, excluding prepared meals	12.7	40.3	47
10.4	Production of vegetable and animal oils and fats	6	24	70
10.5	Production of milk and dairy products	6.8	39.4	57.8
10.6	Production of flour milling products, starch and starch products	11	29	60
10.7	Production of bread and pastry products	32.4	34.6	33.1
10.8	Production of other food products	20	33	47

Source: NSI, Eurostat and authors' own calculations.

Although medium-sized enterprises represent a relatively small part of the total number of companies, they concentrate a significant part of the workforce and production capacity of the sector. The highest concentration of employment in medium-sized enterprises is observed in the sectors "Production of vegetable and animal oils and fats", "Processing and preserving of fish", "Production and processing of meat", "Production of flour milling products" and "Production of milk and dairy products". These subsectors are characterized by a higher degree of industrialization, technological renewal and modernization of production processes. The comparison between the structure of enterprises and the structure of employed persons reveals a clear disproportion. Micro enterprises form the majority of enterprises in the sector, but provide a relatively limited share of employment. Medium-sized enterprises concentrate a significant part of the employment and production potential in the sector, which is why they are crucial for the stability of production processes, for increasing labour productivity and for the implementation of modern technologies and

quality standards. From a food security perspective, such a sector structure has a two-fold significance. On the one hand, the high number of micro and small enterprises contributes to the decentralization of production, the diversity of food products on offer and the development of local food systems, which is particularly important for supplying local markets and maintaining economic activity in rural areas. On the other hand, medium-sized enterprises provide the basic production capacity, the stability of supplies and the opportunities for implementing technological innovations, which are key to ensuring sustainable domestic food production.

Under the conditions of rural development, the food production sector occupies an important place in the regional economy, since its activity is closely linked to the availability of local agricultural raw materials. The spatial proximity between production and raw materials creates prerequisites for economic activity, which is expressed in the creation of jobs, income generation and increasing the added value of primary agricultural production. In this way, food industry is established as an important factor for the economic stability and sustainable development of rural areas. The analysis of the structure of the sector reveals the presence of a pronounced effect of scale. It is important to note that medium-sized enterprises have a limited share of the total number of companies, but concentrate a significant part of employment and production potential, which makes them important carriers of economic activity in the sector. The highest concentration of employment in medium-sized enterprises is observed in the sectors "Production of vegetable and animal oils and fats", "Processing and preserving of fish", "Production and processing of meat", "Production of flour milling products" and "Production of milk and dairy products". These subsectors are characterized by a higher degree of industrialization, technological renewal and modernization of production processes.

Sustainable development of the food production sector requires targeted support for investment, technological modernization, access to finance and incentives for enterprises to scale up. This will increase their competitiveness, strengthen production sustainability, ensure the stability of the agri-food chain and contribute to strengthening food security and rural development.

Market share and competition

Market competition in the food industry is multi-layered, and its analysis is based on the calculation of the market shares of local food production. The determination of market shares can be done in several ways, and here, according to the available data, we have applied the following:

•Market share of local production based on total consumption, known as the classic way to determine the market share of local production, which is obtained by dividing the difference between production and exports by total consumption formed by production plus imports and reduced by exports.

•Market share of local production based on wholesale and retail sales, which is obtained by dividing the difference between production and exports by wholesale and retail sales.

The obtained values of the market share of local food and beverages production are presented in Figure 1.

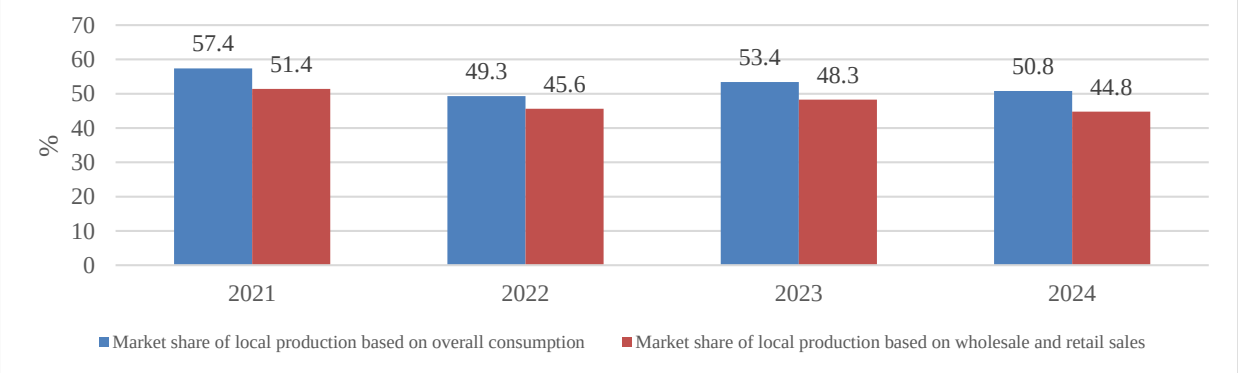

Fig. 1. Market share of local food and beverage production for the period 2021-2024
Source: NSI and authors' own calculations [11].

The analysis of the market share of local food production for the period 2021-2024 shows the maintenance of a stable presence of Bulgarian producers on the market, with over half of the total consumption covered by local production. Initially, in 2021, the market share relative to total consumption was 57.4% and can be defined as high, after which a decline was observed in 2022 to 49.3%. In the following years, a partial recovery was reported with levels of around 53.4% and 50.8% for 2023 and 2024. This shows the resilience and competitiveness of local producers, despite market fluctuations and the influence of external factors. The market share of local production based on wholesale and retail sales is lower and ranges between 51.4% in 2021 and 44.8% in 2024. These lower indicators refer to difficulties in reaching the end consumer, which are caused by low efficiency of distribution channels, strong competition from imported products, as well as insufficient marketing support and a poorly developed sales network, which leads to difficult market realization of the production and limited opportunities for increasing the competitiveness of local producers.

The results of the analysis show that local production remains the main supplier on the market, but there are fluctuations that require stabilization measures. In order to strengthen the presence of local production on the market and establish Bulgarian producers, it is advisable to take measures such as optimizing and expanding distribution channels, improving logistics and access to retail chains, strengthening marketing activities and brand positioning, as well as promoting innovations in the product portfolio in accordance with modern consumer trends. Stimulating local production to increase the degree of self-sufficiency in the domestic market, expanding and diversifying the product portfolio in view of consumer trends, including healthy and functional products, will also contribute to strengthening competitiveness and market share. These measures will contribute not only to a more complete satisfaction of domestic consumption, but also to strengthening the competitive positions of the sector under the conditions of increased competition and globalization. Also, the sustainable development of local production is of strategic importance for ensuring food security and achieving balanced and long-term economic development, including in rural areas.

The practical significance of the study is manifested in the applicability of the obtained results and the formulated conclusions in developing and improving the policies and strategies oriented towards sustainable development of food industry and strengthening of national food security.

The study presents a systematized analysis of the interdependence between food security, food production and rural development as integrated components of sustainable economic development. The formulated guidelines and recommendations can support the process of making management decisions related to stimulating investments in the sector, modernization of production, development of the processing industry and creating a more favourable environment for economic development of rural areas.

The study of the interrelationships between food production, food security and rural development reveals a high degree of interdependence, with these three elements forming the so-called "triangle of sustainability". Empirical data show a steady growth in the production of cereals and, to some extent, dairy products, which ensures a relatively good level of self-sufficiency, but there is a significant dependence on imports of fruits, vegetables and meat, which indicates some structural imbalances and vulnerabilities of the food system.

The unfavourable demographic processes in rural areas, expressed in the reduction and aging of the population, the depopulation of small settlements and the migration of the working population, are a serious limitation for the development of the food industry and the expansion of production capacity.

The insufficient implementation of new technologies and the low degree of processing of raw materials reduce the added value and income of rural areas, which in turn stimulates migration and deepens the demographic crisis. All this shows the need for integrated policies that combine economic, social and environmental aspects to achieve sustainable development.

Based on the analysis performed, the following *recommendations* can be made: Increasing investments in the modernization of processing facilities in order to increase efficiency and added value; Improving the tools for supporting small and medium-sized farms through financial incentives, training and advisory support; Creating conditions for the development of short supply chains and regional brands to reduce dependence on imports; Developing and implementing a system of measures to improve infrastructure, education, healthcare, transport connectivity, etc. in rural areas; Prioritizing the implementation of sustainable practices and stimulating the implementation and development of innovative and sustainable models, organic farming, adaptation to climate change and the rational use of resources.

CONCLUSIONS

Ensuring food security is among the leading objectives of agricultural policy in the European Union, implemented through the Common Agricultural Policy and the activities of the European Commission, aimed at ensuring sustainable food production, stable incomes for farmers and development of rural areas. In Bulgaria, this relationship is of particular importance, since rural areas concentrate the main part of food production.
As a result of the analysis, the main challenges facing the development of food production have been identified - modernization of production, stimulation of investment activity and increasing competitiveness. On this basis, guidelines have been drawn up *for sustainable development of food production and for closer integration between agriculture, the processing industry and rural areas*, namely:
• Food production is a strategic sector for Bulgaria, with proven sustainable growth and stable performance in terms of indicators such as production, enterprises, employment and turnover. It ensures food security, supports the economy and exports, and demonstrates the ability to adapt and innovate despite global challenges.
•The majority of enterprises in the sector are micro - 74%, while small and medium-sized enterprises have a significantly lower share.
lower relative share. However, medium-sized enterprises concentrate almost half of the employed, ensuring the stability of production processes and opportunities for technological innovation. Micro and small enterprises contribute to the local orientation of production, product diversity and employment in rural areas, while medium-sized enterprises form the basis of domestic production and guarantee food security. This structure shows the need to stimulate investment, modernization and clustering in order to increase the productivity, sustainability and competitiveness of the sector. Combining scale and decentralization is key to ensuring stable food supplies, meeting domestic demand and supporting the development of rural areas.
• Provides quality and safe food for the population, stable employment in rural regions, increasing the country's export potential, and implementing sustainable and environmentally friendly technologies.
• Local food and beverage production retains a significant share of the domestic market and remains a key factor in food security. However, fluctuations in market share and the degree of satisfaction of domestic consumption require targeted measures to increase the sustainability and competitiveness of the sector.
• The main challenges are related to high competition in international markets, the need for modernization and digitalization, compliance with European quality and safety standards, dependence on raw materials, etc.
• Food production, food security and rural development are closely linked and determine the sustainability of the national food system and even national security. The identified structural weaknesses, such as dependence on imports and a relatively low level of processing of raw materials, limit the potential for long-term sustainable development. All this confirms the need for an integrated approach, combining modernization, support for farmers, development of local markets and adapted social policies, in order to increase

food security through domestic production, ensure food security, improve incomes and stability of rural areas in Bulgaria.

The results of the study can be useful both in the scientific field and to state institutions and economic entities in the agricultural sector and food production.

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AGRICULTURAL MECHANISATION AND CEREAL CROP PRODUCTIVITY IN ROMANIA: AN ANALYSIS BASED ON NATIONAL STATISTICS

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Abstract

The modernization of agricultural production in Romania represents a necessity in the context of increasing competition on the international market. Investments in advanced technological equipment, together with their efficient use in domestic agricultural holdings, can represent key success factors in enhancing competitiveness relative to farmers in the European Union. For this research, official data from national statistics for the year 2024 were processed. To assess the level of technical endowment of farms in Romania, information regarding three essential categories of agricultural machinery was selected: tractors, combine harvesters, and soil preparation equipment. With more than 169,000 tractors and approximately 26,000 combine harvesters currently in operation, Romanian agriculture demonstrates a clear trend toward increased mechanization. However, the high degree of wear of the existing machinery fleet, together with significant regional disparities, points to the persistence of structural imbalances within the sector. The density of tractors relative to agricultural land remains below the European Union average, which negatively affects productivity levels and limits the adoption of sustainable agricultural practices. Furthermore, modern soil preparation equipment is insufficiently utilized, particularly within small-scale agricultural holdings, where access to advanced technologies remains constrained. The research results highlight the need to develop and implement well-targeted agricultural policies aimed at stimulating investment in mechanization, developing support instruments tailored to farmers' needs, and ensuring the efficient use of European funds available to Romania. The adoption of these measures is essential for reducing technological gaps, strengthening the adaptive capacity of the agricultural sector, and supporting sustainable development in the long term. The study can contribute to a better understanding of the relationship between the level of mechanization and the performance of agricultural holdings in Romania, providing useful conclusions for informing public policies and guiding future research.

Key words**:** *agricultural mechanisation, cereal crops, productivity, national statistics, Romania*

INTRODUCTION

Agriculture represents a strategic sector of the Romanian economy, playing a fundamental role in ensuring food security, supporting rural development, and maintaining socio-economic balance. In the context of increased competition on the European Union market, of the impact of climate change, of the reduction of natural resources, and of the accelerated evolution of agricultural technologies, the modernization of agriculture represents an essential factor for ensuring the competitiveness and sustainability of the domestic agricultural sector.

Agricultural mechanization is widely recognized as a critical driver of agricultural development, contributing to increased productivity, reduced reliance on manual labour, and improved efficiency in the use of available resources. According to international organizations, mechanization facilitates the timely execution of agricultural operations, minimizes physical effort, optimizes the use of inputs, and enhances market access. at the same time, it plays an essential role in adapting agriculture to climate change and promoting long-term sustainability [2].

At the European level, recent trends indicate a significant decline in the agricultural labour force, leading to an increasing dependence on automation and modern technologies. This structural transformation reinforces the

importance of mechanization and digitalization in maintaining productivity and ensuring the competitiveness of agricultural holdings [12]. In this context, mechanization is no longer merely a factor of efficiency, but rather a structural necessity for the functioning of modern agricultural systems.

Segrè and Petrics (2004) highlight that agriculture in Central and Eastern Europe, including Romania, possesses considerable agricultural potential, which remains insufficiently exploited due to the low intensity and efficiency of production systems. This situation is largely associated with the use of outdated technologies and a relatively low level of mechanization, which limits competitiveness in comparison with Western European countries [11]. Furthermore, although Romania's integration into the European Union has triggered a series of structural transformations, convergence in terms of productivity and agricultural performance remains incomplete [9].

In Romania, the agricultural structure is characterized by a high degree of land fragmentation and a pronounced polarization between subsistence farms and commercially oriented holdings [13]. Studies indicate that fragmented land ownership and the predominance of small-scale farms constitute major barriers to the adoption of modern technologies and to increasing the level of mechanization [1].

This structural configuration restricts investment capacity and access to advanced equipment, thereby negatively affecting the economic efficiency of the sector.

Mechanization is closely linked to the productivity and efficiency of agricultural holdings, being influenced by economic, technological, and structural factors. Research conducted by Marin et al. (2023) shows the existence of significant regional differences in terms of the level of mechanization.

Farm mechanization is dependent on investment capacity and access to financial resources [6].

For small farms, the high cost of acquiring agricultural machinery represents a significant barrier. From this perspective, small producers have limited possibilities to invest in advanced equipment and to introduce modern technologies into agricultural production [5].

Transformations in the agricultural sector are significantly influenced by digitalization processes and the use of advanced technologies.

The digitalization of Romanian agriculture involves the integration of IT solutions and digital tools into farm management activities, with positive effects on the efficiency and performance of production processes [10].

In this regard, agricultural modernization is increasingly associated with the incorporation of IT systems and intelligent technologies into agricultural practices [7].

In addition, the development of precision agriculture and the use of artificial intelligence open new opportunities for improving agricultural performance. These technologies enable better resource management, higher yields, and reduced environmental impact, thus supporting the transition towards more sustainable agricultural systems [4]. Their integration is strongly supported by European policies, particularly through the European Green Deal, which promotes a shift towards more efficient and environmentally friendly agricultural practices [9].

Nevertheless, the literature also highlights the existence of significant barriers to modernization, including financial constraints, insufficient infrastructure, and a lack of technical skills, especially among small and medium-sized farms [5].

Under these conditions, agricultural modernization must be approached in an integrated manner, combining mechanization, digitalization, and supportive public policies to reduce technological gaps and enhance sectoral competitiveness.

Starting from these considerations, the present study aims to analyse the level of technical endowment of Romanian agriculture by evaluating the main categories of agricultural equipment and identifying existing regional disparities. The objective is to provide a basis for developing sustainable strategies and for reducing technological gaps within the agricultural sector.

MATERIALS AND METHODS

The research adopts a mixed-method approach, combining the analysis of official statistical data with the integration of findings from the specialized literature. This methodological framework allows for both a quantitative assessment of agricultural mechanization and a qualitative interpretation of the results within a broader scientific context.

The bibliographic documentation was carried out through the consultation of scientific articles indexed in international databases such as Web of Science and ResearchGate, as well as reports and publications issued by relevant international and European organizations, including FAO, the European Commission, and CEMA. These sources provided the conceptual foundation for understanding the role of mechanization in agricultural development and enabled the identification of key trends and challenges at both European and national levels.

The empirical component of the study is primarily based on the analysis of official statistical data provided by the National Institute of Statistics (NIS) [8]. The selected indicators focus on the level of technical endowment of Romanian agriculture, targeting the main categories of agricultural equipment relevant to mechanized production processes. These include the number of tractors, combine harvesters, and equipment used for soil preparation. The data were examined both at national level and across regions, to identify potential territorial disparities and structural imbalances.

The analytical methodology involved the use of descriptive statistical methods, including time-series analysis, the calculation of relative and comparative indicators, and graphical representation of the observed trends and distributions.

Data processing enabled the identification of key patterns related to the evolution of mechanization and facilitated the correlation of these trends with the structural characteristics of Romanian agriculture. The results were interpreted considering the existing literature, with the aim of validating the findings and highlighting similarities or divergences in comparison with previous studies.

To perform the statistical analysis and generate graphical outputs, specialized data processing tools were employed, allowing for the efficient organization, visualization, and interpretation of the data. These tools supported the synthesis of information and enhanced the clarity of the results presented.

An additional component of the research consists of the use of artificial intelligence (AI)-based tools, which were employed to support the processes of data organization, analysis, and content structuring. These tools contributed to improving the coherence of the text and facilitating the integration of empirical findings within the theoretical framework, without replacing the authors' critical analysis. The use of AI was strictly limited to a supportive role and complied with ethical standards and academic requirements regarding originality, transparency, and scientific rigor.

RESULTS AND DISCUSSIONS

Evolution of agricultural land and cereal cultivated area in Romania

The evolution of the total cultivated agricultural area and the area under cereal crops is presented in Figure 1.

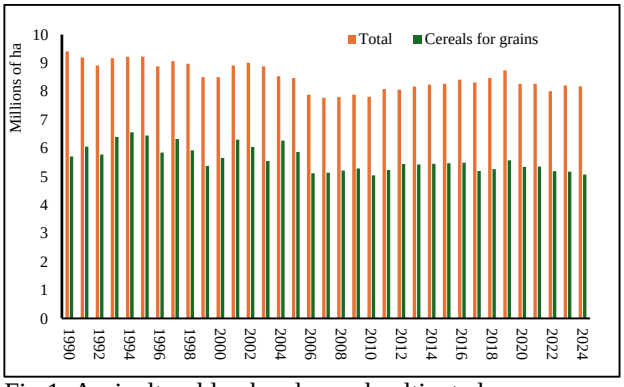

Fig.1. Agricultural land and cereal cultivated area
Source: Authors' processing based on National Institute of Statistics (NIS) [8].

The analysis of agricultural land use in Romania highlights a relatively stable trend of the total agricultural area over the period 1990–2024, fluctuating around 8–9 million hectares. This stability suggests that the

structural basis of the agricultural system has remained largely unchanged over time. In contrast, the area cultivated with cereals shows moderate variability, generally ranging between 5 and 6.5 million hectares.

These fluctuations can be attributed to changes in market conditions, climatic variability, and crop rotation practices.

The relatively constant total agricultural area, combined with the variability of cereal cultivation, indicates that agricultural performance improvements are not primarily driven by land expansion, but rather by increased efficiency in land use. This observation provides a fundamental context for analysing the role of mechanization in enhancing agricultural productivity.

Evolution of agricultural mechanization

The analysis of agricultural mechanization in Romania reveals distinct trends across the main categories of equipment, highlighting both progress and structural imbalances within the sector.

The number of tractors has shown a continuous and significant increase over the analysed period, reaching its highest level in recent years (Figure 2).

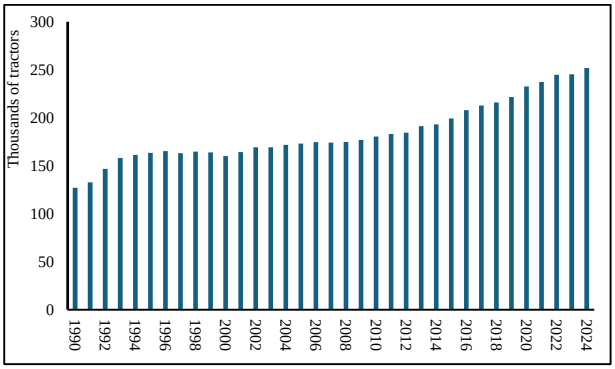

Fig. 2. Evolution of tractors used in Romanian agriculture (1990–2024)
Source: Authors' processing based on National Institute of Statistics (NIS) [8].

This upward evolution highlights the investments made in agricultural equipment and the progressive modernization of the sector, particularly intensified after Romania's accession to the European Union.

The expansion of the tractor fleet suggests an improvement in the capacity to perform agricultural operations more efficiently and within optimal timeframes.

Although a slight stabilization can be observed in recent years, the overall decrease indicates potential limitations in harvesting capacity. This imbalance between the growth in tractors and the reduction in combine harvesters suggests a structural inconsistency in the mechanization process, which may affect the efficiency of crop harvesting.

In contrast, the number of combine harvesters has exhibited a declining trend, especially in the period following the early 1990s (Figure 3).

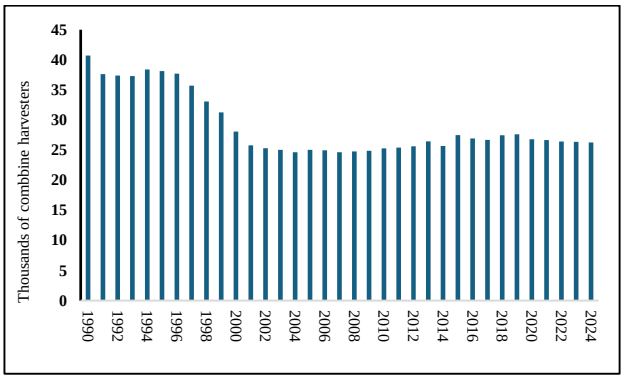

Fig. 3. Evolution of combine harvesters in Romanian agriculture (1990–2024)
Source: Authors' processing based on National Institute of Statistics (NIS) [8].

This evolution may reflect changes in agricultural practices, consolidation of farms, or the adoption of more efficient and multifunctional equipment. A similar pattern is observed in the case of seed drills, where an initial increase is followed by a gradual decline in recent years (Figure 4). However, the reduction in the number of seed drills may also signal constraints in maintaining a balanced mechanization system.

Overall, the results indicate that agricultural mechanization in Romania has evolved unevenly, with significant progress in certain areas, particularly in tractor acquisition, but with stagnation or decline in other essential components of the production chain. This lack of balance may limit the overall efficiency of agricultural operations and reduce the potential benefits of mechanization. These findings are consistent with previous studies, which emphasize that the effectiveness of mechanization depends not only on the

quantity of equipment, but also on its structure, distribution, and level of technological integration [6], [5].

Therefore, achieving a sustainable and efficient agricultural system requires a more balanced development of all mechanization components.

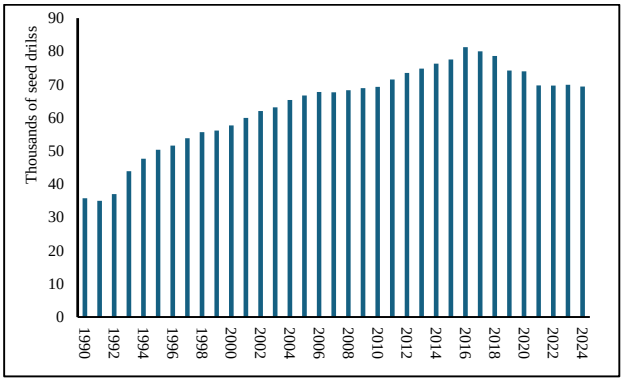

Fig. 4. Evolution of seed drills used in Romanian agriculture (1990–2024)

Source: Authors' processing based on National Institute of Statistics (NIS) [8].

Evolution of cereal production

The analysis of cereal production in Romania over the period 1990–2024 reveals a fluctuating but overall increasing trend, characterized by significant inter-annual variability (Figure 5). While the long-term trajectory indicates an improvement in production levels, the data show pronounced oscillations, reflecting the high sensitivity of agricultural output to external factors.

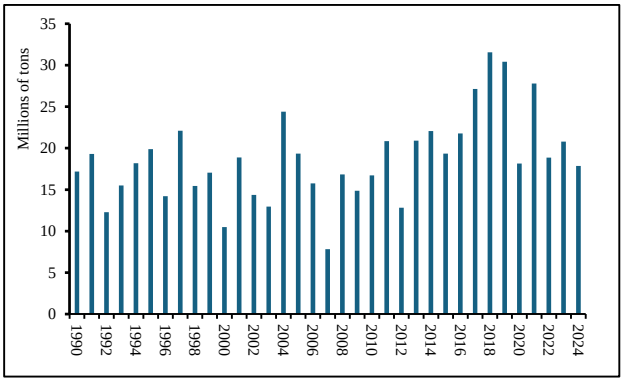

Fig. 5. Cereal production in Romania (1990-2024)

Source: Authors' processing based on National Institute of Statistics (NIS) [8].

Periods of increased production are often followed by sharp declines, suggesting a strong dependence on climatic conditions, particularly droughts and extreme weather events. This fluctuating evolution highlights the fragility of the domestic agricultural sector and shows that productivity growth is not consistently maintained over the long term. Even though, at the national level, there is an increasing number of tractors and signs of an ongoing modernization process in Romanian agriculture, there is no direct and proportional correlation between the evolution of cereal production and these changes. This suggests that mechanization alone is not sufficient to ensure stable increases in agricultural output. Other factors, such as farm structure, input use, technological practices, and environmental conditions, play a crucial role in determining production levels.

These findings are in line with previous studies, which emphasize that agricultural performance is influenced by a complex interaction of technological, structural, and climatic factors [11], [9]. In particular, the persistence of fragmented land ownership and uneven access to modern technologies limits the potential impact of mechanization on productivity.

Therefore, while mechanization contributes to improving agricultural efficiency, its effects on production are mediated by broader structural and environmental constraints. This reinforces the need for integrated approaches that combine technological investments with structural reforms and sustainable agricultural practices.

Relationship between mechanization and production

The comparative analysis of agricultural mechanization and cereal production highlights a complex and non-linear relationship between technological development and agricultural performance in Romania.

On the one hand, the constant increase in the number of tractors suggests a gradual rise in the level of mechanization and indicates an improved capacity to carry out agricultural operations. This evolution is associated with the investments made and with the modernization process, even if it is only partial. On the other hand, the decrease in the number of combine harvesters, together with the oscillating dynamics of seed drills, signals

the existence of structural imbalances within the mechanization system.

When these trends are compared with the evolution of cereal production, it becomes evident that increases in mechanization do not translate directly into proportional growth in agricultural output. Although production levels show an overall upward trend, they are characterized by significant variability, indicating that mechanization is only one of several factors influencing performance.

The results show that the level of mechanization efficiency depends directly on the structure of the agricultural sector. The excessive fragmentation of land and the high share of small-scale farms in Romania restrict the optimal use of machinery, reducing the positive impact of investments in technology.

These findings are consistent with previous research emphasizing that mechanization must be accompanied by structural and organizational improvements to generate substantial productivity gains [1].

Furthermore, the relatively stable agricultural area and the absence of significant expansion in cultivated land indicate that productivity improvements must be achieved primarily through efficiency gains rather than land extension. In this context, mechanization plays a critical role, but its impact is mediated by factors such as technological integration, farm management practices, and environmental conditions.

The results also highlight the importance of adopting a more integrated approach to agricultural modernization. The combination of mechanization with digital technologies, precision agriculture, and data-driven decision-making can enhance resource efficiency and improve resilience to climatic variability [10], [4]. Without such integration, the benefits of mechanization may remain limited.

Overall, the findings demonstrate that while mechanization is a necessary condition for improving agricultural performance, it is not sufficient on its own. A balanced development of agricultural systems, including structural reforms, technological integration, and policy support, is essential for achieving sustainable growth in the Romanian agricultural sector.

CONCLUSIONS

The present study highlights the significant role of agricultural mechanization in the modernization of Romanian agriculture, while also revealing important structural and functional limitations that affect its efficiency.

The results show a clear increase in the number of tractors over the analysed period, indicating a gradual improvement in the level of mechanization and reflecting sustained investment in agricultural equipment. However, this positive trend is not uniformly observed across all categories of machinery. The declining number of combine harvesters and the fluctuating evolution of seed drills point to structural imbalances within the mechanization system, which may reduce the overall efficiency of agricultural operations.

It can be appreciated that the analysis of Romanian cereal production indicates an unstable evolution, marked by significant year-to-year variations [3]. Although a slight upward trend has been observed in recent years, the level of production continues to be largely influenced by external factors, particularly climatic conditions and the structural characteristics of the agricultural sector.

This confirms that mechanization, while essential, is not sufficient on its own to ensure stable increases in agricultural performance.

The relationship between mechanization and agricultural output is therefore complex and mediated by multiple factors, including farm size, land fragmentation, technological level, and management practices. The persistence of a highly fragmented agricultural structure in Romania limits the efficient use of machinery and reduces the potential impact of investments in mechanization.

Another important finding is that the total agricultural area has remained relatively stable, indicating that improvements in agricultural performance must be achieved primarily through efficiency gains rather than land expansion.

In this context, mechanization represents a key driver of productivity, but its effectiveness depends on the balanced development of all components of the

production system.

The study also emphasizes the growing importance of digitalization and advanced technologies, such as precision agriculture and artificial intelligence, in enhancing the efficiency and sustainability of agricultural systems.

The integration of these technologies with traditional mechanization can significantly improve resource use, reduce variability, and increase resilience to environmental challenges.

From a policy perspective, the results underline the need for targeted measures aimed at supporting investment in modern agricultural machinery, improving access to technology for small and medium-sized farms, reducing structural fragmentation through land consolidation, and promoting digital transformation and innovation in agriculture.

The main contribution of this study consists in providing an integrated analysis of agricultural mechanization in Romania, combining official statistical data with insights from the literature, and highlighting the relationship between mechanization, structural factors, and agricultural performance.

Future research directions should focus on the quantitative assessment of mechanization efficiency, the use of advanced econometric models, and the integration of climate-related variables to better understand the determinants of agricultural productivity.

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AN ANALYSIS OF THE ROMANIAN VITICULTURE SECTOR IN THE EUROPEAN CONTEXT (1990–2024)

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Abstract

The Romanian viticulture sector has undergone substantial transformations over the past three decades, shaped by structural adjustments, European policy frameworks, and increasing climatic variability. This study analyses the evolution of Romanian viticulture between 1990 and 2024 in a European context, using official statistical data on vineyard area, grape production, wine production, wine consumption and table grape consumption. The methodological approach combines descriptive time-series analysis with comparative assessment based on national statistics, Eurostat, and OIV data. The results show that Romania remains among the leading European countries in terms of vineyard area, but its viticulture is characterized by strong fragmentation, comparatively modest productivity, and limited market competitiveness. The sector is predominantly oriented toward wine grapes, while table grape production has declined substantially, increasing dependence on imports. Wine production displays pronounced interannual variability, reflecting both climatic sensitivity and continuing structural adjustment. The findings indicate that improving the competitiveness of Romanian viticulture requires sustained vineyard modernization, technological upgrading, stronger orientation toward quality and value-added segments, and better adaptation to changing climatic and market conditions.

Key words**:** *viticulture sector, grape production, wine production, European Union, Romania*

INTRODUCTION

Viticulture represents a strategic branch of the agri-food economy, with major implications for rural development, employment, trade, landscape conservation, and cultural identity. The analysis of the evolution of the global vine and wine sector highlights the presence of significant changes, manifested through shifts in the shares of different cultivated grape varieties, a decline in the areas allocated to vine cultivation, the reaching of historically low thresholds in grape and wine production, a decrease in global wine demand, and the increasing impact of extreme climatic phenomena [11]. The decline in vineyard areas at the global level continued in 2024, reaching approximately 7.1 million hectares after four consecutive years of decrease. The reduction in areas allocated to viticulture is correlated with the attainment of a minimum level of 225.8 million hectolitres in global wine production, marked by a continuous downward trend over the past 60 years [11].

The cumulative impact of climate change and structural shifts in demand has led to a historic low in wine consumption, reaching 214.2 million hectolitres per year in 2024 [11]. Within this broader framework, the European Union remains the main global pole of viticulture. Structural statistics show that vines were grown on about 3.2 million hectares in the EU in 2020, equivalent to around 45% of the world's wine-growing area, while vineyard holdings totalled about 2.2 million, most of them very small [4]. Spain, France and Italy dominate the European vineyard landscape in terms of area, but Romania occupies a distinct position because of its very large number of vineyard holdings and its long-standing viticultural tradition [4]. Romania had the highest number of vineyard holdings in the EU, approximately 0.8 million, representing 37.9% of the EU total, while the average vineyard size was only 0.2 ha per holding, highlighting a structural pattern of extreme fragmentation

[4]. Romania has significant natural and historical potential for viticulture. Earlier studies underline the favourable pedo-climatic conditions for vine growing, the long continuity of vine cultivation, and the country's important position in the European vineyard system [1], [6]. The diagnosis of Romanian viticulture potential emphasized that the country combines suitable natural conditions with a long tradition in vine cultivation, which provides a strong basis for sector development [1]. At the same time, historical and cultural approaches have shown that viticulture in Romania cannot be interpreted only through production indicators, because vineyards are also embedded in local identity, cultural memory, and traditional rural economies [3]. This dual productive-cultural dimension is important for understanding both the resilience and the inertia of the Romanian wine sector.

Over the last three decades, however, the Romanian viticulture sector has undergone major structural transformation. The transition from a centrally planned economy to a market-based system, changes in land ownership, and the progressive alignment with European Union rules reshaped the internal organisation of production and the hierarchy of actors involved in the sector [12]. Research on the Romanian wine field has shown that supranational support, especially through EU policies and regulatory frameworks, played a key role in restructuring the sector, but also generated uneven adaptation between actors and territories [12]. Other studies focusing on the evolution of the wine sector in Romania point to simultaneous trends of modernization, support-driven restructuring, and persistent structural weaknesses related to fragmented holdings, uneven technology adoption, and modest competitiveness compared with major Western producers [15].

A defining structural characteristic of Romanian viticulture is its strong orientation towards wine grapes rather than table grapes. Official European statistics indicate that Romania differs from most other EU Member States not only through the number and small size of holdings, but also through the type of wine production structure [4]. In 2020, Romania was the only EU country in which most of the vine area, 72.1%, was dedicated to table wine rather than quality wine categories, which illustrates a specific structural pattern with important implications for competitiveness and value added [4]. This feature is consistent with national studies showing that Romanian viticulture remains highly oriented towards wine production in volume terms, while the fresh table grape segment has lost ground over time [15], [3]. In the context of the statistical evidence used in the present article, this imbalance is also associated with increasing dependence on imports for table grapes and with limited export strength in higher-value market segments.

Climate change has become one of the most important explanatory variables for recent changes in viticulture. At the global scale, the latest OIV assessment clearly shows that the decline in wine production in 2024 was strongly linked to early frosts, prolonged drought, excessive rainfall, storms, and higher disease pressure [11]. At regional and national level, recent studies dedicated to Romania and Eastern Europe confirm that climate variability is increasingly influencing vineyard suitability, grape quality, yields, and management requirements [8], [5]. Research on new viticultural areas in Romania demonstrates that climatic changes are already modifying the geographical distribution of viticultural suitability, generating both losses in traditional areas and opportunities in newly suitable territories [8]. At the same time, Eastern European review literature stresses the growing relevance of smart irrigation, improved water management, and digital monitoring technologies as adaptive responses to water stress and climatic instability [5].

Climatic pressure is not limited to drought and heat stress. In temperate continental conditions, frost remains a major source of vulnerability for vineyards. Romanian review studies on frost resistance show that winter temperature extremes continue to affect both varietal suitability and production stability, with important differences between varieties and regions [2]. From a broader historical

perspective, climate-induced disruption in wine production is not a new phenomenon in Europe. Long-term historical evidence from Central Europe indicates that shifts in temperature regimes can trigger severe production crises with wide economic and social effects [9]. This historical perspective is useful because it frames the current Romanian situation not as an isolated anomaly but as part of a broader and recurrent relationship between viticulture, climate variability, and economic adjustment [2], [9].

Besides climate and institutions, technological modernization has become central to the future competitiveness of Romanian viticulture.

The research conducted by a group of authors coordinated by Topan et al. (2025) [14] aimed to provide a comparative assessment of the economic and technological impact of mechanized versus manual grape harvesting in Romanian vineyards. The findings indicate that the choice of harvesting method should not be approached solely from the perspective of reducing labour-related costs. Although mechanized harvesting significantly lowers labour costs and increases operational efficiency (in terms of harvesting speed and area covered), from a technological standpoint, manual harvesting leads to better must quality (by avoiding berry crushing and reducing oxidative processes), resulting in superior oenological parameters of the wine [14].

Based on these considerations, the authors argue that mechanized harvesting may be more suitable for table wines, whereas manual harvesting is preferable for premium wines, where market positioning largely depends on consumer preferences. The use of modern viticultural technologies based on IoT and AI, including drone-based remote sensing, GIS mapping using NDVI methods, and parcel-level monitoring, provides valuable results in assessing vine development, identifying missing plants, and improving management decisions [17].

Drawing on the two studies mentioned above, it can be stated that, at the national level, the viticulture sector is characterized by significant structural differences among vineyards, with pressing needs for technological modernization to enhance productivity and reduce risks, while also requiring careful selection of appropriate production systems to maintain international competitiveness [14], [7].

The integration of vineyards into the sustainable development of rural areas is increasingly emphasized in the literature, including in Romania. Tancelov and Dobre (2024) [13] highlight the importance of sustainable practices and organic farming in aligning the development of the wine sector with broader regional objectives, including economic, environmental, and public health goals [13]. Turek-Rahoveanu and Turek-Rahoveanu (2024) [16] underline the need to correlate viticultural strategies with data on production, consumption, imports, and entrepreneurial approaches to strengthen the position of domestic producers on the internal market [16].

In the current approach to wine tourism, vineyards should not be viewed solely as production units, but also as entities with cultural and gastronomic potential. Romanian wineries can contribute to the development of sustainable tourism by promoting traditional gastronomy, cultural heritage, and natural resources. The promotion of local brands and the development of infrastructure represent key factors in attracting visitors and supporting regional development. Thus, the domestic wine sector can evolve beyond its traditional functions by adopting diversified and adaptive development strategies [6], [17].

Despite this growing body of literature, an important gap remains. Existing studies are often focused on one dimension only: climate suitability [8], [5], [2], harvesting technology [14], precision viticulture [7], sustainability [13], market dynamics [16], wine tourism [6], [17], or institutional restructuring [5]. Much less attention has been given to integrated long-term analysis combining vineyard area, grape production, wine production, wine consumption, table grape consumption, and foreign trade in a single framework, while positioning Romania comparatively within the European context. This gap is particularly important because Romania combines high

vineyard potential [1], [3], marked structural fragmentation [4], ageing plantations [4], significant climatic exposure [11], [8], [5], [2], and only moderate international competitiveness [15], [16].

The main objective of the research conducted in this paper is to evaluate the evolution of the Romanian viticulture sector between 1990 and 2024 in a European context. The analysis is based on official data provided by national statistics regarding vineyard areas, quantities of grapes harvested, wine production, wine consumption, as well as table grape consumption, and Romania's external trade in wine and viticulture-related products.

By combining national data from the National Institute of Statistics [10], FAOSTAT [18], Eurostat [4], and OIV benchmarks [11], the paper seeks to identify the main structural trends, market imbalances, and development constraints affecting Romanian viticulture, while also outlining the main directions for improving competitiveness and long-term resilience.

MATERIALS AND METHODS

The study is based on a mixed methodological approach combining quantitative statistical analysis with qualitative bibliographic research. The objective is to assess the evolution and structural characteristics of the Romanian viticulture sector in the period 1990–2024, in a comparative European context.

Data sources

The main data source is represented by the National Institute of Statistics (INS), through the TEMPO Online database, including datasets on vineyard area (AGR111A), grape production (AGR112A, AGR112B), and average yields (AGR113A) [10]. These data were complemented with international statistical information from Eurostat [4], FAOSTAT [18], and the International Organisation of Vine and Wine (OIV) [11], ensuring comparability at European and global levels.

Additional data regarding wine production, consumption, and trade were integrated from international databases and reports.

Bibliographic documentation

The research was supported by a review of relevant scientific literature indexed in international databases such as Web of Science and ResearchGate. The selected studies focus on viticulture development, production trends, and market dynamics, contributing to the contextualisation of the Romanian sector within broader European developments [15], [8], [5].

Methods of analysis

The methodological approach is based on descriptive statistical analysis and time-series evaluation. The main indicators analysed include vineyard area, grape production, wine production, wine consumption, and table grape consumption.

Comparative analysis was used to position Romania in relation to major European wine-producing countries and to identify structural trends, production variability, and market imbalances.

Use of AI tools

Artificial intelligence tools were used as auxiliary instruments for text structuring and language refinement, without affecting the integrity of the data or the scientific interpretation.

RESULTS AND DISCUSSIONS

Vineyard area and structural evolution

The evolution of vineyard area in Romania during the period 1990–2024 highlights significant structural transformations influenced by economic transition, agricultural policies, and sectoral restructuring (Figure 1).

At the beginning of the analysed period, Romania had a vineyard area exceeding 250 thousand hectares, reaching a peak in the late 1990s (around 1997–1998).

Relatively large vineyard areas, characterised by the presence of direct-producing hybrids, are specific to the extensive agricultural production system applied during the communist regime [10]. Low wages, as well as controlled costs of electricity, fuels and agricultural inputs, made the system viable and allowed competitive export prices, especially for raw materials. Figure 1 presents

the evolution of vineyard areas and the share of grafted vines, respectively direct-producing hybrids, in total.

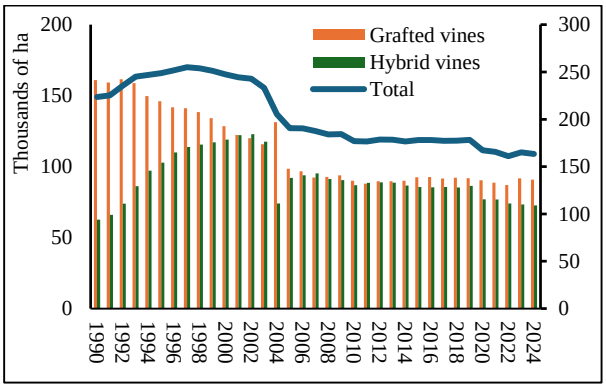

Fig. 1. Evolution of vineyard area and structure in Romania (1990–2024)
Source: Authors, by using [10].

After the political change in 1990, the fragmentation of agricultural land cultivated with vines led to an increase in the share of hybrid vines, which, although producing lower-quality wines, are more resistant, better adapted to Romania's specific conditions and require a lower level of agricultural work. The reduction of vineyard areas, more evident after 2003, is due to vineyard restructuring strategies in the context of negotiations for accession to the European market. European funds were made available for vineyard renewal, planting of grafted vines and reducing the share of direct-producing hybrids [12], [10].

The share of grafted vineyards in total vineyard area decreased from about 70% in 1990 to approximately 50% in the early 2000s, due to the persistence of hybrid vineyards (easier to maintain in small family farms), after which a slight upward trend was recorded, exceeding 60% in recent years, as a result of the modernisation of the sector [10]. The values recorded in 2004 reflect methodological adjustments in national statistics. Vineyards in Romania are mainly specialised in the production of grapes for wine (over 90% of total), while areas cultivated with table grape varieties have continuously decreased. This shift reflects both market demand and policy support mechanisms, which have favoured wine production over table grape cultivation [15], [3].

At the European level, Romania ranks among the leading countries in terms of vineyard area, occupying approximately the 5th–6th position within the European Union, with around 180 thousand hectares [11], [4]. However, despite this favourable position in terms of area, the sector is characterised by relatively low productivity compared to major producers such as Spain, France, and Italy.

Another important structural feature is the high fragmentation of vineyard holdings. Romania has one of the largest numbers of vineyard holdings in the European Union, accounting for a significant share of total holdings, but with very small average sizes. This fragmentation negatively affects efficiency, mechanisation, and competitiveness. Regionally, vineyard areas are unevenly distributed, with major concentrations in the Moldavian Hills, Muntenia and Oltenia regions, and Dobrogea. These regions benefit from favourable pedo-climatic conditions and represent the core of Romanian viticulture. At the global level, Romania ranks among the top 10 countries in terms of vineyard area, confirming its importance in the international viticulture sector [11]. Overall, the evolution of vineyard area in Romania reflects a transition from an extensive and fragmented system towards a more structured and quality-oriented sector. However, structural constraints, including fragmentation and productivity gaps, continue to limit competitiveness.

Grape production dynamics

The analysis of grape production trends in Romanian vineyards highlights significant fluctuations over the study period (1990–2024). These variations can be explained by several factors, including the impact of climate change, structural transformations within the domestic agricultural sector, the relatively low level of modernization in agricultural practices, and the strong dependence on precipitation due to limited irrigation in the viticultural sector.

The dynamics of total grape production, by category (wine grapes and table grapes), are presented in Figure 2.

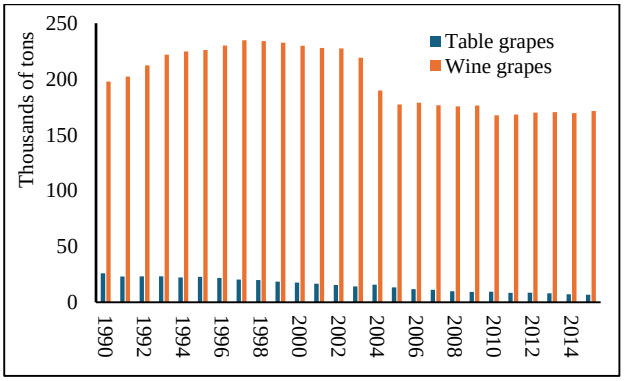

Fig. 2. Evolution of grapes production in Romania, by category (1990–2024)
Source: Authors, by using [10].

At the beginning of the analysed period, grape production levels were relatively high, frequently exceeding 1,000 thousand tonnes, with peak values recorded in favourable climatic years such as 1996–1997. However, production levels show considerable fluctuations from one year to another, indicating a strong dependence on weather conditions.

A significant decline is observed around 2005, when grape production dropped sharply, corresponding to unfavourable climatic conditions and the ongoing restructuring of vineyards, including the removal of hybrid plantations and the temporary reduction in productive capacity [10].

After 2007, production partially recovered, but variability remained high. Periods of increased production (e.g., 2008–2009 and 2018–2019) alternate with years of lower output, confirming the sensitivity of the sector to climatic variability.

From a structural perspective, Romanian grape production is overwhelmingly dominated by wine grapes. As shown in Figure 2, wine grapes consistently account for more than 90% of total production, while table grape production represents only a small and continuously declining share.

The evolution of vineyard productivity further explains these dynamics. The average yields per hectare for grafted and hybrid vineyards are presented in Figure 3.

As illustrated in Figure 3, productivity remains relatively unstable over time, reflecting both climatic influences and differences in vineyard management practices. Although certain improvements in yields can be observed in recent years, particularly in modernised vineyards, overall productivity remains below the levels observed in major European producers.

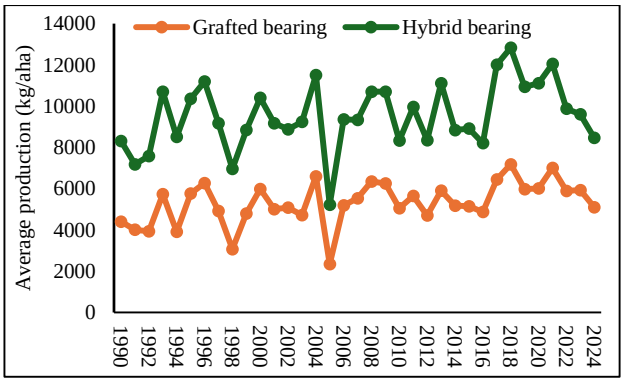

Fig. 3. Evolution of average grape yields in Romania: grafted and hybrid vineyards. (1990–2024, kg/ha)
Source: Authors, by using [10].

The decline of table grape production and cultivated areas in Romania after 1990 can be explained by a combination of structural, economic, and policy-related factors. First, the competitiveness of Romanian table grape varieties has been relatively low compared to imports from countries such as Italy, Greece, Spain, and Turkey, which offer higher quality and better market adaptation [15], [3].

Second, many existing plantations are characterised by low productivity and inferior quality, reflecting ageing vineyard structures and insufficient adaptation to modern market requirements. In addition, the fragmentation of agricultural land following the transition period has led to reduced efficiency in vineyard management, resulting in lower maintenance levels and, in some cases, the abandonment of plantations.

Agricultural policies and support measures have also played a significant role, as European funding programmes have been primarily oriented towards wine-producing vineyards, which are easier to integrate into quality schemes and market support mechanisms.

In addition to production dynamics, the structural imbalance between grape categories becomes more evident when considering market-oriented aspects. While wine grapes dominate total production, the limited and declining output of table grapes has not been

sufficient to meet domestic consumption needs. This imbalance suggests an increasing reliance on imports, particularly in the context of Romania's integration into the European market, where competition from more competitive producers has intensified. Consequently, the domestic grape sector exhibits a dual structure: a relatively stable, wine-oriented production system and a structurally vulnerable table grape segment.

Wine production and consumption

The evolution of wine production and consumption in Romania during the period 1995–2024 reflects significant structural changes, influenced by climatic variability, vineyard restructuring, and changing market conditions. The dynamics of these two key indicators, together with the market balance, are presented in Figure 4. At the beginning of the analysed period, both production and consumption levels were relatively high, frequently exceeding 6,000 thousand hectolitres.

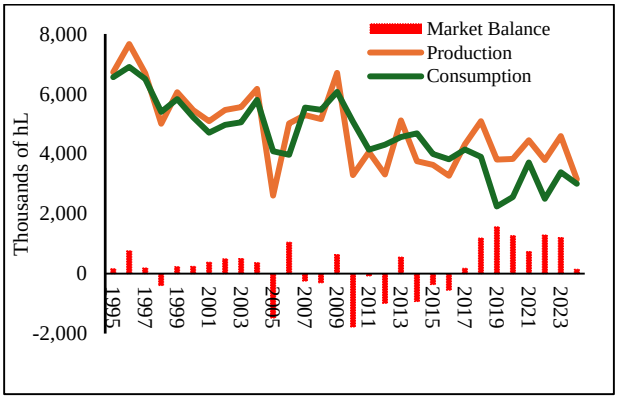

Fig. 4. Evolution of wine production, consumption and market balance in Romania (1995–2024)
Source: Authors, by using [10].

The Romanian wine market was relatively balanced during the late 1990s, with small differences between production and consumption levels.

A major disruption is observed in 2005, when wine production dropped sharply to approximately 2,600 thousand hectolitres, mainly due to unfavourable climatic conditions and the ongoing restructuring of vineyards. This decline generated a significant market deficit, highlighting the vulnerability of the sector to external shocks.

Figure 4 presents the evolution of domestic wine production, population consumption, and Romania's trade balance in wine. The dependence of the sector on meteorological conditions, particularly precipitation levels, is more evident in years with unfavourable climatic conditions, when significant declines in production are recorded. The years 2009 and 2013 were characterised by favourable weather conditions, reflected in higher levels of production.

Consumption shows a relatively more stable evolution compared to production. After 2010, a slight downward trend in wine consumption can be observed, mainly driven by changes in consumer preferences.

The trade balance (market balance) represents the difference between production and consumption. After 2010, situations are frequently recorded in which consumption exceeds production, with market demand being covered by imports. Although Romania has a tradition in wine production, the reduction of vineyard areas and the lower competitiveness of the domestic sector encourage wine imports, especially in periods with unfavourable climatic conditions.

It can be concluded that the Romanian wine sector is characterised by a high degree of volatility, driven by inconsistent production and increasing dependence on imports

CONCLUSIONS

The Romanian viticulture sector has undergone significant structural and functional transformations during the period 1990–2024, driven by economic transition, European integration, and increasing climatic variability. Although Romania remains among the leading European countries in terms of vineyard area, the sector continues to be affected by structural fragmentation, relatively low productivity, and limited competitiveness compared with major wine-producing countries.

The analysis highlights a strong orientation towards wine production, with wine grapes consistently accounting for the dominant share of total output. In contrast, the table grape segment has experienced a continuous decline, leading to increased dependence on

imports and reinforcing structural imbalances within the sector.

Wine production exhibits pronounced interannual variability, reflecting the sensitivity of vineyards to climatic conditions, while consumption follows a more stable but gradually declining trend. The resulting fluctuations in market balance indicate recurrent mismatches between supply and demand, often compensated through external trade.

Improving the competitiveness and resilience of Romanian viticulture requires continued vineyard modernization, consolidation of holdings, adoption of advanced technologies, and stronger orientation towards quality and value-added segments. In addition, better adaptation to climate change and improved integration into European and global markets will be essential for the long-term sustainability of the sector.

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AGROTOURISM DEVELOPMENT IN THE GALAȚI–CAHUL–GAGAUZIA CROSS-BORDER AREA: A STRUCTURAL AND STRATEGIC ASSESSMENT

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Abstract -

Agrotourism represents an important pathway for economic diversification and the sustainable valorisation of rural resources, particularly in cross-border regions. This paper analyses the agrotourism development potential of the Galați area (Romania) and the southern regions of the Republic of Moldova (Cahul, Gagauzia and Taraclia), a territory characterised by rich rural traditions, local gastronomy, viticulture and valuable natural landscapes, which remain insufficiently integrated into coherent tourism products. The study is based on secondary data and institutional documents, aiming to assess the structural and strategic framework for agrotourism development in the analysed cross-border area. The methodology combines descriptive statistical analysis, a comparative territorial approach, and the application of SWOT and PESTEL analyses, supported by the triangulation of statistical databases, regional development strategies and public policy documents, including materials related to the cross-border project ROMD 00389. The results reveal significant territorial disparities, with Galați County showing a more advanced tourism infrastructure and higher tourism flows, while the southern regions of the Republic of Moldova remain less developed, despite their considerable natural and cultural potential. The research findings also highlight a set of development pathways for the region with significant potential, particularly in the areas of cross-border cooperation, the valorisation of rural heritage, and the orientation of activities towards sustainable forms of tourism. In this context, the paper outlines several strategic directions aimed at supporting the design and promotion of integrated agritourism services, as well as strengthening cross-border cooperation, thereby contributing to the enhancement of competitiveness and sustainability in Galați County and the southern part of the Republic of Moldova.

Key words**:** *agritourism, territorial disparities, tourism infrastructure, regional development, cross-border cooperation, sustainability*

INTRODUCTION

Agrotourism activities have become, in recent decades, an essential component of rural development strategies, being regarded as an effective instrument for diversifying the local economy, improving the use of agricultural resources and preserving cultural heritage.

In the context of European policies oriented towards sustainable development, rural tourism and agrotourism contribute to increasing incomes in rural areas, to the creation of new jobs and to the reduction of territorial disparities [5], [16], [22].

Border regions present a particularly significant potential for the development of agrotourism, due to their cultural diversity, the complementarity of available resources and the opportunities generated by cross-border cooperation.

However, in many cases, these regions face structural challenges, such as insufficiently developed infrastructure, low levels of investment and the absence of integrated tourism development strategies.

The Galați (Romania) – Cahul, UTA Găgăuzia and Taraclia (Republic of Moldova) cross-border area represents a territory characterised by significant resources for agrotourism, including agricultural traditions, viticulture, local gastronomy and attractive rural landscapes. Nevertheless, these

resources are not sufficiently capitalised, while cooperation between the two countries in the field of tourism remains limited.

The paper aims to analyse the development of agrotourism in the studied area, by evaluating tourism infrastructure, accommodation capacity and tourism flows, based on official statistical data [15], [13], [7]. Within the research framework, the authors aimed to highlight territorial disparities and to identify potential development directions capable of supporting the design of integrated tourism services through cross-border cooperation.

In the context of sustainable rural development, agritourism and rural tourism can represent sustainable alternatives to traditional agricultural activities, generating economic opportunities for the local population and contributing to the improvement of the living standards of rural communities [9].

Agrotourism can contribute to increasing farmers' incomes, to the creation of new jobs and to the preservation of both cultural and natural heritage [24], [13], [17]. Rural tourism experienced a significant increase, particularly in the context of the COVID-19 pandemic, being perceived as a more sustainable and safer alternative compared to mass tourism. Recent scientometric analyses indicate a significant increase in scientific production in this field during the period 2020–2024, with a focus on sustainability, rural resilience and digitalisation [20].

Grillini et al. [15] mention that agrotourism represents an effective mechanism for integrating agriculture with the service sector, contributing to the transformation of farms into multifunctional units. At the same time, this transformation implies changes in the organisation of agricultural activities and in farmers' development strategies [1].

In Europe, rural tourism is considered an important pillar of regional development policies, being supported through programmes and initiatives aimed at reducing territorial disparities and stimulating economic and social cohesion. The integration of tourism activities into agricultural and rural development policies can have a significant impact on increasing the attractiveness of rural areas and on the development of local economies [5], [6], [16].

A specific area of interest for researchers is represented by tourism activities carried out in border regions. The intensification of cross-border cooperation can be an important factor in the development of rural tourism in these areas. Studies conducted at the European level highlight that joint initiatives and the development of integrated tourism products contribute both to increasing the visibility of these regions and to the valorisation of shared heritage.

Although it represents an opportunity for economic development, in some regions important structural constraints may occur, such as insufficiently developed infrastructure, lack of investments and fragmentation of tourism supply, which limit the development of agrotourism. These factors are frequently encountered in peripheral and border regions, especially in Eastern Europe.

The use of innovation and digitalisation in the development of rural tourism can represent a success factor, highlighting the need to integrate digital technologies and smart promotion strategies to increase the competitiveness of rural destinations.

In the Romanian scientific literature, agrotourism is analysed in correlation with the development of agri-food systems and sustainability policies, being considered a factor of innovation in rural areas and an instrument for strengthening local identity [3], [19]. The establishment of the Romania–Republic of Moldova gastronomic route, a recent initiative that highlights culinary heritage and local resources on both sides of the Prut River, can be considered a representative example in the field of cross-border tourism. This route integrates traditional restaurants, tourist guesthouses, wineries and other cultural objectives, promoting local products and authentic experiences [11].

The development of agritourism in the Republic of Moldova has been increasingly recognised as a viable strategy for diversifying rural economies and enhancing the value of agricultural activities. According to Lusmanșchi et al. [16], agritourism

represents not only a complementary source of income for rural households but also provides opportunities for integrating local agricultural production into tourism services, creating favorable conditions for the development of integrated and diversified tourism products.

Recent studies highlight the growing importance of agritourism in the Republic of Moldova, where it is considered a relevant instrument for diversifying the rural economy and enhancing tourism attractiveness at the international level. Colesnicova and Iatîsin [4] highlight that foreign tourists perceive Moldovan agrotourism as an authentic and experience-based form of tourism, strongly linked to local traditions, gastronomy and rural lifestyles. The development of agritourism is conditioned by the interaction of economic, social, and institutional factors, such as income levels, the degree of tourism infrastructure development, the effectiveness of promotional activities, and the involvement of local communities. Iosim and Popescu [8] point out that the development of rural tourism, and implicitly agritourism, is closely linked to the implementation of well-defined promotion strategies and to the adaptation of tourism services to consumer requirements. In this respect, marketing and information activities play an essential role in stimulating tourism demand and increasing the visibility of rural destinations.

Although the specialised literature highlights the strategic role of agrotourism in rural development and in reducing territorial disparities, it is necessary to emphasise the need for integrated approaches, especially in border regions, where cooperation between territories represents a key factor for valorising tourism potential.

The aim of the paper is to assess the potential and the level of development of agritourism in the Galați–Cahul–UTA Gagauzia–Taraclia cross-border area. Based on the research findings, strategic directions for regional development are outlined, focusing on strengthening cross-border cooperation mechanisms and designing integrated tourism packages, with benefits for the business environment on both sides of the Prut River.

MATERIALS AND METHODS

The materials used within the research consist of official statistical data regarding tourism activity, collected from national and international databases. For the bibliographic documentation, a comprehensive review of the specialised literature was carried out, using open-access scientific articles indexed in relevant international databases (Clarivate Web of Science). Official public reports and documents, prepared by national and international institutions with responsibilities in the fields of tourism and rural development, were analysed whenever relevant information was available. For statistical data regarding the development of the business environment in Romania, information provided through the TEMPO-Online platform of the National Institute of Statistics (NIS) was used, while for the Republic of Moldova, data available on the website of the National Bureau of Statistics (BNS) were considered. Official public reports and documents, prepared by national and international institutions with responsibilities in the fields of tourism and rural development, were analysed whenever relevant information was available. For statistical data regarding the development of the business environment in Romania, information provided through the TEMPO-Online platform of the National Institute of Statistics (NIS) was used, while for the Republic of Moldova, data available on the website of the National Bureau of Statistics (BNS) were considered. Official public reports and documents, prepared by national and international institutions with responsibilities in the fields of tourism and rural development, were analysed whenever relevant information was available.

For statistical data regarding the development of the business environment in Romania, information provided through the TEMPO-Online platform of the National Institute of Statistics (NIS) was used, while for the Republic of Moldova, data available on the website of the National Bureau of Statistics (BNS) were considered. These statistical data include information on the capacity of tourism accommodation establishments, their utilisation, and tourism flows, for the recent period of analysis [15], [13], [7].

The research is focused on the cross-border area Galați (Romania) – Cahul, UTA

Găgăuzia and Taraclia (Republic of Moldova), selected due to geographical proximity, the complementarity of tourism resources and its relevance within the framework of cross-border cooperation. The selection of these territorial units allows for a comparative analysis between two different national systems, interconnected through their tourism development potential.

The research methodology is based on a quantitative and comparative approach, using descriptive statistical analysis of the main tourism indicators, such as the number of accommodation establishments, accommodation capacity expressed in number of places, and their occupancy rate, as well as indicators related to tourism circulation (number of arrivals and overnight stays). The data were processed and synthesised to highlight development trends and territorial differences.

The comparative analysis enabled the identification of disparities between the analysed regions, highlighting both the level of development of tourism infrastructure and the intensity of tourism flows. In this regard, time series data covering several consecutive years were used, to capture the dynamics of the tourism phenomenon and possible trends of convergence or divergence between territories.

For an integrated interpretation of the results, the research was complemented with strategic analysis tools, namely SWOT analysis and PESTEL analysis, which allowed the evaluation of internal and external factors influencing the development of agrotourism in the studied area.

These methods contribute to identifying strengths and opportunities, as well as structural and institutional constraints specific to border regions.

During the elaboration of the paper, artificial intelligence-based tools were used exclusively for support in drafting and structuring, without influencing the interpretation of the data, the results or the conclusions of the research, which belong entirely to the authors.

The limitations of the present research are mainly determined by the exclusive use of secondary data and by the methodological differences existing between national statistical systems, which may affect the comparability of certain indicators. However, the triangulation of data sources and the use of a comparative approach contribute to increasing the relevance and validity of the obtained results.

A significant limitation is related to the limited availability and low level of detail of statistical data at the regional level in the Republic of Moldova. Although there are data regarding tourism circulation (arrivals and overnight stays), the information related to tourism infrastructure – the number, typology and capacity of accommodation establishments – refers primarily to the Municipality of Chișinău and is not systematically reported for regions such as Cahul and UTA Găgăuzia, being largely aggregated at national level or concentrated around the capital city.

Under these conditions, the analysis was structured in a differentiated manner: for Galați County, a comprehensive evaluation of tourism infrastructure and tourism flows was carried out, while for the regions in the Republic of Moldova, the analysis was based on the available indicators and on qualitative interpretations. This limitation does not reduce the relevance of the results but rather highlights the need to develop more detailed regional statistical systems, capable of supporting the formulation of effective tourism policies and the valorisation of the potential of areas such as Cahul and UTA Găgăuzia.

RESULTS AND DISCUSSIONS

Galați County, Romania

The evolution of accommodation establishments in Galați County during the period 1990–2024 is presented in Figure 1. For a clearer visual representation, data were displayed at five-year intervals. The evolution of accommodation infrastructure in Galați County highlights a significant transformation over the analysed period. The number of accommodation units decreased in the post-transition period, from 22 units in 1990 to 11 units in 2000, followed by a gradual recovery

after 2005 and an accelerated growth after 2010, reaching 67 units in 2025 (Fig. 1).

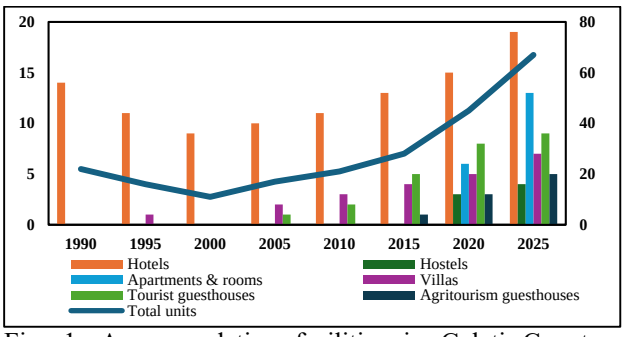

Fig. 1. Accommodation facilities in Galați County (1990–2025)
Source: Authors, by using NIS (2026) [15].

The dynamics of accommodation facilities reflect the transformation of the local tourism sector, as well as the diversification of accommodation types, including tourist guesthouses, agritourism units, and rental apartments, highlighting a gradual adjustment to evolving tourist demand.
The evolution of the number of tourist arrivals in Galați County during the period 1990–2024 is presented in Figure 2.

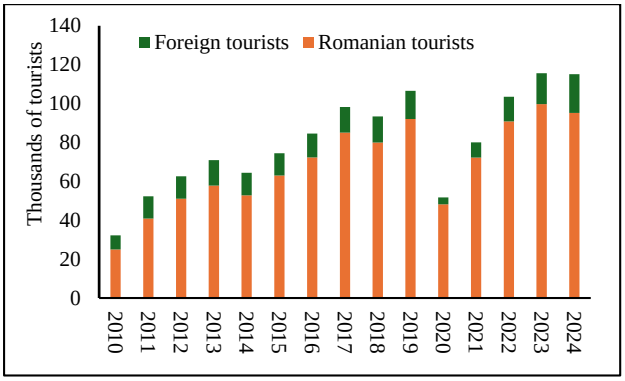

Fig. 2. Tourists' arrival in Galați County (2010-2024)
Source: Authors, by using NIS (2026) [15].

A relevant indicator for the interpretation of tourist behaviour is the average length of stay, calculated as the ratio between overnight stays and arrivals.
The evolution of the number of overnight stays in Galați County is presented in Figure 3.
The evolution of tourism activity confirms the general trend of development. The total number of arrivals in tourist accommodation establishments in Galați increased from 32,236 tourists in 2010 to 115,104 in 2024, while the number of overnight stays increased from 75,001 to 175,480 over the same period. The dynamics clearly highlight a constant increase up to the year 2019, followed by a significant decrease in 2020, as a direct effect of the restrictions associated with the COVID-19 pandemic, and subsequently by a rapid recovery in the period 2021–2024, reaching values that are close to or even higher than the pre-pandemic level. The analysis of foreign tourists also indicates an increase in the attractiveness of the destination, with arrivals increasing from 7,287 in 2010 to 19,913 in 2024, and overnight stays increasing from 23,207 to 33,157.

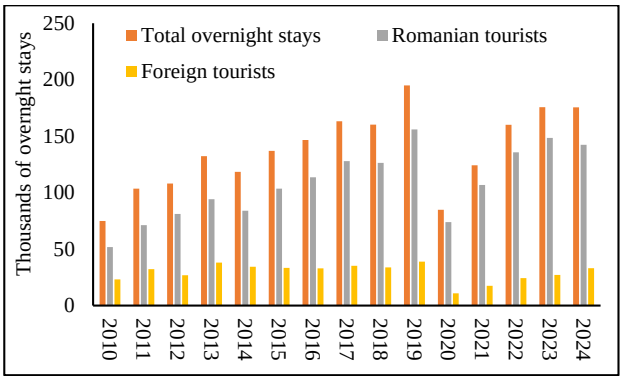

Fig. 3. Tourists' overnight stays in Galați County (2010-2024)
Source: Authors, by using NIS (2026) [15].

In Galați County, this indicator decreased from 2.33 nights per tourist in 2010 to approximately 1.52 nights per tourist in 2024. This trend shows that, although the county attracts an increasingly higher number of tourists, short-duration visits predominate, which suggests a stronger orientation towards urban tourism, transit tourism or business tourism, rather than towards longer-duration experiential forms of tourism, including agrotourism.
For a comprehensive synthesis of the main tourism indicators and of their evolution, Table 1 presents the comparative values corresponding to the reference years 2010, 2019 and 2024.
The analysis of the data presented in the table highlights an upward trend in the development of the tourism sector in Galați County, both in terms of infrastructure development and the increase in tourist flows. The growth in the number of accommodation

units, correlated with the growth in arrivals and overnight stays, indicates the gradual consolidation of the destination on the tourism market. However, the relatively short duration of stay and the limited share of agritourism guesthouses suggest that the rural tourism potential is not yet fully valorised at an optimal level. The development of integrated tourism products, based on local gastronomy, viticulture and authentic rural experiences, could contribute to increasing competitiveness and to extending the length of stay.

Table 1. Main tourism indicators in Galați County

Indicator	2010	2019	2024
Total accommodation units	21	43	59
Tourist arrivals	32,236	106,540	115,104
Overnight stays	75,001	195,005	175,480
Average length of stay	2.33	1.83	1.52
Foreign tourist arrivals	7,287	14,463	19,913
Foreign tourist overnight stays	23,207	38,947	33,157

Source: Authors, by using NIS (2026) [15].

Southern Republic of Moldova

The assessment of tourism facilities in the southern part of the Republic of Moldova highlights a relatively low level of infrastructure compared to that of Galați County. Nevertheless, a considerable potential can be observed, supported by natural resources and cultural, historical, and culinary traditions, which remains insufficiently exploited. In the absence of detailed statistical data at the regional level, the analysis is based on information available from official reports and specialised studies, complemented by qualitative interpretations [14], [12].

In Cahul district, the accommodation offer is characterised by the predominance of small-scale units, such as tourist guesthouses and rural-type accommodation structures. Tourism activity is concentrated in the municipality of Cahul and in areas with high natural potential, such as Văleni and the Lower Prut protected area, where forms of ecological and agrotourism are developing. Through the investments made, as well as the tradition and recognition it enjoys, the Cahul balneary resort can be considered an important component of the local tourism potential [23], [21].

In terms of tourism flows, the region is characterised by a low volume of tourists and a short average length of stay, which is typical for emerging destinations. Tourism is oriented mainly towards domestic visitors and tourists from Romania, being influenced by geographical proximity and cross-border relations [2]. The development of the local sector is mainly constrained by underdeveloped tourism infrastructure and the low effectiveness of promotional activities [14].

Although these weaknesses are frequently highlighted, the region benefits from valuable natural resources, such as Lake Beleu and the ecosystems of the Lower Prut area, which, in combination with specific local traditions, can support the development of agritourism and ecotourism. The valorisation of these resources and their integration into well-structured tourism services, together with the strengthening of cross-border cooperation with Galați County, can significantly contribute to increasing the region's tourism attractiveness [20], [21].

The situation of tourism development in UTA Găgăuzia and Taraclia district is like that of Cahul district, being characterised by a limited availability of detailed statistical data at regional level. Under these conditions, the analysis is based on information from regional studies and institutional reports, complemented by qualitative interpretations regarding the structure and dynamics of the tourism sector [18], [14].

UTA Găgăuzia can be considered one of the most active tourism areas in the southern part of the Republic of Moldova, particularly due to the valorisation of ethno-cultural heritage and viticultural areas. Tourism activity is concentrated in urban centres such as Comrat, Ceadîr-Lunga and Vulcănești, while the accommodation offer is dominated by small-scale units, especially guesthouses and family-type structures. Tourism is supported by cultural and traditional events and by the development of wine tourism [18].

In contrast, Taraclia district is characterised by a very low level of tourism development, with accommodation infrastructure being limited and mainly concentrated in the town

of Taraclia. Tourism activity is poorly developed and has a predominantly transit character, with a cultural potential associated with the local Bulgarian community but insufficiently capitalised at present [24].

From a comparative perspective, the regions in the southern part of the Republic of Moldova have a poorly developed tourism infrastructure and are characterised by a strong dependence on domestic tourism. However, there are significant differences between territories, with UTA Găgăuzia having a higher degree of dynamism due to the diversification of tourism products, while Cahul benefits from important natural resources, and Taraclia remains a marginal area from a tourism perspective [18], [21].

Overall, these regions have a considerable potential for the development of agrotourism and rural tourism, but its valorisation is limited by insufficiently developed infrastructure, low levels of promotion and the absence of integrated tourism development strategies at regional level [12].

To provide a structured assessment of the external factors influencing agrotourism development, a PESTEL analysis was conducted, as presented in Table 2.

The PESTEL analysis highlights the external factors influencing the development of agrotourism in the analysed cross-border area.

From a political perspective, the institutional framework is favourable to the development of cross-border cooperation through European programmes and bilateral initiatives.

The existence of differing administrative and legislative regulations between Romania and the Republic of Moldova may reduce the efficiency of implementing joint projects.

From an economic perspective, the analysed regions are characterised by a relatively low level of investment in tourism, but also by significant development opportunities supported by European funds and financing programmes dedicated to rural areas.

From a social perspective, cultural heritage and authentic local traditions represent essential resources that can form the basis for the development of agritourism products. However, population migration and demographic ageing represent important constraints.

Table 2. PESTEL analysis of agrotourism development in the Galați–Cahul–Gagauzia–Taraclia cross-border area

Factor	Key aspects	Implications for agrotourism development
Political	Existence of cross-border cooperation programs (Interreg, ENI), regional development strategies	Supports joint tourism initiatives and integrated cross-border products, but administrative differences may slow implementation
Economic	Limited local investments, dependence on public funding, rural economic disparities	Opportunities for development through EU funds, but constrained by low private investment capacity
Social	Strong local traditions, cultural diversity, rural heritage; demographic decline and migration	Favors development of authentic tourism experiences, but reduces local workforce availability
Technological	Increasing use of digital platforms, low digitalization in rural areas	Potential for improving visibility and marketing, but uneven technological adoption limits competitiveness
Environmental	Valuable natural resources (Danube, Prut River, Lake Beleu, rural landscapes)	High potential for ecotourism and sustainable tourism, requiring environmental protection measures
Legal	Differences in tourism regulations between Romania and Republic of Moldova	Romania has a more developed regulatory framework; harmonization is needed for cross-border tourism development

Source: Authors, based on [18, 23, 21, 2, 14, 12].

From a technological perspective, digitalisation and the use of online tourism promotion platforms represent major opportunities for increasing the visibility of rural destinations. However, the level of digitalisation remains uneven between regions.

Environmental factors are favourable to the development of agrotourism, due to the existence of valuable natural resources, such as the wetlands of the Lower Prut and rural landscapes. At the same time, it is necessary to adopt sustainable practices to protect these resources.

From a legislative perspective, it can be observed that in Romania the regulatory framework governing tourism and agritourism is more developed compared to the Republic of Moldova, resulting in differences in the regulation and standardisation of tourism services.

Compared to Galați County, the southern regions of the Republic of Moldova are characterised by a lower level of tourism infrastructure, particularly in terms of accommodation facilities, a situation that is reflected in the dynamics of tourist flows. It can therefore be concluded that structural disparities exist within the cross-border area, with implications for regional development.

CONCLUSIONS

The analysis conducted within the research highlights the existence of a high potential for the development of agritourism in the Galați–Cahul–UTA Gagauzia–Taraclia cross-border area. The main arguments supporting this conclusion are represented by valuable natural resources, specific cultural traditions, and a distinct culinary heritage.

At the same time, the comparative assessment has demonstrated the existence of important disparities between territories, mainly generated by differences in the level of development of tourism infrastructure and the institutional framework.

The positive evolution recorded in the tourism sector of Galați County indicates an upward trend both in infrastructure development and in the dynamics of tourist flows, while the regions in the southern part of the Republic of Moldova are characterised by a lower level of development, but also by significant opportunities for growth, particularly in the agrotourism and ecotourism segments.

The PESTEL analysis has shown that the development of agrotourism is influenced by a combination of political, economic, social and technological factors, which may act both as opportunities and as constraints.

It can be considered that, from a sustainable development perspective, cross-border cooperation, the availability of funding, and the valorisation of local resources may play a decisive role in the evolution of the tourism sector.

In line with the research findings, it can be considered that the development of integrated tourism products that capitalise on local gastronomy, viticultural potential, and authentic rural experiences, together with the strengthening of cooperation among regional stakeholders, may have a significant impact on the competitiveness and attractiveness of the Galați–Cahul–UTA Gagauzia–Taraclia cross-border area.

The paper contributes to the specialised literature through a comparative and strategic approach to agrotourism in border regions and provides support for the formulation of public policies oriented towards the sustainable valorisation of rural resources.

The findings of this study can support policymakers in designing targeted interventions aimed at improving tourism infrastructure, strengthening cross-border cooperation and enhancing the competitiveness of rural destinations in the analysed area.

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AN ANALYSIS OF CONSUMER PREFERENCES AND PERCEPTIONS OF BARREL-AGED WINES

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Abstract

This study investigates consumer preferences and perceptions of wine, with a focus on barrel-aged wine, based on a questionnaire that identifies the main factors influencing purchasing decisions. It considers several aspects such as taste, aroma profile, appearance, label, type of oak, and aging duration. Responses were collected from a diverse group of consumers, and demographic factors were also take into account when analysing preferences. Most respondents were familiar with barrel-aged wine, even if they were not aware of the specific term, and they usually consume it occasionally at home. The most important factors for them were taste complexity and aroma profile. Preferred wines were mainly fruity, made from a single grape variety without blending, with an emphasis on clarity and aroma purity.

Key words**:** *barrel-aged wine, consumers, preferences, aroma, taste complexity*

INTRODUCTION

Wine is the most noble beverage, with a long tradition and hundreds of years of consumption. Choosing it is associated by consumers with an entire philosophy, ranging from aesthetics to taste [7], [1].

The wine market is highly fragmented and complex, driven by the purchasing decisions of most consumers of alcoholic beverages. These decisions are influenced by a series of intrinsic factors related to the grape variety, quality, and sensory perception of the wine, as well as extrinsic factors, including brand, packaging, price, and the consumer's attention to health considerations [11], [7]. Indeed, consumers are increasingly taking the potential health impact into account when selecting a wine [4].

Understanding consumers' perceptions and familiarizing them with the term barrel-aged wine, that is referring to traditional maturation in barrels, influences the development of marketing, communication, and wine production strategies from a qualitative perspective.

To produce barrel-aged wine, wooden barrels are an important source of complex aromas that contribute to the production of some of the finest wines worldwide [9]. However, the consumers' ability to evaluate the sensory characteristics and quality of wine during barrel aging is limited and remains insufficiently explored [3]. Consumers rarely discern the differences between wines themselves, but perceive differences in closure systems differently, which vary according to the material used.

Romanians represent a wide spectrum of alcoholic beverage consumers, and according to the Romanian National Institute of Statistics, alcoholic drinks play an important role in consumption and purchasing behaviour in Romania. Beer remains the most consumed and best-selling beverage, reaching 80.5 liters per capita in 2024.

Wine consumption stood at 22.8 liters per capita in 2024, showing a 6.14% decrease compared to 24.2 liters per capita in 2023 [6], [10], [1].

Wine consumption in Romania is mainly shaped by economic, cultural, and demographic factors, while purchasing decisions are generally directed toward everyday wines, bought either through planning or on impulse [12], [14].

Given the relevance of this topic, this study focuses on consumer perceptions and preferences regarding both non-barrel and barrel-aged wines. It aims to identify the factors that influence purchasing decisions and to understand how sensory attributes, oak type, aging duration, and bottle related elements affect wine choice.

The research design is structured around: research questions (Q), objectives (O), and hypotheses (H), which guide the analysis.

Research objectives and hypotheses

Q1. What is the level of consumer familiarity with the term barrel-aged wine?

O1. For evaluation of respondents' knowledge about barrel-aged wine and collect socio-demographic data (gender, age, education, income).

H1. Familiarity with the term is generally low, depending on the level of available information, as discussed in the literature [3].

Q2. How frequently do consumers drink wine and barrel-aged wine?

O2. To identify the percentage of wine consumption in general and of barrel-aged wines specifically.

H2. Barrel-aged wines are generally consumed less frequently than wines produced using conventional methods due to the maturation process [11].

Q3. Which are consumers' preferences according to wine type (origin, sugar content)?

O3. Determining consumer preferences regarding wine type, sugar concentration and origin.

H3. Consumers exhibit different perceptions of barrel-aged wine compared to other wines [11].

Q4. During which occasions are wine and barrel-aged wine consumed?

O4. Determining the main occasions of consumption.

H4. Barrel-aged wines are consumed in formal or semi-formal contexts such as festive meals, at home, in restaurants, or at events [1].

Q5. What are the most important factors in choosing a barrel-aged wine?

O5. Illustration of the most important elements appreciated by consumers when choosing barrel-aged wines (taste complexity, aroma, packaging, label).

H5. Maturation in oak barrels determines sensory characteristics and consumers are influenced by taste and aroma [2].

Q6. Which factors influence the purchase decision for barrel-aged wines?

O6. Identification of the factors that influence the purchase decision (quality, price).

H6. Both quality and the desire to experience new tastes are reasons for choosing barrel-aged wine [2].

Q7. How important are maturation and barrel wood for consumers?

O7. Determining the preferred aging duration, the type of oak, and perception of barrel quality.

H7. Consumers perceive a long maturation period and the use of barrels as significant [2].

Q8. How much do consumers pay for a 750 ml bottle of wine?

O8. Determining the price accepted by consumers.

H8. Consumers are willing to pay an average price when it comes to buying a bottle of wine [13].

Q9. How are barrel-aged wines perceived compared to non-barrel-aged wines?

O9. Identifying consumer perception of barrel-aged wine in comparison to non-barrel-aged wines.

H9. Barrel-aged wines are considered superior to non-barrel-aged wines, but at a higher cost [11].

Q10. How do consumers perceive future consumption of barrel-aged wine?
O10. Analysis of the intention to increase consumption of barrel-aged wine.
H10. A significant portion of consumers intends to consume more barrel-aged wine in the future [11].

MATERIALS AND METHODS

For the construction of the opinion poll on non-barrel-aged and barrel-aged wine consumption, we choose to conduct a quantitative analysis. The research questions were defined prior to conducting the survey, and the questionnaire was distributed online, allowing participants to respond via various social media platforms such as Facebook, Instagram, WhatsApp. The data received were then processed [8]. The questionnaire included four sections to identify behavioural patterns and consumer preferences regarding wine. The first section assessed the respondents' socio-demographic characteristics of the respondents, referring to gender, age, education level, place of residence, occupation, and income .
The second section evaluated respondents' general wine consumption behaviours, including the regularity of consumption, preferred type of wine, places of consumption, purchase of the beverage, price and finally consumer preference regarding sugar content.
The third section focused on consumer's level of knowledge, perception, and preference regarding barrel-aged wine. It focused questions about familiarity with the term barrel-aged wine, frequency of consumption, preferred barrel-aged wines, elements considered when purchasing (e.g., aroma, taste, label), preferred aging period, type of oak and barrel characteristics and, comparisons between barrel-aged and non-barrel-aged wines. The final section assessed consumer preferences regarding the origin of wines and their intention to increase consumption of barrel-aged wines.

RESULTS AND DISCUSSIONS

A total of 166 consumers, aged 18 to over 55 years, completed the survey. The socio-demographic structure of the respondents shows a high proportion of women (57.2%) compared to men (42.8%). Regarding age, the majority of responses fall in the 26-35 age group, followed by 18-25 years, while respondents over 55 years were less represented. In terms of educations, most respondents hold university or postgraduate degrees, and the predominant place of residence is urban. The most common income ranges fall between 3,000-5,000 lei and 5,000-8,000 lei and most respondents are employed. This socio-demographic breakdown is shown in Table 1.

Tabel 1. Demographic profile of respondents

Variable	Category	Number of respondents	Precentage (%)
Gender	Female	95	57.2%
	Male	71	42.8%
Age	18–25 years	48	28.9%
	26–35 years	63	37.9%
	36–45 years	27	16.3%
	46–55 years	21	12.7%
	Over 55 years	7	4.2%
Education	Seconday education	34	20.5%
	Univeristy degree	85	51.2%
	Postgraduate degree	47	28.3%
Residence	Urban	112	67.5%
	Rural	54	32.5%
Monthly net income	Under 3.000 RON	38	22.9%
	3.000–5.000 RON	62	37.3%
	5.000–8.000 RON	41	24.7%
	Peste 8.000 RON	25	15.1%
Occupation	Employed	101	60.8%
	Student	27	16.3%
	Unemployed	13	7.8%
	Retired	6	3.6%
	Job seeker	2	1.2%
	Entrepreneur	17	10.2%

Source: original data recorded from the research.

From the perspective of household alcoholic beverage purchases, the majority of respondents specified that they were the person who most frequently bought alcoholic beverages within the family (31%), while 69% indicated that they were not the

responsible for purchase and that the purchase decisions were made by another family member. This criterion was crucial because the preferences expressed consistently aligned with the actual purchasing decision (Figure 1).

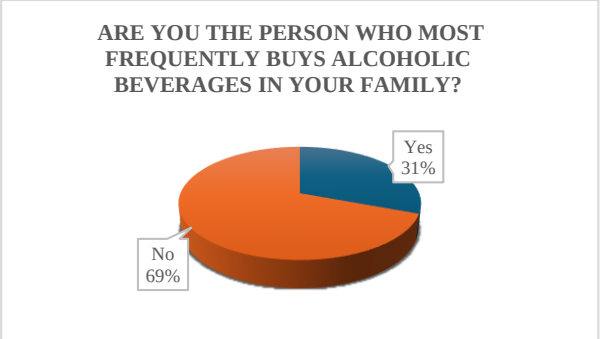

Fig.1. Respondent's answers to the question: Are you the person who most frequently buys alcoholic beverages in your family.
Source: original data recorded from the research

Regarding the percentage of wine consumption, the majority of respondents indicated that they consumed wine a few times per year (60%). A small number of respondents (3%) never consumed wine. Monthly consumption applied to 22% of respondents, weekly to 14% and daily consumption by 1%, which was relatively moderate. Most respondents consumed wine occasionally, reflecting cultural and social habits specific to the Romanian context (Figure 2).

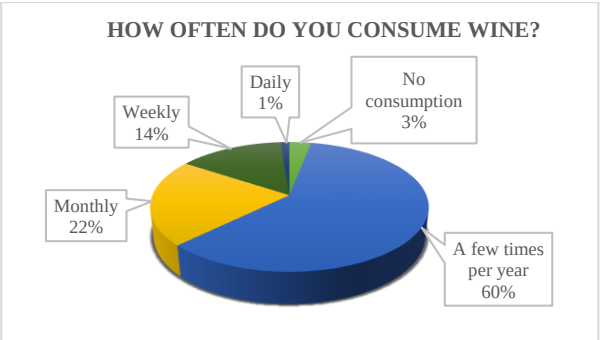

Fig. 2. Respondents' answers to the question: How often do you consume wine?
Source: original data recorded from the research.

The majority of respondents (50%) preferred rosé wine, followed by red wine (35%) and white wine (33%). Sparkling wine is preferred by 9.6% and a small number expressed no preferences for any type of wine (6.6%). Consumers display a fairly varied distribution of preferences, with rosé wine mostly popular among young adults in different contexts, while red and white wines were more flexible and suitable for meals and occasions (Figure 3).

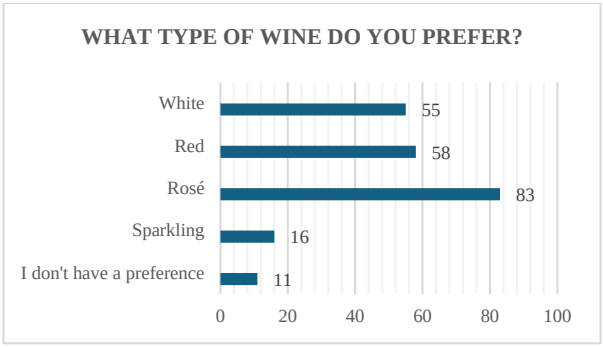

Fig. 3. Respondents' answers to the question: What type of wine do you prefer?
Source: original data recorded from the research.

In order to understand general consumer behavior in the context of wine consumption, the consumption environment also played an important role, as could favor or affect the purchase of alcoholic beverages.
Respondents' most preferred to consume wine at home (50%), followed by events (29%) and restaurants (18%). Winery tastings were indicated by consumers at a marginal percentage (3%), suggesting a limited sample of consumers interested in oenological experiences (Figure 4).

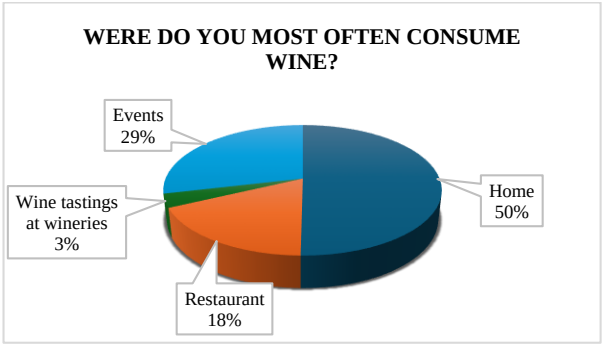

Fig. 4. Respondents' answers to the question: Were do you most often consume wine?
Source: original data recorded from the research.

As such, for the acquisition of a bottle of wine, the budget allocated by 48% of respondents was indicated by the price range of 40-80 RON, while a smaller segment paid between 80-100 RON (15%) or over 100 RON (10%) per bottle. A considerable percentage (27%) of respondents choose to

pay under 40 RON when buying a bottle of wine, indicating a preference for more affordable wines, while a smaller portion of them were oriented towards mid-priced wines or wines with special characteristics (Figure 5).

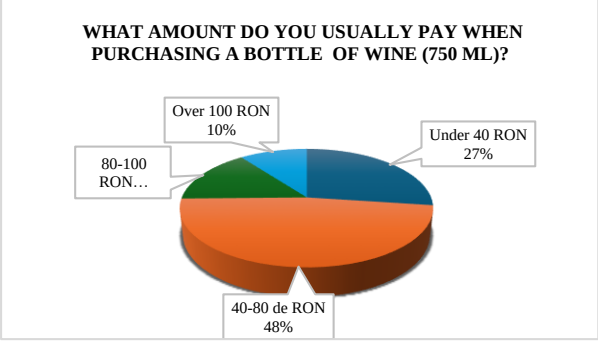

Fig. 5. Respondent's answers to the question: What amount do you usually pay when purchasing a bottle of wine (750 ml)?
Source: original data recorded from the research .

Preferences for wine type are closely associated with sugar content [5], a significant factor that determined taste perception and wine appeal. Most respondents preferred wines with low sugar content, reflecting their general tastes and experiences. Dry wines (13%) and sweet wines (11%) receive lower preference, while respondents tended to choose semi-sweet wines (43%) and medium-dry wines (33%), which were balanced in terms of sugar content (Figure 6).

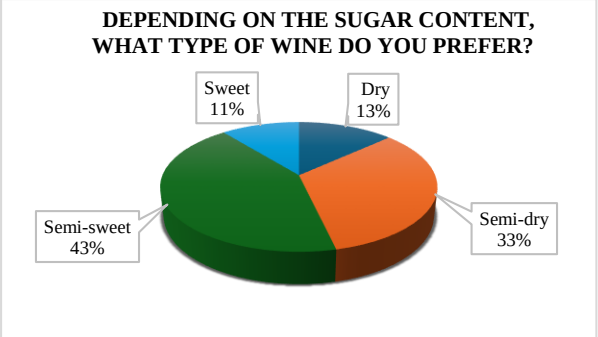

Fig. 6. Respondent's answers to the question: Depending on the sugar content, what type of wine do you prefer?
Source: original data recorded from the research.

In the context of consumption habits and consumer budget, the following question determined the respondents' familiarity with the term "barrel-aged wine", which was essential for understanding preferences and behavior. The term "barrel-aged" wine was relatively unknown, as reflected in the percentage (36%). A number of respondents (20%) indicated that the term is little known, while for 22% of respondents were familiar with it, and a majority (11%) were very familiar. A similar number of people (11%) reported that the term was less know (Figure 7).

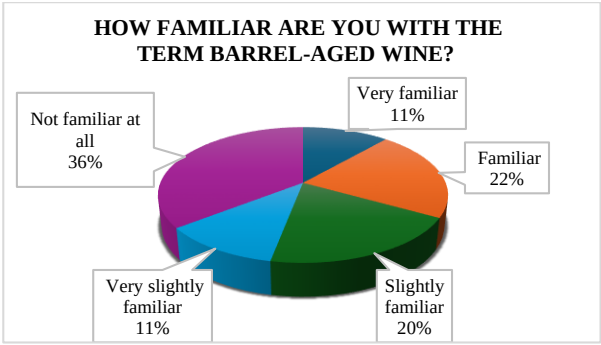

Fig. 7. Respondent's answers to the question: How familiar are you with the term "barrel-aged wine"?
Source: original data recorded from the research.

Clarifying the level of familiarity with the term, respondents answered how often they consumed barrel-aged wine in order to analyze the correlation between familiarity and consumption frequency.

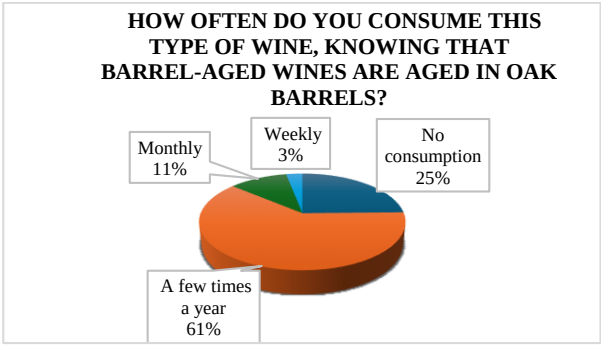

Fig. 8. Respondent's answers to the question: How often do you consume this type of wine, knowing that barrel-aged wines are aged in oak barrels?
Source: original data recorded from the research.

The majority of them consumed barrel aged-wine a few times per year (61%), followed by respondents who never consumed it (25%) and respondents who consumed it monthly (11%) or weekly (3%). None of the respondents reported daily consumption of barrel-aged wine. Although wine was consumed on average, experience with barrel-aged wine remained quite limited (Figure 8).

The main criteria for choosing a barrel-aged wine were taste complexity and harmony (45%) and aroma (31%). Other characteristics, such as wine color (12%) or bottle and label (8%), received lower relevance in consumer responses. A small number of respondents provided individual answers represented in the others section of the chart including factors such as producer, not drinking alcohol, no prior tasting, disregarding this feature, or generally not consuming alcohol. This show low relevance and consumption of barrel-aged wine among respondents (Fig. 9).

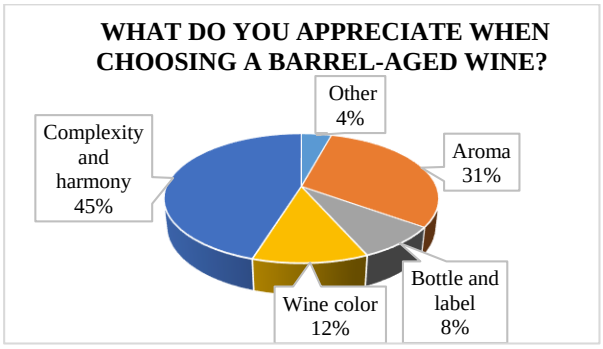

Fig. 9. Respondent's answers to the question: What do you appreciate when choosing a barrel-aged wine?
Source: original data recorded from the research.

Regarding the preferred type of barrel-aged wine, rosé wine was mentioned most often (33%), followed by red wine (28%) and white wine (20%), while 19% of respondents did not express a clear preference.

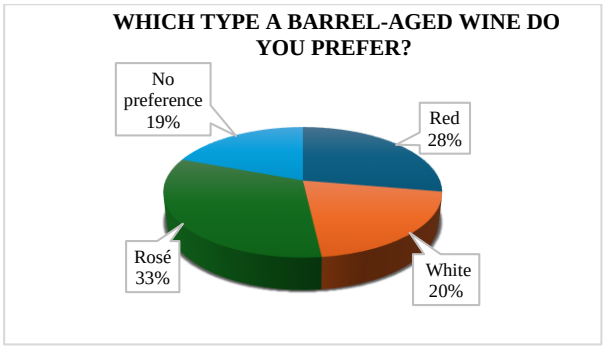

Fig. 10. Respondent's answers to the question: Which type of barrel-aged wine do you prefer?
Source: original data recorded from the research.

Consumer preferences were varied, mainly influenced by personal taste, with some respondents remaining undecided, indicating limited knowledge of barrel-aged wines (Figure 10).

Based on respondents' preferences for the barrel-aged wine, the next question addressed purchasing behavior. Respondents were asked when they last purchased a barrel-aged wine. Most of them could not remember (49%) or had never purchased it (15%), while a smaller percentage reported buying it in the last 15 days (14%) or within the past 3-6 months (11%) (Fig. 11).

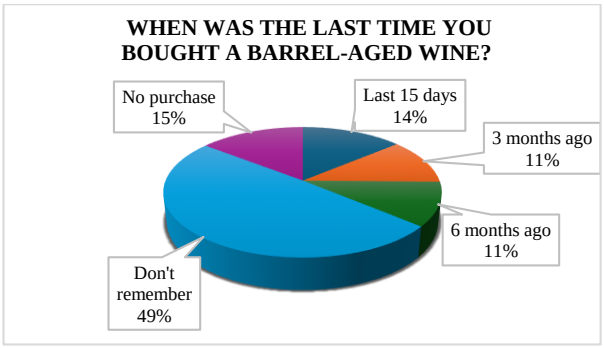

Fig. 11. Respondent's answers to the question: When was the last time you bought a barrel-aged wine?
Source: original data recorded from the research.

As barrel-aged wine was purchased only occasionally by most respondents, the maturation period played an important role in both consumer preferences and the final characteristics of the product. For most respondents, the duration of wine maturation was a relevant factor (44%), although a segment considered it only slightly important (30%) or irrelevant (8%).

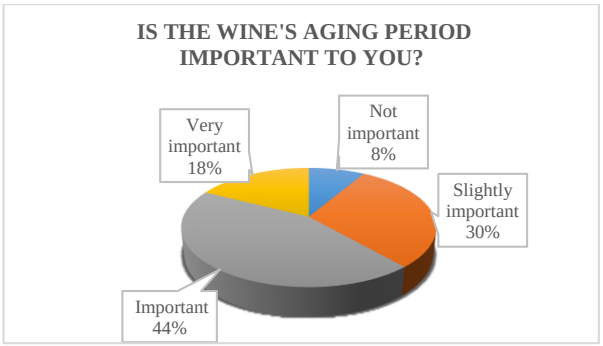

Fig.12. Respondent's answers to the question: Is the wine's aging period important to you?
Source: original data recorded from the research.

These variations in response highlighted the degree of attention paid to technological criteria, while sensory perception and the ability to appreciate wine influenced the maturation process (Figure 12).

Most respondents preferred a maturation period of 6-12 months (46%). A considerable number appreciated long maturation (2 years or more), showing interest in a high degree of complexity, while only a few respondents preferred minimal maturation (under 6 months). For consumers who preferred barrel-aged wine, the maturation period was an important characteristic, influencing both the choice and the level of satisfaction with the product (Figure 13).

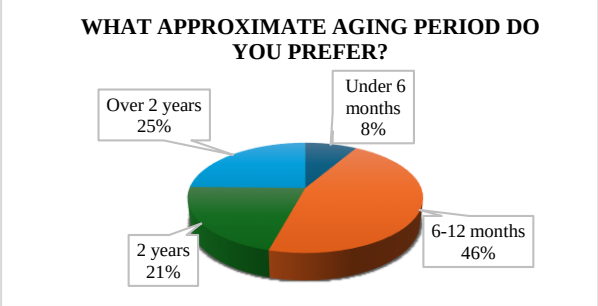

Fig. 13. Respondent's answers to the question: What approximate aging period do you prefer?
Source: original data recorded from the research.

Apart from the maturation period, respondents showed a low level of knowledge about the type of oak that positively influenced the quality of barrel-aged wine. Some were oriented towards Romanian oak (28%) or internationally relevant types (American and French). Romanian and international oak provided wine with more intense aromas than other species, emphasizing smoother toasted notes (Figure 14).

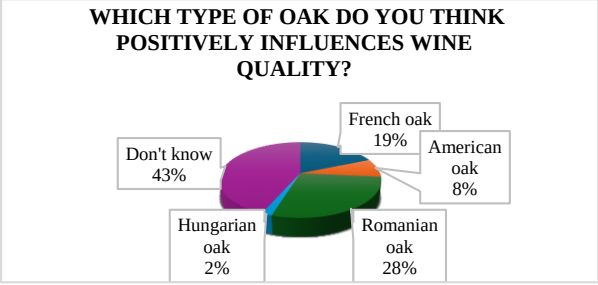

Fig. 14. Respondent's answers to the question: Which type of oak do you think positively influences wine quality?
Source: original data recorded from the research.

In relation to the type of oak used, an essential element in the barrel-aging process was the type of barrel employed. New barrels (21%) generated intense aromas, while old barrels preserved woody notes. Based on the data, the level of uncertainty and knowledge was low among respondents. The majority preferred old barrels (28%), others a combination of old and new barrels (22%) while a significant portion could not discern their impact on the wine's aroma (29%) (Figure 15).

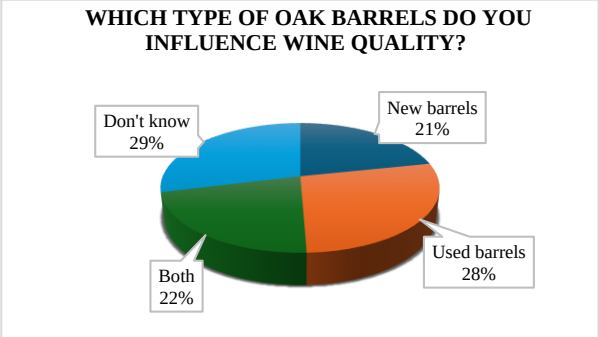

Fig. 15. Respondent's answers to the question: Which type of oak barrels do you think influence wine quality?
Source: original data recorded from the research.

When choosing barrel-aged wine, consumers primarily considered elements that inspired confidence in quality and origin, with the most important being the name of winery (30%) and the vintage (29%). Details about barrel maturation (19%) were relevant for some respondents. Visual or technical elements such as bottle design (17%) or the type of closure (10%) were less influential and played a secondary role in the purchase decision (Figure 16).

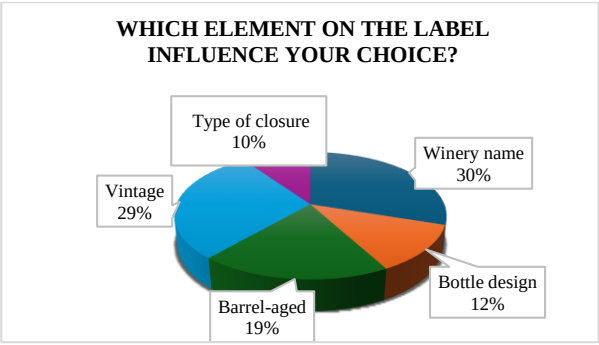

Fig. 16. Respondent's answers to the question: Which element on the label influence your choice?
Source: original data recorded from the research.

Consumer preferences were also influenced by the type of wine, and most respondents preferred wines from a single variety (58%). Blended wines, whether between two different

varieties (12%) or the same variety from different years (10%) were less familiar, and general information on wine categories from the Aurelia Vișinescu brand was considered in the questionnaire design [15]. Additionally, 12% of respondents were uncertain about which type of wine preferred. More complex blends, such as those combining more than two varieties, attracted only a small group of respondents (8%). Preference for a single variety may have played a role in the appreciation of barrel-aged wine among consumers, especially regarding the aromas contributed by maturation (Figure 17).

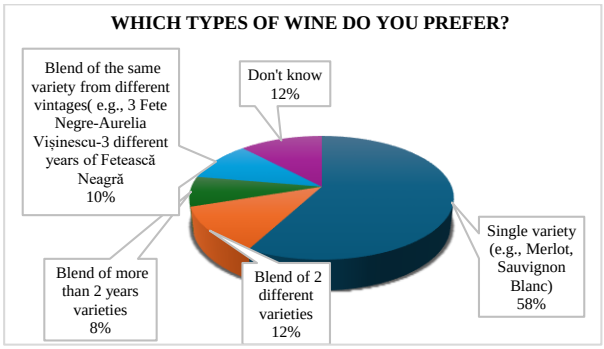

Fig. 17. Respondent's answers to the question: Which types of wine do you prefer?
Source: original data recorded from the research.

When it came to barrel-aged wine, most participants preferred wines with fruity aromas (55%). Aromas derived directly from barrel aging, such as smoke and spices (16%) or vanilla (11%), were less popular, while 18% mentioned other aromas (Figure 18).

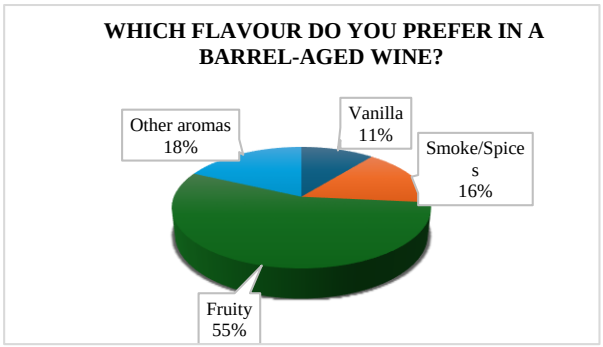

Fig. 18. Respondent's answers to the question: Which flavour do you prefer in a barrel-aged wine?
Source: original data recorded from the research.

The main criteria for choosing a barrel-aged wine were quality (45%) and recommendations from others (31%). Consequently, the experience and opinions of those around consumers played a decisive role in wine purchasing. Other aspects, such as trying new flavors (18%) or an attractive bottle design and label (6%) were less significant (Figure 19).

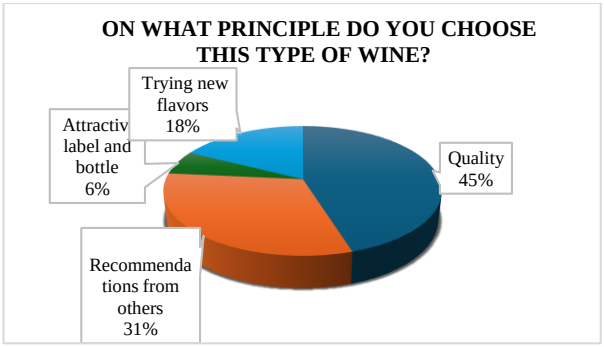

Fig. 19. Respondent's answers to the question: On what principle do you choose this type of wine?
Source: original data recorded from the research.

Barrel-aged wine was regarded by some respondents as an ideal wine, most served at family events (38%) and dinners (44%), followed by tastings, gifts or professional meetings. Barrel-aged wine didn't emerge as a wine for daily consumption and was considered a product associated with socializing and festive events (Figure 20).

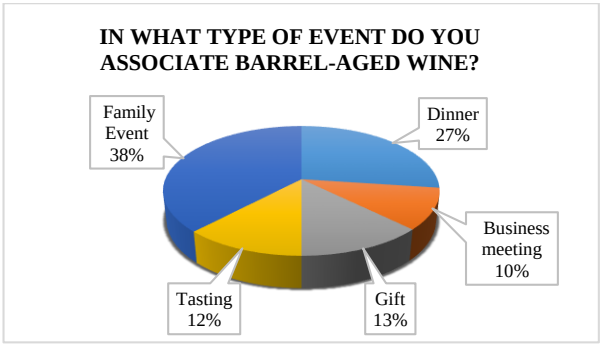

Fig. 20. Respondent's answers to the question: In what type of event do you associate barrel-aged wine?
Source: original data recorded from the research.

Most respondents (63%) believe that barrel-aged wines were superior to non-barrel-aged wines. At the same time, some participants associated them with special occasions (17%), while only a few considered these wines are quite expensive (5%). Barrel-aged wines were regarded as having added value through their quality and not just their price. This positive perception could influence purchasing decisions and consumption patterns, as it was

directly related to preferences for fruity aromas or overall wine quality (Fig. 21).

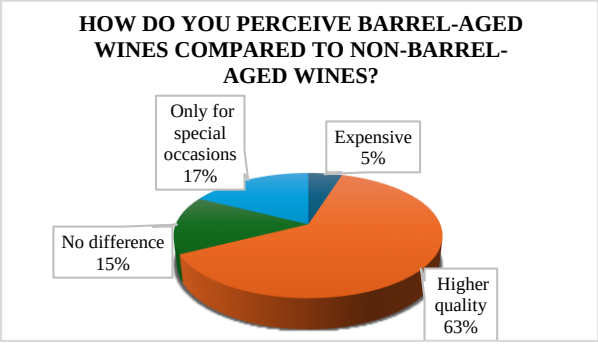

Fig. 21. Respondent's answers to the question: How do you perceive barrel-aged wines compared to non-barrel-aged wines?
Source: original data recorded from the research.

The origin of wine appeared to be highly important to consumers, with local wines being the most favorite (64%) followed by wines from Europe (32%), while wines from other continents attracted only a small segment (4%). Local wines were perceived with confidence, while European wines were appreciated for their reputation and international quality standards (Figure 22).

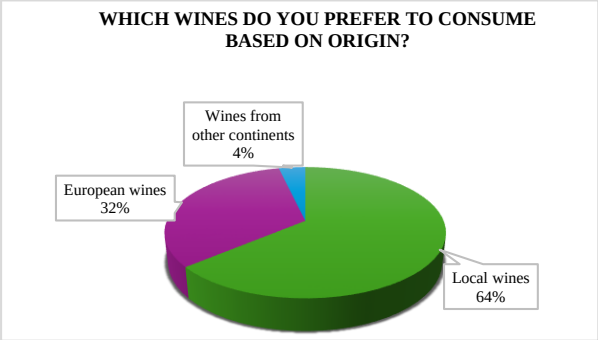

Fig. 22. Respondent's answers to the question: Which wines do you prefer to consume based on origin?
Source: original data recorded from the research.

Most respondents would like to include barrel-aged wine in their daily consumption: 36% of respondents expressed probable willingness and 33% confirmed their intention to consume. Some were still undecided (23%) and very few expressed a desire to reduce consumption (7%). Barrel-aged wines were perceived as an attractive option for the future, but familiarity with this type of wine remained an important factor. The undecided segment suggested that opportunities still existed to educate and attract consumers through tastings, recommendations or information about flavors and styles, which could have transformed potential interest into actual consumption (Figure 23).

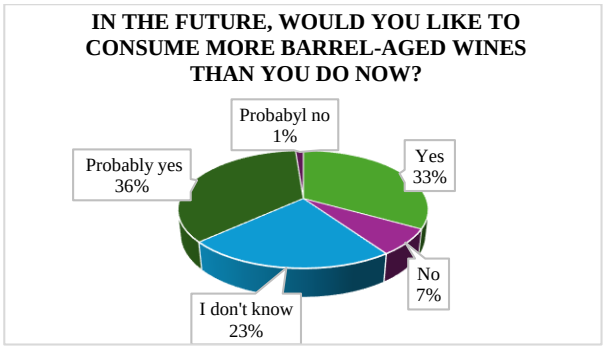

Fig. 23. Respondent's answers to the question: In the future, would you like to consume more barrel-aged wines than you do now?
Source: original data recorded from the research.

Within the present research, the central objective is represented by the profile of the wine consumer, through the analysis of data obtained from the use of the questionnaire. Some of the starting hypotheses were confirmed by the collected data, while others were partially confirmed. The analysis highlights the fact the term "barrel aged" wine is not widely known among respondents, with most stating that they either do not know it or know it only a little , while around 22% consider it to be very well known. The data confirm H1, showing that familiarity with this type of wine is relatively low, indicating a need for consumer education to support growth and appreciation of the product.
Regarding consumption frequency, wine is consumed occasionally, with a large percentage of respondents reporting consumption throughout the year. Barrel-aged wines are consumed more rarely, with a high percentage consuming them occasionally and a lower number not consuming them at all. The results confirm H2, indicating that barrel-aged wines are consumed quite rarely compared to regular wines and the perception of this type of wine remains limited.
Preferences for wine type reflected a range of tastes, with rosé wine being the most appreciated, followed by red wine and white wine. When it comes to barrel-aged wines, rosé remains the most popular, but white and

red wines also hold a considerable share. Also, H3 which indicates that consumers exhibit different perceptions of barrel-aged wine compared to other wines, is partially confirmed, mentioning the diversity of tastes and experience with multiple types of wine.

The circumstances of barrel-aged wine consumption are mainly focused on social moments, such as family events and dinners while tastings and professional settings are mentioned more rarely. The results confirm H4, according to which barrel-aged wines are associated with formal occasions being used as special or festive products.

In terms of factors considered important, complexity and harmony of taste, as well as overall aroma, are key selection criteria, while the visual appearance of the bottle and label is less relevant. These data partially confirm H5, as the sensory profile of wine is largely determined by barrel aging with an impact on consumer preferences.

Elements that influenced the purchase decision indicated that perception of quality and recommendations from others were predominant, while the desire to experience new tastes is lower. H6, regarding the influence of quality and the desire for knowledge is partially confirmed indicating the importance of experience and social recommendations in purchase decisions.

Most respondents consider the aging period of wine important or very important preferring aging periods of 6-12 months, while their knowledge of the type of oak and barrels is quite limited. The results partially confirm H7, as both aging and the type of wood influence consumer preferences, although taste and aroma experience matters more than technological knowledge.

The budget allocated for a standard bottle of wine generally supported H8, indicating that most preferred a medium price, while a smaller segment is oriented towards premium wines.

Preference for barrel-aged wines was generally positive, as they are considered superior to non-barrel-aged wines and only low percentage perceived them as expensive. This partially confirms H9, showing that barrel-aged wines are considered superior, but the perception of high cost was not dominant.

Overall, regarding the future consumption intentions, high percentage of respondents expressed a desire to consume more barrel-aged wine, while some others are undecided. The results confirm H10, demonstrating that there is a segment of consumers intending to include barrel-aged wines in their consumption more frequently in the future.

CONCLUSIONS

The article focused on Romanian consumers' preferences for barrel-aged wine, with the purpose of identifying consumption patterns, perceptions of quality, and the key factors that determine purchase decisions. The information obtained from this research can support wine producers in implementing marketing strategies related to the product, communication and consumer education. The study highlights several key conclusions. Awareness of the term barrel-aged wine is particularly low, yet the general trend regarding this type of wine is positive. Barrel-aged wine are consumed more occasionally compared to regular wines. Consumers place high importance on taste complexity, aroma, and quality associated with maturation in oak barrels.

Quality, winery reputation and recommendations from others are among the main factors influencing the purchase decisions, while that technical knowledge about the type of oak or the aging process remains limited. Barrel-aged wine are generally considered as superior to non-barrel-aged wines, and price is not considered as a major factor. At the same time, a considerable percentage of respondents expressed their intention to consume more barrel-aged wine in the future.

In general, most of the hypotheses were confirm (some partially), indicating the presence of consistent trends in consumer behavior, but also the need of informational campaigns and tastings to increase the consumption of barrel-aged wine.

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AN INTEGRATED APPROACH FOR PROMOTING SUSTAINABLE GRAINS: THE ECONOMIC IMPACT OF RAIL FREIGHT TRANSPORT

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Abstract

In the context of the article the grain logistics topic is approached, as cereals movement from production to processing/consumption locations directly influences sustainability, food safety and security. Particularly, research is focused on cereals rail freight mode, as it is a solution with low carbon footprint and for its cost-effective; despite these advantages, rail transport mode remains underutilized, with road transport being preferred, but more polluting and contributing to grain quality degradation, too. Previous studies have explored the sustainability benefits of the rail freight mode, but there is a research gap related to economic aspects of green grain supply chains. The proposed approach addresses this gap by critically assess the economic viability of rail freight transport in grain logistics, adopting an integrated, holistic-multidisciplinary perspective. Thus, the research methodology combines economic analysis, transport process modelling and sustainability indicators. The research results are useful for agricultural policymakers and stakeholders, and for logistics service providers, too. Conclusions of the research support the development of sustainable and more resilient food transport systems.

Key words**:** *Sustainability, grain logistics, supply chain, rail freight transport, risk management, digital technology*

INTRODUCTION

The global demand for grains, a staple food commodity, requires highly efficient, cost-effective, and environmentally sustainable transport solutions. Given that around 15% of global cereal production is lost to microbial pests (Athanassiou et al., 2019) [1], enhancing food safety and sustainability emerges as the most effective strategy to minimize economic losses (Baer et al., 2019) [2]. Grain supply chains are inherently complex, extending from agricultural production fields, through various stages of handling and transport, to final consumption or pro-cessing. To be sustainable in the sector, it is necessary to go beyond cultivation practices to encompass the entire supply chain, including transport logistics. The goal is to minimize environmental impacts, such as carbon emissions, while ensuring food security and economic viability. Food consumption significantly impacts the environment, with 20–37% of global emissions linked to the food system, 29% of which stem from supply chain activities such as transport, retail, and packaging (Baldacchino et al., 2024) [3]. Rail transport is highly praised for its significant capacity to move large volumes of bulk cargo, such as grain, over long distances. This mode of transport typically offers a lower cost per tons kilometre and a relatively smaller carbon footprint than road transport, positioning it as a theoretically ideal choice for large-scale grain transport (Chelladurai et al., 2020) [4].
We recognize the premise that it is cheaper to transport grain by rail, a perceived economic advantage that underpins logistics decisions. However, even with these compelling advantages, there are significant and often underestimated challenges that are associated with quality degradation and time-related losses during rail transport. The rail network plays a vital role in grain transportation; for

example, 72% of U.S. wheat was transported by rail between 2001 and 2010 (Choudhury et al., 2024) [5].

Although rail transport is perceived as more environmentally friendly and much more cost-effective per unit distance, substantial grain quality losses and delays can create the opposite effect. If the cost efficiency of rail transport is achieved at the expense of significant grain quality degradation and time losses, this has a direct impact on the economic value of the cargo.

Loss of quality means reduced economic market value, increased waste and potentially the need to use additional resources (land, water, energy) to produce other replacement grains. This can lead to a higher overall ecological footprint, due to wasted energy and resources and the need for new production. Therefore, an apparently "green" mode of transport that results in significant post-harvest losses can have an overall negative economic and environmental impact, highlighting the need for a holistic view of the entire value chain. Real-time monitoring of intergranular variables within the grain mass enables the indirect assessment of potential physical and technological changes in the grains, using predictive algorithms, while supporting quality preservation and minimizing post-harvest losses (Crippa et al., 2021) [6].

In this context, the present research approach aims to critically evaluate the economic viability of rail freight transport in grain logistics by designing and implementing a holistic and multidisciplinary approach.

To provide a comprehensive understanding of the research approach, the structure of this article is organized as follows: Section 2 outlines the materials and methods, detailing the systematic literature review and the criteria used to identify relevant studies on sustainable grain logistics and rail transport. Section 3 presents and discusses the results, structured into thematic subsections that explore environmental impacts, economic attractiveness, critical risks related to quality degradation and time delays, and the role of digital technologies in mitigating these challenges. In addition, there will be synthesized broader sustainability considerations and value chain trade-offs, emphasizing the need for systemic approaches and there will be offered strategic recommendations for optimizing rail grain transport, including technological, logistical, and policy-level interventions. Finally, Section 4 summarize the key findings, acknowledging limitations, and proposing directions for future research aimed at enhancing the sustainability and economic viability of grain logistics through rail freight transport.

MATERIALS AND METHODS

To investigate the factors that influence the economic of rail transport in the context of sustainable cereal production, a systematic review of the literature was conducted; the methodological approach is presented in Figure 1. The research focused on articles indexed in the PubMed and Springer databases, both recognized for the accuracy and relevance of their scientific publications. The inclusion criteria targeted articles containing the following keyword combinations: sustainability, cereals, digitalization, transport (35 articles identified); sustainability, cereals, digitalization (38 identified articles); transport, cereals (1,560 articles identified). In total, 2,233 articles were initially retrieved.

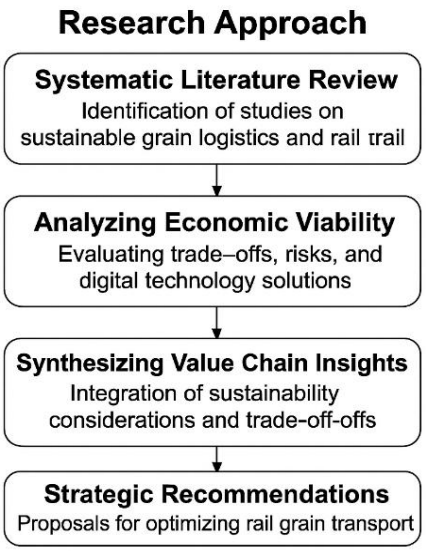

Fig. 1. The research approach
Source: Authors' conception.

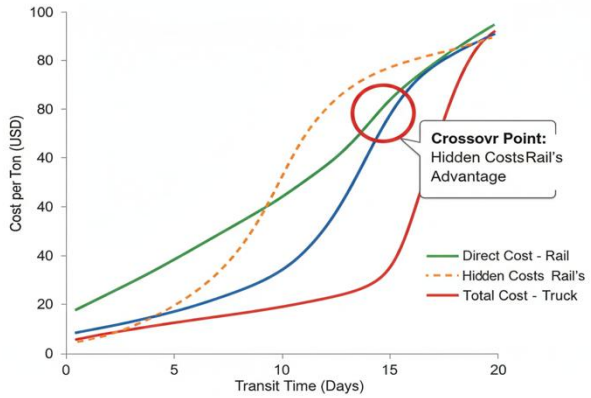

Fig. 2. Cost-quality-time trade-off in grain transport
Source: Authors' conception.

The selection process continued by applying exclusion criteria, eliminating articles that: focused on goods other than cereals; addressed modes of transport other than rail.
After applying these filters, 16 relevant articles were retained and further analysed to extract data related to the economic impact of rail transport in the context of sustainable agricultural production. Figure 2 reflects the cost-quality-time trade-off in grain transport.

RESULTS AND DISCUSSIONS

Environmental Impact of Rail Transport and Packaging

Studies on greenhouse gas emissions from rail transport highlight the need to evaluate sustainability and environmental impact (da Fonseca-Soares et al., 2024) [7], with a specific focus on emissions occur-ring during evening hours, particularly in relation to the cereal packaging and products' design and manufacturing.
A traditional siloed approach to logistics, where, for example, procurement focusses exclusively on minimizing transportation costs without considering the impacts at the end of the journey, will fail to capture all the eco-nomic and environmental consequences. Research of (da Rocha & Branco, 2024) [8] highlights the usefulness of a dynamic system approach to identifying value chain trade-offs. Such a methodology, which explicitly models the feedback loops, delays, and interdependencies between the various components of the supply chain, is crucial.

Globally, food systems are responsible for about one-third of all greenhouse gas emissions generated by human activities. In 2015, the food sector produced approx. 18 gigatonnes of CO_2 equivalent per year, or 34% of total global emissions; of these, 71% came from agricultural processes and land use or land use change, with the remainder being driven by supply chain activities (e.g., transport, retail, consumption, waste management, industrial processes, and packaging) (Freita-Silva et al., 2014) [19]. The graph in Figure 2 illustrates how the low direct cost of rail transport can be diminished by the risks of low quality and time losses, leading to a higher real total cost.
The major economic advantage of rail grain transport is the ability to transport quantities (bulk), with high profitability over long distances (substantial advantages compared to road transport) (Grijalva et al., 2024) [11].
Beyond its low costs advantage, rail transport generally shows a lower carbon footprint per ton-kilometre (mile) than road transport (this is a usual unit measure in rail transport field 1 ton-kilometre = 1,000 kg-km). This environmental advantage contributes directly to broader sustainability objectives, to significantly reduce greenhouse gas (GHG) emissions. (Hagstrum & Subramanyam, 2009) [12] underline the importance of assessing sustainability and environmental impact, with particular focus on greenhouse gas emissions, in the context of cereal and confectionery packaging, underlining the importance of reducing GHG emissions across the entire cereal supply chain. Thus, the demonstrably lower emissions profile of rail transport contributes positively to this broader sustainability objective, making it an attractive option from an environmental perspective.
However, this environmental benefit is only fully realized if the risks that may be as-sociated with quality degradation and time loss are effectively managed, preventing the need for resource-intensive new production. This situation highlights that economic viability and environmental sustainability are not isolated objectives but are deeply inter-connected within a supply chain. A mode of

transport that is economically and environmentally efficient (which can be the rail, under optimal conditions) is essential to achieve truly sustainable grain supply chains. However, if this small perceived cost of rail transport leads to significant quality losses and subsequent waste, the real cost, which includes the economic value of the lost product, the environmental burden of reprocessing, and the potential health impacts caused by degraded grain, could cancel out the economic and environmental gains initially established. This reinforces the need for a strong cost-benefit analysis that internalizes externalities and considers the impact of the entire supply chain cycle (Baldacchino et al., 2024; Hernandez Nopsa et al., 2015) [3, 13].

Critical risks of quality degradation

The grain quality is very open to weather changes when moved and kept for a long time. Heat and wetness are the two main things that affect how quickly and far spoilage, germs, and bugs grow. Changes in these conditions, mainly within the closed and often unknown space of train cars, can accelerate decay quickly (Crippa et al., 2021; Hagstrum & Subramanyam, 2009) [6, 12].

The research realized by Nunes et al., of focusses on this weakness, explaining a "sensor-wire device and sample for quick finding and guessing of dry stuff loss and current corn grain quality in moving and keeping" (Hagstrum & Subramanyam, 2009) [12]. This study shows the clear effect of weather on grain quality while moving and points out the need for non-stop checking sign of quality drop – is a clear and expected danger during moving and keeping. The truth that new and emergent technology answers are being made and used, such as machine learning plans to cheque and guess the quality of corn in moving and after harvesting steps, shows that the loss of quality from outside factors is a large and money-related problem in grain transport. In addition, study clearly shows that dry matter loss, a clear sign of quality loss, is something we can measure and expect during movement and keeping (Hagstrum & Subramanyam, 2009) [12]. The clear talk about real-time checking with sensors means these outside conditions change fast and need constant watching to stop big losses.

Beyond simple moisture content, dry matter loss represents a direct and quantifiable reduction in both the physical quantity and nutritional value of grains. This critical form of loss can be caused by various biological processes, including grain respiration, microbial metabolic activity (e.g., mold growth), or deterioration caused by insect infestation. All these detrimental processes are significantly exacerbated by unfavourable temperature and humidity conditions, prevalent during prolonged transit or inadequate storage. Research explicitly identifies "dry matter loss" as a key quality parameter that sensor technology aims to detect and predict (Higgins et al., 2020) [14]. The focus on dry matter loss underscores its direct correlation with economic loss, as it directly decreases the marketable volume and intrinsic quality of the grain, leading to reduced market value or outright rejection. Although not focusing exclusively on transport, other studies support general risks. For example, Lactobacillus buchneri has been identified from rice grain silage, indicating the potential for microbial activity in stored grains. Likewise, the detection of wheat coccinellids highlights the general concern for pest infestations in cereals, a risk amplified during prolonged transport (Krauter et al., 2022; Kumar et al., 2021; Liu, J., Zhang, et al., 2022; Liu, Y., Wilson, et al., 2022) [15, 16, 17, 18].

It is very important to discuss the main causes and their implications on the grains deterioration when rail grain transport is being used. First, the respiration process must be discussed because grains are living biological entities that continue to respire after harvest. This process consumes stored dry matter and generates both heat and moisture. In the enclosed, often poorly ventilated, environment of railway wagons, this can lead to the rapid development of hot spots and localized increases in moisture, creating a self-reinforcing cycle that accelerates spoilage (Lu et al., 2025; Mao et al., 2020) [19, 20]. Second, the fungal growth process can incuse supporting

the grains deterioration. High moisture levels (above safe storage limits, often around 14-15%) combined with warm temperatures create ideal conditions for the proliferation of mold and other fungi (Massa, 2018; Mogale et al., 2021) [21, 22]. This fungal growth not only reduces grain quality but can also lead to the production of mycotoxins – toxic secondary metabolites that render grain unsafe for human or animal consumption, potentially reducing its market value to zero. Third, the insect infestation on grains must be discussed in the context of the deterioration mechanism because stored product insects (e.g., weevils, beetles) thrive in warm, humid conditions can occurred. Infestations can cause direct physical damage to grain, introduce contaminants (e.g., insect fragments, feces), and contribute to heat and moisture generation within the grain mass, further accelerating spoilage and creating an unsanitary environment (Neethirajan et al., 2021; Nunes et al., 2023) [23, 24].

As can be seen, while the direct cost of rail transport may appear lower initially, this seemingly lower cost often masks substantial latent costs associated with quality degradation (Pitt & Miller, 2016) [25]. These latent costs include, but are not limited to, reduced market prices for compromised grain, outright rejection of shipments, the need for costly reprocessing, or, in severe cases, complete product loss. Such losses can significantly erode or even outweigh the initial transport cost savings, shifting the focus from a simple transport cost to the total cost of ownership or total delivered cost of the grain, which must account for quality assurance, waste, and potential reprocessing. This represents a critical economic trade-off that requires explicit quantification and strategic consideration. The strong emphasis in research on prediction and real-time monitoring signals a fundamental shift in grain logistics from reactive damage assessment to proactive risk management (Qin et al., 2021) [26]. Instead of simply identifying spoilage after it has occurred and value has been lost, these advanced technologies enable interventions before significant losses materialize. This capability fundamentally transforms the risk landscape of rail freight transport, potentially making it a much more viable and reliable option by directly mitigating its primary disadvantages. The development and use of advanced technological solutions, such as machine learning models for monitoring and assessing corn quality during transport and post-harvest stages, highlights that quality degradation caused by external factors is a significant and financially impactful issue in grain transportation. These new methods also have certain vulnerabilities, as illustrated using a sensor-cable-probe and sampler system designed for the early detection and prediction of dry matter loss and real-time monitoring of corn grain quality during transport and storage (Richard, 2007; Rodrigue et al., 2020) [28, 29].

Table 1 presents the key determinants and research findings regarding grain quality during transport and storage.

Table 1. Key factors and research findings on grain quality degradation during transport and storage (based on literature review)

Factor	Impact on Grain Quality	References	Mitigation Strategy (Brief)
Temperature Fluctuations	Reduced viability/germination, Nutrient degradation, splinter	(Crippa et al., 2021 [6]; Hagstrum & Subramanyam, 2009) [12]	Real-time monitoring, Ventilation
High Moisture Content	Microbial growth (mould), Mycotoxin production, Dry matter loss	(Hagstrum & Subramanyam, 2009 [12]; Rodrigues et al., 2024) [30]	Real-time monitoring, Humidity control
Grain Respiration	Heat and moisture generation, Dry matter loss	(Hagstrum & Subramanyam, 2009) [12]	Aeration, CO2 monitoring
Dry Matter Loss	Reduction in physical quantity and nutritional value, Economic loss	(Crippa et al., 2021 [6]; Hagstrum & Subramanyam, 2009) [12]	Early detection, Predictive analysis
Microbial Activity (Fungi/Mold)	Spoilage, Mycotoxin production, Reduced market value	(Rodrigues et al., 2024) [30]	Humidity and temperature control, Hygiene
Insect Infestation	Physical damage, Contamination, acceleration of spoilage	(Krauter et al., 2022) [15]	Pest monitoring, Preventive measures

Source: Authors' synthesis based on [6, 12, 15, 30].

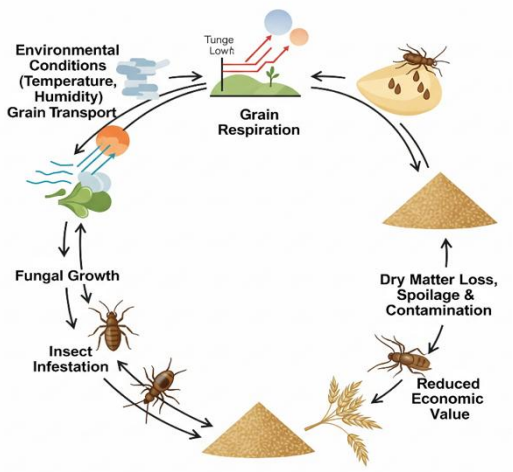

Fig. 3. Factors of grain quality degradation in transit
Source: Developed by authors.

Figure 3 also shows how grain quality could be affected during the transportation by the interplay between environmental conditions and biological mechanisms that lead to degradation of grain quality and economic losses during transport.

Critical risks of time-related losses

Delays and extended transit times - Although rail transport is highly efficient for large volumes, it can be inherently susceptible to operational delays arising from various factors such as network congestion, infrastructure limitations (e.g. single-track sections, limited sidings) (Mao et al., 2020) [20], mechanical failures or unforeseen operational issues. Prolonged transit times directly increase the duration of grain exposure to potentially adverse environmental conditions (temperature, humidity) (Lu et al., 2025) [19], thus significantly exacerbating the quality degradation risks already dis-cussed. The need for early detection and real-time data implies that time is a critical and dynamic factor in preserving grain quality (Qin et al., 2021) [26].

Time is not merely a static factor in grain transport, but an active risk multiplier. The longer grains are in transit or storage, the greater their cumulative exposure to adverse environmental conditions (Liu et al., 2022) [18], such as elevated temperatures, humidity, or pest activity. This prolonged exposure directly increases the likelihood and severity of dry matter loss, microbial spoilage, and insect infestation (Mao et al., 2020) [20]. Therefore, delays in rail transport directly accelerate the rate of quality degradation, effectively transforming a time-related logistical problem into a quantifiable quality-related economic loss. This underscores that efficient time management and logistic predictability in rail operations are essential for both quality preservation and overall economic viability (Pitt & Miller, 2016) [25].

Delayed deliveries in grain logistics can lead to substantial and often overlooked opportunity costs. These include, but are not limited to, missed market windows (e.g., inability to capitalize on peak prices), financial penalties for late delivery as stipulated in contracts, and increased inventory holding costs (e.g., storage fees, insurance, capital locked in inventory) at both origin and destination. For commodities like grains, which can de-grade over time, timely delivery is crucial not only to maintain product quality but also to preserve market value and ensure competitive advantage (Freita-Silva et al., 2014; Hagstrum & Subramanyam, 2009; Sadura & Janeczko, 2021; Schmidt et al., 2018) [10, 12, 31, 32]. Some studies dis-cuss identifying value chain trade-offs (da Rocha & Branco, 2024; Sadura & Janeczko, 2021) [8, 31].

Delays represent a critical manifestation of such a trade-off, where initial cost savings in transport (by choosing rail) are offset by significant market value losses or increased holding costs further down the supply chain. The concept of value chain trade-offs directly applies here: a strategic choice to use a slower or potentially less predictable transport mode, such as rail, for its direct cost savings, could ultimately lead to a substantial loss of overall value due to missed market opportunities, reduced product quality, or increased operational expenses (Hagstrum & Subramanyam, 2009; Crippa et al., 2021) [12, 6]. This negatively impacts the holistic profitability and efficiency of the entire grain supply chain. The initial cheapness of rail freight transport, as stated in the user's query, might only reflect the direct unit transport cost. However, if rail transport inherently involves longer transit times, greater unpredictability, or requires larger batch sizes,

it can lead to significantly higher indirect costs. These include higher inventory holding costs (more capital tied up in goods in transit or storage, increased warehousing needs), and substantial opportunity costs (missing peak market prices, inability to respond quickly to market demand shifts, or failure to fulfil just-in-time delivery contracts). These hidden systemic costs can rapidly erode or even outweigh the direct transport savings, making the "cheaper" transport option ultimately more expensive when considering total supply chain cost, capital efficiency, and responsiveness to dynamic market conditions (Freita-Silva et al., 2014; Sinha, 2005; Tanaka et al., 2023) [10, 33, 34].

Leveraging technology for risk mitigation: digitalization and sensors

The advent of advanced sensor technologies has revolutionized the ability to ensure grain quality during transit and storage. These technologies enable continuous real-time monitoring of critical environmental parameters within grain shipments, including in-ternal temperature, relative humidity, and even CO_2 levels (which can indicate increased respiration or microbial activity). This constant stream of data provides unprecedented visibility into the condition of the grain. A direct example is the description of a "sensor-cable probe and sampler for early detection and prediction of dry matter loss and re-al-time corn grain quality in transport and storage" (Hagstrum & Subramanyam, 2009) [12]. This research demonstrates a practical, research-backed application of sensor technology to address the fundamental problem of quality degradation. It highlights the practical application of sensor technology to address the fundamental problem of quality degradation by providing immediate and actionable data on the precise condition of the grain throughout its journey. This capability is fundamental to identifying problems as they arise, rather than after they have caused significant damage (Hagstrum & Subramanyam, 2009) [12].

Beyond mere data collection, the integration of machine learning (ML) models with real-time sensor data enables sophisticated predictive analytics. These models can analyse vast datasets to identify subtle patterns that indicate imminent spoilage, quality loss, or the onset of pest/ insect activity, often before human observation or traditional methods would detect them. This capability allows for truly proactive interventions. Research provides compelling evidence for this, detailing "monitoring and predicting corn grain quality on the transport and post-harvest operations in storage units using sensors and machine learning models" (Crippa et al., 2021) [6]. This showcases the advanced application of artificial intelligence in mitigating complex logistical risks. The crucial shift from mere detection to pre-diction is transformative. Machine learning can process complex, multivariate sensor data to forecast potential problems, enabling supply chain managers to implement timely corrective actions, such as rerouting shipments, accelerating delivery, or initiating immediate quality cheques upon arrival. This proactive approach significantly minimizes losses and preserves the economic value of the grain (Crippa et al., 2021) [6].

Digitalization extends beyond individual sensor implementations to encompass the creation of a more transparent and responsive end-to-end supply chain. Data streams from transport and storage units can be seamlessly integrated into broader logistics management platforms, providing comprehensive real-time visibility throughout the entire journey. The keyword "digitalization", while a general term, supports the overall theme of digital transformation as a strategic imperative in agricultural logistics.

This broad keyword signifies that digitalization is widely recognized as a critical enabler for improving overall efficiency, resilience, and sustainability within the agricultural value chain, directly contributing to effective transport-related risk management (Crippa et al., 2021; Tanizawa et al., 2020) [6, 35].

Table 2 presents the findings from the selected scientific literature.

Figure 4 illustrates how advanced technologies, from sensors to machine learning, enable proactive management of grain quality throughout the supply chain.

Digitalization, particularly through the implementation of advanced sensors and machine learning, fundamentally transforms risk management into grain logistics. Changes the paradigm from a reactive process, where losses are managed after they occur, to a proactive and predictive one (Richard, 2007).
Table 2 shows how technological innovations could mitigate quality and time losses in grain transport.

Table 2. Technological innovations to mitigate quality and time losses in grain transport (based on literature review)

Technology /Innovation	Key functionality	Benefits for grain transport	References
Sensor-Cable-Probe Wireless IoT Sensors	Continuous monitoring (temperature, humidity, CO2)	Significant reduction in quality degradation, Proactive risk management	(Hagstrum & Subramanyam, 2009) [12]
Machine Learning Models	Predictive analysis for spoilage, Early detection of pest/ yeast activity	Minimizing time-related losses, Improved decisions	(Crippa et al., 2021) [6]
Real-Time Data Analytics Platforms	Enhanced supply chain visibility, Optimization of transit routes, schedules	Increased transparency, Preservation of economic value	(da Rocha & Branco, 2024) [8]
Global Positioning System (GPS) Tracking/Telematics	Monitoring transport location and progress	Reduced delays, Increased predictability	(Crippa et al., 2021 [6]; Qin et al., 2021) [26]
Digital Twin Concepts	Simulation and optimization of supply chain operations	Improved operational efficiency, Risk reduction	(Thakur et al., 2023 [36]; Utomo et al., 2022) [37]

Source: Authors' synthesis based on [12, 6, 8, 26, 36, 37].

This capability not only directly mitigates quality and time losses, but also adds substantial value to the grain, ensuring its integrity and market readiness throughout the supply chain.
This implies that the initial cheaper cost of rail transport can truly be realized and justified only when complemented by strategic investments in digital infrastructure that actively ensure value preservation, effectively shifting the focus from merely transporting grain to preserving its inherent value during transport (Liu et al., 2022; Rodrigue et al., 2020) [18, 29].

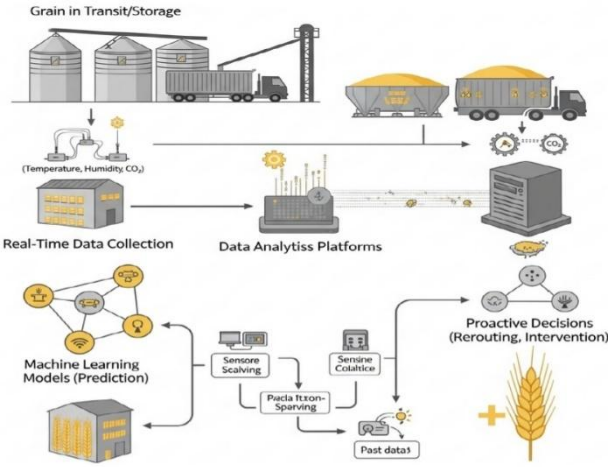

Fig. 4. Data and decision flow in grain logistics with advanced technologies
Source: Authors' conception.

Collective evidence from these studies indicates a clear and accelerating trend: agricultural logistics is evolving into a highly data-driven and technologically sophisticated domain (Rodrigue et al., 2020) [29]. This is not merely about adding isolated sensors; it involves systematic collection, advanced analysis, and intelligent action on granular data to optimize inherently complex biological and logistic (Richard, 2007) [28]. This evolution is critical to effectively manage the inherent variability, perishability, and market sensitivity of agricultural commodities, far exceeding traditional, less precise, or reactive methods (Lu et al., 2025) [19]. It strongly suggests critical aspects in grain transport will largely depend on the widespread adoption of these advanced technological capabilities and the development of a robust data analytics infrastructure (Qin et al., 2021) [26].

Broader Sustainability and Environmental Considerations in Grain Supply Chains

Although rail transport offers distinct advantages in reducing direct transport emissions, the overall ecological footprint of grain extends far beyond the transport mode itself. Other critical stages, such as packaging, play a significant role in determining the total environmental impact. The choice of sustainable packaging is therefore crucial to minimizing the overall ecological burden of the supply chain, explicitly explained by the study of Verghese et al. (2022) [38]. that highlights a specific, yet often overlooked,

aspect of the ecological footprint of the grain supply chain. This broadens the perspective beyond mere transport emissions, underscoring that sustainability in the grain supply chain is inherently multi-faceted. It requires comprehensive consideration of all stages, including post-transport handling, processing, and packaging, to achieve true ecological responsibility (Wilson et al., 2018) [39]. This aspect emphasizes that the concept of sustainable grains is far more extensive than simply optimizing transport. Although rail transport's lower emissions represent a significant ecological benefit, the overall sustainability profile of grains is determined by a multitude of factors throughout the entire lifecycle. This includes agricultural production practices (e.g., yield estimation, breeding, land use), processing, and packaging (Verghese et al., 2022; Wilson et al., 2018) [38, 39]. The necessity of a comprehensive lifecycle assessment approach is crucial to truly evaluate sustainability, where transport is a critical, but not exclusive, component. A narrow focus risks sub-optimizing the system.

Optimizing an isolated segment of the supply chain, for example, minimizing direct transport costs, without carefully considering its cascading effects on other interconnected parts (e.g., grain quality, waste generation, packaging requirements, or overall market responsiveness), can often lead to suboptimal or even detrimental outcomes. A truly systemic approach is indispensable for identifying, quantifying, and effectively managing these complex trade-offs across the entire value chain (Thakur et al., 2023; Utomo et al., 2022) [36, 37]. Research explicitly advocates for and utilizes a system dynamics approach to identify value chain trade-offs in the context of fruit and vegetable aggregation services. This conceptual framework is directly and highly applicable to understanding the complexities within grain supply chains. It reinforces the critical idea that achieving authentic sustainability and maximizing eco-nomic efficiency requires a holistic and integrated view of the supply chain. It recognizes that decisions made regarding transport can have far-reaching and often unintended consequences throughout the value chain, affecting not only direct costs but also product quality, waste generation, and ultimately the long-term profitability and environmental performance of the entire enterprise. A system dynamics framework offers an exception-ally powerful and robust tool for effectively understanding and managing complex, often nonlinear relationships and feedback loops inherent in the grain supply chain. It provides a methodological lens to model how strategic decisions regarding transport modes, the adoption of new technologies, or specific storage practices impact not only direct financial costs but also indirect costs (e.g., waste, reprocessing, brand damage), the overall ecological footprint, and long-term market competitiveness. This approach transcends simplistic cost-benefit analyses, enabling stakeholders to foresee and mitigate the long-term systemic consequences of short-term, isolated optimizations, thereby fostering more resilient and sustainable supply chains (Zhang et al., 2023) [40].

Recommendations for optimizing rail grain transport

It is imperative to prioritize the widespread adoption and seamless integration of re-al-time sensor technologies and advanced machine learning models. These tools are crucial for continuous and granular quality monitoring throughout the entire rail transport journey and during associated storage periods. Such investments should not be considered as optional upgrades but as fundamental necessities for mitigating inherent risks. This recommendation is directly and strongly supported by research findings that demonstrate the effectiveness and potential of these technologies. These technologies are not just enhancements; they are transformative tools that enable proactive risk management. By providing immediate data and predictive insights, they allow for timely interventions, transforming rail freight transport into a truly reliable and value-preserving option for grain movement (Crippa et al., 2021; Hagstrum & Subramanyam, 2009) [6, 12].

The development and implementation of more robust, data-driven scheduling and routing

strategies is essential to minimize transit times and reduce the potential for de-lays. Currently, strategic investments in critical rail infrastructure improvements, such as upgrading rail lines, expanding dedicated grain terminals, and improving intermodal transfer points, are vital for alleviating bottlenecks, improving overall efficiency and in-creasing the predictability of grain movements. This recommendation is a necessary and logical extension to address the time losses highlighted in the user's query and to improve the overall operational efficiency and reliability of rail transport (Choudhury et al., 2024) [5].

Fostering stakeholders management in the grain supply chain is essential, including farmers, grain aggregators, rail operators, logistics providers, grain handlers and end-users. This collaborative ecosystem should aim to share critical data, seamlessly coordinate logistics, and collectively implement best practices for the preservation of grain quality from the farm to the destination (Lu et al., 2025; Neethirajan et al., 2021) [19, 23]. The concept of value chain trade-offs implicitly suggests that effective solutions to complex, interconnected problems require a collaborative effort among different actors in the chain to manage these interdependencies efficiently and holistically. A fragmented or siloed approach, where each entity optimizes its own segment in isolation, will inevitably fail to address systemic issues. Collaborative frameworks ensure that all stakeholders are aligned on quality standards, risk mitigation strategies, and common objectives for overall supply chain efficiency and sustainability (da Rocha & Branco, 2024) [8].

Governments and regulatory bodies have a crucial role in facilitating the transition to more sustainable and resilient grain transport. This may involve implementing policies that encourage the adoption of advanced monitoring technologies, providing financial support or regulatory frameworks for the development of critical infrastructure, and establishing clear and enforceable quality standards for grains in transit. Policy interventions can help overcome market failures, encourage necessary private sector investment, and create a level playing field that ultimately benefits the entire supply chain, ensures food quality, and contributes to broader social goals of sustainability and food security (Choudhury et al., 2024; da Rocha & Branco, 2024) [5, 8].

CONCLUSIONS

Rail freight transport presents a compelling opportunity to enhance the sustainability of grain logistics by reducing emissions, lowering costs, and minimizing road congestion. However, its full potential can only be realized through a systemic approach that ad-dresses quality degradation, time sensitivity, and infrastructure limitations.

This research has demonstrated that while rail freight transport presents a compel-ling economic and environmental case for large-scale grain movement, its true sustainable potential is inextricably linked to the effective management of its inherent risks. The significant challenges posed by quality degradation and time-related losses cannot be over-looked, as they can substantially erode perceived cost-effectiveness and environmental benefits. In addition, this study contributes to the knowledge field by emphasizing the importance of integrating digital technologies, such as real-time monitoring and predictive analytics, to safeguard grain integrity and optimize delivery performance.

The integration of cutting-edge technologies, particularly real-time sensors and advanced Artificial Intelligence (AI) and Machine Learning models, alongside a holistic, system-level approach to supply chain management is essential. This strategic combination will allow stakeholders to move beyond a simplistic cost-per-mile calculation and embrace a comprehensive understanding of the total delivered value. By proactive preservation of grain quality and optimizing transit times, the industry can ensure both the economic viability and long-term sustainability of the global grain supply chain, transforming rail freight into a truly optimized and responsible transport solution. By shifting

the focus from cost-per-mile to total delivered value, the research intro-duces a more holistic framework for evaluating transport efficiency. It also aligns with broader sustainability goals, including reducing food waste, improving supply chain resilience, and supporting climate-smart agriculture. The findings offer actionable insights for policymakers, logistics providers, and agribusiness stakeholders seeking to build greener, more economically viable grain transport systems.

This research offers a strategic perspective on the economic and sustainability potential of rail freight in grain logistics. However, several limitations should be acknowledged. First, the analysis is based primarily on secondary data and conceptual modeling, which may not fully capture the complexities of real-world operations. Second, the findings are context-dependent and may vary across regions with different infrastructure, regulatory environments, and grain supply chain dynamics. Third, while the integration of digital technologies is emphasized, their practical implementation, cost implications, and stake-holder readiness were not empirically assessed.

Future research should aim to validate these insights through field-based studies and pilot projects that measure grain quality, transport efficiency, and environmental impact in operational settings. Comparative analyses across transport modes (road, rail, and in-land waterways) would help identify optimal logistics strategies under varying conditions. Additionally, expanding the scope to include lifecycle assessments and circular economy principles could provide a more comprehensive view of sustainability. Investigating the adoption of smart technologies and the role of policy incentives would further support the transition toward greener and more resilient grain transport systems.

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ASSESSING FARMERS` AND FORESTERS` READINESS FOR RENEWABLE ENERGY ADOPTION AND ENERGY COMMUNITY PARTICIPATION

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Abstract

The study presents a comprehensive methodology for assessing farmers` and foresters` readiness to adopt renewable energy solutions and participate in energy communities across four European countries: Bulgaria, Estonia, Slovenia, and Spain. The assessment framework adapts the Triple Layer Business Model Canvas (TLBMC) into the Individual Triple-Layer Readiness Framework (ITLRF), which evaluates readiness across economic, technical, and social dimensions. The technical dimension reformulates the original TLBMC environmental layer for individual-level analysis (capturing the operational and informational preconditions for environmental action), while environmental values are relocated to and operationalised within the social dimension. The questionnaire examines respondent profiles, current energy situations, renewable energy awareness, investment willingness, barriers to adoption, energy community interest, support preferences, business model considerations, and future outlook. Two composite indices are constructed and validated: the RES Readiness Index (RRI) and the Energy Community Potential Index (ECPI). Respondents are segmented into categories ranging from `Ready Adopters` to `Unaware` based on weighted calculations. This multi-dimensional assessment provides a robust analytical framework for understanding the factors influencing renewable energy adoption in rural areas and offers valuable insights for developing targeted policy recommendations and support mechanisms to accelerate the rural energy transition.

Key words**:** *rural areas, energy transition, energy communities, RES adoption*

INTRODUCTION

The European Green Deal and the revised Renewable Energy Directive (EU 2018/2001, RED II) [8] have established ambitious targets for decarbonising energy systems, with particular emphasis on empowering citizens and communities to participate actively in the energy transition. Rural areas represent both a significant opportunity and a persistent challenge. Farmers and foresters possess land, biomass resources, and operational energy demands that align naturally with distributed renewable generation, yet adoption rates remain uneven across European regions (European Commission, 2023) [7].

A critical gap persists in the availability of standardised, multi-dimensional tools for assessing the readiness of agricultural and forestry stakeholders to adopt renewable energy solutions (RES) and participate in energy communities (ECs). Established technology adoption models were not designed for rural energy transitions, where economic viability, environmental stewardship, and social cooperation intersect in distinctive ways (see Literature Review). Energy communities, defined under the Clean Energy Package (Directive 2019/944) [9] and RED II, offer a particularly promising mechanism for rural renewable deployment by enabling farmers and foresters to pool resources, share investment risks, and generate community-level benefits. However, assessing readiness for such communities requires analytical tools that capture social capital, cooperative willingness, and governance preferences (Caramizaru and Uihlein, 2020) [3].

This paper presents a replicable methodology developed and validated within the ECOLOOP Horizon Europe project (HORIZON-CL5-2022-D3-02-07) across four pilot countries (Bulgaria, Estonia, Slovenia, and Spain) selected to span diverse European agricultural contexts, policy environments,

and stages of renewable energy market development. The framework adapts the Triple Layer Business Model Canvas (TLBMC) into the Individual Triple-Layer Readiness Framework (ITLRF), which operationalises economic, technical, and social readiness at the individual stakeholder level, and constructs two composite indices: the RES Readiness Index (RRI) and the Energy Community Potential Index (ECPI). The contribution is threefold: (1) a theoretically grounded questionnaire architecture mapped to the ITLRF; (2) transparent index construction with explicit weighting rationale; and (3) empirical validation demonstrating that the indices discriminate meaningfully between known groups.

Literature Review

Research on renewable energy adoption in agriculture draws on several established theoretical traditions. The Technology Acceptance Model (TAM) posits that perceived usefulness and perceived ease of use determine adoption intentions (Davis, 1989) [4]. The Unified Theory of Acceptance and Use of Technology (UTAUT) extends this by incorporating performance expectancy, effort expectancy, social influence, and facilitating conditions (Venkatesh et al., 2003) [18]. The Diffusion of Innovations framework emphasises the role of relative advantage, compatibility, complexity, trialability, and observability in shaping adoption trajectories across populations (Rogers, 2003) [15].

While these frameworks have been applied to agricultural technology adoption (Pierpaoli et al., 2013) [14], they share a common limitation when applied to the rural energy transition: they treat adoption as primarily an individual decision, underweighting the collective and cooperative dimensions that are central to energy community formation. Bauwens (2016) [2] demonstrated that community energy initiatives require social capital, trust networks, and governance capacity that extend beyond individual cost-benefit calculations. Similarly, Wirth (2014) [19] emphasised that successful renewable energy cooperatives depend on institutional frameworks, local social norms, and collective self-efficacy. Kotilainen and Saari (2018) [11] further noted that energy prosumer adoption in rural contexts depends on perceived community benefits and the availability of trusted intermediaries, factors that individual-level adoption models do not capture.

At the national level within the ECOLOOP pilot countries, Todorova (2022) [17] surveyed Bulgarian farmers and found that willingness to adopt eco-innovations was driven by a combination of perceived environmental impact, expected income changes, and the adequacy of state policy, confirming that adoption decisions in agricultural contexts are inherently multi-dimensional and cannot be reduced to a single technology acceptance construct. This evidence from a Southeast European agricultural population reinforces the need for assessment tools that simultaneously capture economic, environmental, and institutional dimensions of readiness.

Several attempts have been made to adapt these frameworks for the energy sector. Wolsink (2012) [20] proposed a social acceptance framework distinguishing market acceptance, socio-political acceptance, and community acceptance of renewable energy. Sovacool (2014) [16] developed energy justice indicators encompassing availability, affordability, and sustainability dimensions. However, these broader frameworks operate at the policy or societal level and do not provide the individual-level diagnostic granularity needed for targeted programme design in rural agricultural populations. This visibility challenge extends to specific technologies as well: Marcuța et al. (2023) [12] concluded that agrivoltaic technology, despite its demonstrated dual benefits for energy production and crop protection, still lacks sufficient visibility and accessibility among farmers, underscoring the persistent gap between technical viability and farmer-level awareness that the present assessment framework seeks to quantify.

The Triple Layer Business Model Canvas (TLBMC), introduced by Joyce and Paquin (2016) [10], offers a structured approach for integrating economic, environmental, and social dimensions into a single analytical

framework. The TLBMC extends the classical Business Model Canvas (Osterwalder & Pigneur, 2010) [13] by adding environmental and social layers that capture lifecycle environmental impacts and stakeholder-oriented social value creation. The environmental layer examines material and energy flows, resource use, emissions, and circularity potential, while the social layer addresses stakeholder engagement, equity, and wider societal impact. Within the ECOLOOP project, the TLBMC was applied to evaluate pilot site business models across the four partner countries, providing the conceptual foundation for the readiness assessment presented here.

The adaptation of this framework for individual-level readiness assessment is novel and is detailed in the Materials and Methods section.

MATERIALS AND METHODS

Theoretical Framework: From TLBMC to the Individual Triple-Layer Readiness Framework (ITLRF)

The Triple Layer Business Model Canvas (TLBMC) was originally formulated by Joyce and Paquin (2016) [10] as an organisational tool with three layers – economic, environmental, and social – capturing how a business model creates value, manages environmental flows, and engages stakeholders. The present study adapts this framework for a fundamentally different unit of analysis: the individual farmer or forester as a prospective adopter of renewable energy and a prospective member of an energy community. This shift requires explicit conceptual translation rather than direct application, since several core TLBMC environmental constructs (organisational material flows, lifecycle emissions accounting, end-of-life management, organisational circularity) are not meaningfully measurable at the individual readiness level prior to adoption.

To resolve this conceptual mismatch transparently, the adapted framework is named and defined as the Individual Triple-Layer Readiness Framework (ITLRF). The ITLRF preserves the TLBMC's core principle of balanced multi-dimensional assessment but reformulates the environmental layer into a technical readiness layer that captures the individual operational and informational preconditions for environmental action. The justification for this reformulation is twofold.

First, at the individual readiness level, environmental impact is the consequence of an adoption decision rather than an ex-ante measurable attribute of an individual. What is meaningful to assess prospectively is the technical readiness that enables environmental action: technology familiarity, current operational experience with RES, and depth of information engagement. These variables function as direct precursors to the environmental outcomes that the original TLBMC environmental layer is designed to capture at the organisational level. Second, environmental values and stakeholder-oriented impact expectations are not eliminated but relocated to the social layer, which now combines the TLBMC's stakeholder logic with environmental motivation indicators. This relocation is consistent with literature on rural energy transitions, where environmental concern manifests primarily as a value dimension and a peer/community phenomenon rather than as an individual measurable flow (Bauwens, 2016 [2]; Wirth, 2014 [19]). The mapping between TLBMC original layers and ITLRF dimensions is summarised in Table 1.

Table 1. Mapping between TLBMC original layers and ITLRF dimensions

TLBMC original layer (organisational)	ITLRF dimension (individual)	Conceptual translation
Economic	Economic readiness	Preserved: financial capacity, investment willingness, cost sensitivity
Environmental	Technical readiness	Reformulated: operational and informational preconditions for environmental action (technology familiarity, current RES use, information engagement)
Social	Social readiness	Extended: stakeholder-oriented logic plus relocated environmental values (environmental importance, social impact expectation)

Source: Author's own elaboration based on Joyce and Paquin (2016) [10]

The three ITLRF dimensions are operationalised as follows. The Economic layer captures energy cost sensitivity, investment willingness, investment timeline, perceived importance of economic factors, and interest in revenue generation from renewable energy. The Technical layer comprises technology familiarity ratings, current RES adoption status, and information engagement depth. The Social layer encompasses energy community awareness, interest in collective participation, preferred governance roles, perception of peer interest, environmental values, social impact expectations, and willingness to engage in follow-up activities. This tripartite structure ensures that the assessment captures the full complexity of rural energy adoption decisions, which are simultaneously economic investments, technical transitions, and social commitments. The weighting scheme (Economic 40%, Technical 30%, Social 30%) reflects the empirical finding, consistent across the ECOLOOP pilot countries and the broader literature (Engelken et al., 2016) [5], that financial considerations are the primary determinant of adoption decisions while technical capacity and social dimensions exert approximately equal complementary influence.

Questionnaire Architecture

The survey instrument comprises 48 questions organised across eight thematic sections. Section A (Respondent Profile) captures demographic and operational characteristics using factual, closed-ended items. Section B (Current Energy Situation) establishes the baseline energy context through questions on energy needs, costs, cost concern, and current RES use. Section C (RES Awareness and Readiness) employs Likert-scale ratings of technology familiarity, multiple-choice items on technology preferences and motivations, and a scaled investment willingness item. Section D (Energy Community Interest) addresses awareness, interest, motivations, concerns, preferred role, and perception of peer interest regarding energy communities. Section E (Information and Support Needs) uses rating scales for eight information topics and categorical items for preferred advisors and communication channels. Section F (Impact Assessment) employs Likert ratings for economic, environmental, and social factors. Sections G and H capture future orientation (investment timeline, 10-year energy vision) and engagement willingness (follow-up consent, contact details).

The questionnaire was deployed simultaneously in Bulgarian, Estonian, Slovenian, and Spanish through language-specific Google Forms, maintaining identical numeric coding across all versions. This approach preserves cultural and linguistic naturalness while enabling direct cross-national comparison through unified numeric variables. Translation followed a forward-backward protocol as items were translated from the English master version by native-speaking project partners in each country, then independently back-translated to verify semantic equivalence. All categorical response options use identical numeric codes regardless of language, ensuring that quantitative analysis operates on a unified dataset.

The questionnaire design follows established principles of progressive complexity. Sections A and B begin with factual, low-cognitive-load items (demographics, farm characteristics, energy costs) before moving to attitudinal and evaluative questions in Sections C through F. Sections G and H conclude with forward-looking and engagement items. This sequencing minimises respondent fatigue and anchors subjective assessments in the concrete context established by the earlier factual sections. The mix of question formats – single-choice categorical (21 items), multiple-choice multi-select (8 items), Likert-scale ratings (14 items across multiple sub-batteries), binary yes/no (3 items), and open-ended text (2 items) – provides both quantitative indices and qualitative context for interpretation.

RES Readiness Index Construction

The RES Readiness Index (RRI) is a weighted composite score normalised to a 0-100 scale, calculated as:

$$RRI=0.40\times ECON+0.30\times TECH+0.30\times SOC \quad \ldots\ldots\ldots\

where: ECON, TECH, and SOC are the normalised dimension scores. Each dimension aggregates its component variables (Table 2), with individual items first normalised to a 0-100 scale using min-max normalisation within each variable's theoretical range, then averaged within the dimension.

Table 2. RES Readiness Index component variables and normalisation

Dimension	Weight	Component Variables	Normalisation Rule
Economic	40%	Energy cost concern	Likert 1-5 → 0-100
		Investment willingness	Ordinal scale → 0-100
		Investment timeline	Proximity scale → 0-100
		Economic factor importance	Mean of 1-5 ratings → 0-100
		Revenue interest	Mean of 1-5 ratings → 0-100
Technical	30%	Technology familiarity	Mean of 1-5 ratings → 0-100
		Current RES use	Ordinal 3-point → 0-100
		Information engagement	Mean of 1-5 ratings → 0-100
Social	30%	EC awareness	Ordinal 3-point → 0-100
		EC interest	Likert 1-5 → 0-100
		Preferred EC role	Active role = higher score
		Network effect (peer interest)	Likert 1-5 → 0-100
		Environmental importance	Likert 1-5 → 0-100
		Social impact expectation	Likert 1-5 → 0-100
		Follow-up willingness	Ordinal → 0-100

Source: Author's own elaboration.

The 40/30/30 weighting was determined through a combination of literature-informed prioritisation and empirical barrier analysis. Financial barriers consistently rank as the primary adoption obstacle across all four countries (reported by 58.0% of respondents), justifying the elevated economic weight. The equal weighting of technical and social dimensions reflects the balanced importance of individual technical capacity and collective social readiness for community-based energy transitions.

Energy Community Potential Index Construction

The Energy Community Potential Index (ECPI) measures the potential for respondents to participate in collective energy initiatives. It combines seven variables specifically related to community formation capacity (Table 3), normalised and averaged on a 0-100 scale. Unlike the RRI, the ECPI does not apply differential weighting across components, as the literature does not provide a clear basis for prioritising any single aspect of community formation potential over others.

Table 3. Energy Community Potential Index component variables

Variable	Rationale	Scoring
EC awareness	Baseline knowledge	Familiar=100, Heard=50, Never=0
EC interest	Stated willingness	Very interested=100 → Not=0
Preferred EC role	Engagement depth	Leader=100 → No interest=0
Network effect	Peer perception	Many interested=100 → None=0
Follow-up willingness	Action commitment	Enthusiastic=100 → No=0
Investment willingness	Financial commitment	Mapped from ordinal scale
Investment timeline	Temporal proximity	Already started=100 → >10yr=0

Source: Author's own elaboration.

Respondents with missing values on three or more ECPI components were classified as "Insufficient Data" (n=9) and excluded from the ECPI distribution analysis, yielding N=103 valid ECPI scores. The ECPI classification uses the following thresholds: High Potential (≥70), Moderate Potential (50-69), Low Potential (25-49), and Not Ready (<25). Across the valid sample, 14 respondents (13.6%) qualified as High Potential, 58 (56.3%) as Moderate Potential, 27 (26.2%) as Low Potential, and 4 (3.9%) as Not Ready.

The normalisation procedure for all index components follows a consistent min-max approach. For Likert-scale items rated 1-5, the formula is:

$$\text{Normalised score} = (\text{raw value} - 1)/(5 - 1) \times 100 \quad \text{.....(2)}$$

yielding a score from 0 (minimum engagement) to 100 (maximum engagement). For multi-item batteries (e.g., the six-technology familiarity assessment or the eight-item information needs battery), the individual item scores are first normalised and then averaged to produce a single component score. Ordinal categorical variables (e.g., investment willingness, farm size) are mapped

to equidistant scores that reflect their rank order. This ensures that all variables, regardless of their original measurement scale, can be combined on a common 0-100 basis.

Segmentation Framework

Respondents are classified into four readiness segments based on RRI thresholds, each associated with a distinct intervention strategy. Thresholds were set at natural quartile-informed breakpoints that produce substantively interpretable categories: "Ready" (≥75) identifies individuals who can be fast-tracked into pilot programmes; "Preparing" (50-74) captures the core audience requiring targeted support; "Exploring" (25-49) identifies those needing awareness-building; and "Unaware" (<25) flags respondents requiring fundamental education.

Data Collection and Quality Assurance

Data were collected between October 2025 and February 2026 through four language-specific Google Forms distributed via farmer associations, agricultural extension services, partner networks, and printed versions where digital access was limited. The raw dataset comprised 114 submissions across the four countries.

A three-phase quality assurance pipeline was applied. Phase 1 (Consolidation) merged the four language-specific datasets into a unified database with standardised variable names and numeric coding, producing 73 variables per respondent. Phase 2 (Validation) applied five automated checks: completeness analysis (items answered vs. total applicable items), duplicate detection (matching on timestamp, country, and response patterns), range validation (ensuring all coded values fall within defined scales), straight-lining detection (flagging respondents with zero variance across Likert batteries), and open-ended response quality assessment.

Two submissions were removed as near-empty records (1.6% completion), and one respondent was flagged for straight-lining but retained with a quality control flag for sensitivity analysis. Phase 3 (Index Computation) calculated the RRI, ECPI, dimension scores, and segment classifications. The final validated sample comprises N=112 respondents with a mean completion rate of 92.1%.

The cross-country response distribution is uneven, with Slovenia contributing 50.0% of validated responses (n=56), Estonia 20.5% (n=23), Bulgaria 15.2% (n=17), and Spain 14.3% (n=16). This imbalance reflects the partner-mediated nature of survey distribution rather than a sampling design choice. The Slovenian national coordinator operated through long-established cooperative networks and farmer associations with active digital member engagement, achieving substantially higher dissemination reach than partners in countries with more fragmented agricultural representative structures. In Bulgaria, Estonia and Spain, distribution depended on a smaller number of intermediary organisations with consequently slower response accumulation. No country quotas were applied, and the sample reflects naturally observed response patterns under uniform recruitment effort, which is acknowledged as a methodological limitation of partner-mediated rural surveys.

The implications of this distribution are addressed in three ways throughout the analysis. First, all pooled descriptive statistics are presented alongside country-disaggregated figures (see Sample Characteristics and Index Distributions sections), allowing the reader to distinguish overall patterns from country-specific signals. Second, the discriminant validity analysis (Section:

Discriminant Validity) compares respondents grouped by current RES use status across the pooled sample; because all four countries contribute users and non-users to each comparison group, the validity test does not depend on equal country representation. Third, weighted recalibration to equal country shares was considered but not adopted, as the absence of validated population-level frames for farmers and foresters across the four countries would have required arbitrary weighting assumptions. The limitations section explicitly addresses the resulting constraint on country-level inference.

RESULTS AND DISCUSSIONS

Sample Characteristics

The validated sample of 112 respondents spans four countries: Slovenia (n=56, 50.0%), Estonia (n=23, 20.5%), Bulgaria (n=17, 15.2%), and Spain (n=16, 14.3%). Farm owners or operators constitute 76% of the sample, 64% hold university or postgraduate degrees, and 53% have more than 20 years of experience in agriculture or forestry. Nearly half the sample (48.2%) already uses some form of renewable energy, predominantly solar photovoltaics, though this figure is driven largely by the Slovenian subsample (69.6% current adoption). Current adoption in the remaining countries is substantially lower: Spain (31.3%), Estonia (26.1%), and Bulgaria (23.5%).

Index Distributions and Segmentation

The RRI distribution across all 112 respondents yields a mean of 58.7 (SD=11.3), a median of 60.7, and a range of 20.0-79.8 (Table 4). The Economic dimension scores highest (mean=60.8, SD=12.7), followed by Technical (mean=62.2, SD=17.0) and Social (mean=52.5, SD=15.5). The lower Social dimension score reflects limited energy community awareness across the sample. The ECPI (N=103 valid scores) has a mean of 51.9 (SD=15.4) and a range of 3.8-85.5.

Table 4. Validation summary: index descriptive statistics and known-group comparison

Group	N	ECON	TECH	SOC	RRI	SD	ECPI
Overall	112	60.8	62.2	52.5	58.7	11.3	51.9
Current RES Users	54	66.0	73.9	56.3	65.5	7.3	56.9
No, but interested	49	57.8	53.5	51.7	54.7	9.0	50.7
No, not interested	8	45.0	36.3	32.0	38.5	11.6	27.6

Source: Author's own elaboration.

The segmentation (Table 5) reveals a predominantly "Preparing" population: 73.2% of respondents (n=82) fall in the 50-74 range, indicating that the majority possess moderate awareness and willingness but require concrete support to advance toward adoption. Only 4.5% (n=5) qualify as "Ready" (≥75), while 21.4% (n=24) remain in the "Exploring" phase. A single respondent from Spain falls in the "Unaware" category, suggesting that baseline renewable energy awareness has penetrated even the least engaged segments.

Table 5. Readiness segmentation: thresholds, distribution, and intervention logic

Segment	RRI Range	N	%	Intervention Strategy
Ready	≥ 75	5	4.5%	Fast-track support; potential champions for pilot energy communities
Preparing	50–74	82	73.2%	Targeted training, financial guidance, and administrative simplification
Exploring	25–49	24	21.4%	Awareness programmes, demonstration projects, and peer examples
Unaware	< 25	1	0.9%	Fundamental education; direct engagement and peer influence strategies

Source: Author's own elaboration.

Cross-country segmentation patterns vary meaningfully. Slovenia exhibits the highest "Preparing" concentration (80.4%) and the highest mean RRI (62.9), consistent with its established adoption baseline of 69.6% current RES use. Bulgaria shows the largest "Exploring" share (35.3%), reflecting lower technical readiness (Technical dimension mean=51.6, the lowest among the four countries) despite a comparatively strong Social dimension (56.9). Estonia's pattern (65.2% Preparing, 30.4% Exploring) reflects adequate technical capacity but the weakest social engagement in the sample (Social dimension mean=44.2), driven by limited energy community awareness. Spain is the only country with a respondent in the "Unaware" segment and shows the most diverse occupational profile, with only 44% being farm owners compared to 88% in Bulgaria and Slovenia.

Country-level RRI means for Slovenia (62.9), Bulgaria (55.0), Spain (54.6), and Estonia (54.3) reveal an 8.6-point spread from highest to lowest. Notably, the country ranking differs across dimensions: Bulgaria ranks second on Social (56.9) but last on Technical (51.6), while Estonia scores comparatively well on Economic (58.0) but ranks last on Social (44.2). These cross-dimensional profiles suggest that intervention strategies must be country-specific: technical capacity building in Bulgaria, social engagement and EC awareness in Estonia, investment confidence building in Spain, and community governance

support for the already advanced Slovenian context.

Discriminant Validity

To demonstrate that the RRI and ECPI produce substantively meaningful differentiation, scores were compared across a theoretically relevant known group: current RES use status. Respondents who currently use renewable energy (n=54) should score higher on the RRI than those who do not, and those who express no interest in adoption should score lowest.

The results confirm strong discriminant validity. Current RES users score 65.5 on the RRI (SD=7.3), compared to 54.7 for non-users who express interest (SD=9.0) and 38.5 for non-users who are not interested (SD=11.6). This 27.0-point spread between the highest and lowest groups spans all three dimensions: the economic gap is 21.0 points, the technical gap is 37.6 points, and the social gap is 24.3 points. The largest differentiation occurs in the Technical dimension, which is expected since current users possess direct operational experience with renewable energy technologies.

The ECPI shows a parallel pattern: current users average 56.9, interested non-users 50.7, and uninterested non-users 27.6. The 29.3-point ECPI spread between current users and uninterested non-users confirms that the community formation potential index captures meaningful variation related to actual energy behaviour and attitudes.

Drivers and Barriers of Adoption

The descriptive results allow several explanatory observations about why farmers and foresters in the sample do or do not adopt renewable energy. While the cross-sectional design does not permit causal inference, the patterns documented above support a coherent interpretation grounded in the ITLRF dimensions.

The single largest discriminator between current users and uninterested non-users is the Technical dimension, where the gap reaches 37.6 points – substantially larger than the Economic gap (21.0 points) or the Social gap (24.3 points). This pattern is consistent with a self-reinforcing dynamic in adoption: farmers who have already installed renewable technologies acquire operational familiarity, develop information networks, and engage more deeply with technical content, all of which raise their measured Technical readiness. The implication is that initial technical exposure, through demonstration projects, peer site visits, and hands-on training, may have a disproportionate effect on adoption decisions compared to communications focused only on financial incentives. This finding aligns with Marcuța et al. (2023) [12], who identified visibility and accessibility (rather than technical viability per se) as the binding constraint on agrivoltaic uptake.

The financial barrier reported by 58.0% of respondents is the most frequently cited adoption obstacle, yet the segmentation distribution suggests that this barrier is more informational than capital-based. Only 0.9% of respondents fall into the “Unaware” segment, while 73.2% are “Preparing”, meaning the dominant audience already possesses baseline awareness and willingness but lacks the practical pathway to convert intent into action. If the barrier were purely capital, the “Preparing” group is expected to show high economic-dimension scores blocked by infrastructure or financing constraints. Instead, their pattern is moderate scores across all three dimensions, consistent with diffuse information friction rather than a binding capital constraint. This interpretation reframes financial barriers in policy-relevant terms: targeted advisory services, transparent investment pathways, and access to comparable peer cases may yield greater leverage than capital subsidies alone.

Cross-country patterns clarify the diversity of adoption bottlenecks. Slovenia, with the highest current adoption rate (69.6%) and the highest mean RRI (62.9), demonstrates how a mature institutional environment combined with visible peer adoption produces self-reinforcing readiness across all three dimensions. Bulgaria presents an opposite profile. Relatively strong Social readiness (56.9) but the weakest Technical readiness (51.6) of the sample, suggests that community willingness exists but technical knowledge of available technologies is the binding

constraint on adoption (current adoption: 23.5%). Estonia inverts this pattern. An adequate Technical readiness coexists with the lowest Social score in the sample (44.2), indicating that limited energy community awareness and weaker peer networks constrain collective adoption pathways despite individual technical capacity. Spain combines a comparatively favourable solar resource with the most occupationally diverse sample (only 44% farm owners), where adoption decisions are dispersed across mixed roles and decision authorities, contributing to slower individual-level adoption (31.3%).

Taken together, these results indicate that adoption in the sample is driven primarily by technical operational experience and a supportive institutional context, while non-adoption persists through a combination of country-specific bottlenecks: technical knowledge gaps in Bulgaria, community-engagement gaps in Estonia, and decision-authority complexity in Spain. The framing of financial barriers as predominantly informational rather than capital-based is supported by the dominance of the "Preparing" segment across all four countries and is consistent with prior evidence from the Bulgarian context (Todorova, 2022) [17]. This interpretation supports targeted, country-specific intervention design rather than uniform awareness-building campaigns.

Discussion

The methodology presented in this paper offers several advantages over existing approaches to rural energy readiness assessment. First, the ITLRF, explicitly derived from but conceptually distinct from the original organisational TLBMC, captures the full dimensionality of rural energy adoption decisions at the individual stakeholder level, avoiding the technology-centric bias of TAM and UTAUT models that underweight social and community factors. The tripartite structure ensures that economic, technical, and social readiness are assessed with comparable depth, providing a balanced diagnostic tool for policymakers and programme designers. The inclusion of a dedicated Energy Community Potential Index alongside the individual-level RRI addresses an important gap identified by Caramizaru and Uihlein (2020) [3], who noted that most existing assessment tools focus on individual adoption without capturing the collective dimensions that are essential for energy community formation.

Second, the explicit index construction methodology enhances replicability. The variable selection, weighting rationale, normalisation rules, and segmentation thresholds are fully specified, enabling researchers in other regions or sectors to reconstruct the indices or adapt them for different contexts. The 48-item questionnaire, while comprehensive, maintains a practical completion time of 25-30 minutes, and its deployment across four languages with identical numeric coding demonstrates cross-cultural applicability. The three-phase data quality pipeline provides a transferable quality assurance protocol that could be adopted for other multi-language survey instruments in international energy research.

Third, the segmentation framework provides directly actionable output. By classifying respondents into four categories with associated intervention strategies, the methodology bridges the gap between academic assessment and practical programme design. The finding that 73.2% of respondents fall into the "Preparing" segment, requiring targeted rather than fundamental support, has immediate implications for resource allocation in rural energy transition programmes. This insight challenges a common assumption in policy design that rural populations require primarily awareness-building interventions; rather, the evidence suggests that the majority of farmers and foresters already possess basic awareness and require concrete, practical support to advance toward adoption.

The discriminant validity results provide particularly compelling evidence for the framework's utility. The 27.0-point RRI spread between current RES users and uninterested non-users is both statistically and substantively meaningful, confirming that the index captures real variation in readiness rather than measurement noise. The largest differentiation occurring in the Technical

dimension (37.6 points) is theoretically coherent. Current users possess operational experience, higher technology familiarity, and more developed information networks than non-users. The parallel ECPI pattern (29.3-point spread) reinforces this finding and suggests that individual energy behaviour and community formation potential are related but distinct constructs.

Several limitations should be noted. The sample (N=112) is sufficient for exploratory methodology validation but does not support advanced statistical techniques such as confirmatory factor analysis or structural equation modelling that would require larger samples.

The uneven country distribution (Slovenia contributing 50.0% of validated responses) is methodologically addressed through country-disaggregated reporting and through a discriminant validity test that does not depend on equal country representation. Nonetheless, country-level comparisons remain descriptive rather than inferential, and pooled means should be read as Slovenia-weighted summaries. Future deployments should adopt stratified quota sampling, ideally with population-weighted recalibration once national agricultural population frames become available, as to enable formal cross-country statistical comparison. The cross-sectional design captures readiness at a single point in time and cannot track how readiness evolves in response to interventions.

The 40/30/30 weighting scheme, while empirically informed, represents a methodological choice that could be questioned. Alternative weightings (such as equal 33/33/33) would shift the index distribution but, based on sensitivity analysis, would not fundamentally alter the segmentation structure, as the Economic and Technical dimensions correlate positively across the sample. Future work should explore data-driven weighting approaches, such as principal component analysis, once larger samples are available.

Compared with existing readiness assessment tools in the energy sector, such as the Smart Readiness Indicator for buildings (European Commission, 2020) [6] or household energy adoption surveys (Balcombe et al., 2013) [1], the present framework is distinctive in its focus on the agricultural sector, its integration of energy community formation potential alongside individual adoption readiness, and its grounding in the TLBMC's balanced multi-dimensional logic adapted as the ITLRF. The framework is transferable to other European regions and potentially to other sectors where distributed renewable energy and community energy models are relevant. The open documentation of all components supports direct replication and adaptation.

CONCLUSIONS

This paper presents a replicable, ITLRF-grounded methodology for assessing farmer and forester readiness for renewable energy adoption and energy community participation. The framework – the Individual Triple-Layer Readiness Framework (ITLRF) – is explicitly derived from the Triple Layer Business Model Canvas (Joyce and Paquin, 2016) [10], with the original environmental layer reformulated as a technical readiness layer for individual-level analysis and environmental values relocated to the social dimension. This conceptual translation is justified by the shift in unit of analysis from organisation to individual stakeholder. The framework makes three contributions to the field of rural energy transition research.

The 48-item questionnaire, deployed in four languages across Bulgaria, Estonia, Slovenia, and Spain, captures economic, technical, and social dimensions through a structured eight-section architecture mapped to the Triple Layer Business Model Canvas framework. The instrument design balances comprehensiveness with practical feasibility, achieving a 92.1% mean completion rate across 112 validated responses.

Two composite indices - the RES Readiness Index and the Energy Community Potential Index - are constructed with transparent weighting (Economic 40%, Technical 30%, Social 30% for the RRI) and normalised to a 0-100 scale. All variable selections, normalisation rules, and scoring procedures

are fully documented to support direct replication by other researchers.

Validation demonstrates that the indices differentiate meaningfully between known groups: current RES users score 27.0 points higher on the RRI than non-users who are not interested in adoption, with the largest gap in the Technical dimension (37.6 points). The parallel ECPI validation confirms a 29.3-point spread between users and uninterested non-users.

The four-category segmentation framework (Ready, Preparing, Exploring, Unaware) provides directly actionable output for programme designers. The predominance of the Preparing segment (73.2%) across all four countries indicates that the majority of European farmers and foresters in the study possess baseline awareness and require targeted practical support rather than fundamental awareness building. The explanatory analysis links this segmentation pattern to country-specific bottlenecks supporting the case for differentiated rather than uniform intervention design.

Future research should apply the framework longitudinally to track readiness evolution in response to policy interventions, extend the sample size to enable confirmatory factor analysis and structural equation modelling, and test the framework's transferability to other rural sectors and geographical contexts beyond the four ECOLOOP pilot countries.

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RISK ASSESSMENT OF OCCUPATIONAL ACCIDENTS AND DISEASES IN AGRICULTURAL ACTIVITIES: AN APPLIED STUDY IN THREE COMPANIES FROM CONSTANȚA COUNTY, ROMANIA

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Abstract

This study investigates the occupational risks associated with activities carried out in three representative agricultural companies, using the INCDPM risk assessment methodology and the work-system approach. Results show that although the overall risk levels fall within the "acceptable" category, the structure of risk factors varies significantly depending on the operational profile of each company. In highly mechanised units, dominant risks are mechanical, technical and operational, with a substantial contribution of worker-related factors, highlighting the importance of training and preventive behaviour. In contrast, the livestock-based company is characterised by biological, ergonomic and environmental risks, which tend to be chronic and cumulative. Its lower risk level is also influenced by the fact that it is newly established and equipped with modern technology that meets international standards. The use of new technologies, smart farming solutions and digitalised systems reduces exposure to hazards and optimises operational processes. The comparative analysis confirms the need for differentiated prevention strategies tailored to the technological and organisational specificities of agricultural activities. The study emphasises the crucial role of integrated risk management in ensuring workers' health and safety.

Key words**:** *agriculture, agricultural machinery, occupational health and safety, occupational risk assessment, risk management*

INTRODUCTION

Agriculture represents one of the economic sectors most exposed to risks, both in terms of economic uncertainty and occupational health and safety. The risks associated with agricultural activities are multiple and complex, affecting both the economic performance of farms and the stability of the agricultural sector as a whole. The specialized literature highlights that agricultural activities are carried out in a highly volatile environment, shaped by climatic, biological, technical, economic, and organizational factors (Komarek et al., 2020) [13]. In this context, rigorous risk management becomes an essential condition for maintaining the competitiveness and sustainability of agricultural businesses.

In its modern understanding, risk is defined as a combination of the probability of an undesirable event and the severity of its consequences, while its management involves both hazard identification and the implementation of appropriate control measures (Aven & Renn, 2010) [2]. In agriculture, risks are not limited to economic aspects but also include operational, environmental, and occupational health and safety risks. In recent years, the emphasis on risk management in this sector has increased significantly, with research highlighting the need for effective prevention and adaptation tools (Barducz & Jitea, 2024; Matei et al., 2025) [4, 15].

In the current context of increasing pressures on agricultural systems, the issue of risk can no longer be analyzed exclusively from an economic or technological perspective but must be correlated with educational, social, and environmental responsibility dimensions. Recent literature emphasizes that education,

awareness, and continuous training play an essential role in promoting responsible agricultural practices that contribute both to biodiversity conservation and to reducing workers' exposure to occupational risk factors (Buzatu et al., 2023) [5]. At the same time, analyses of crop management in Romania show that operational, technological, and organizational risks are amplified by climate variability, the level of mechanization, and work organization practices, which necessitate the adoption of integrated assessment and prevention approaches. The identification and management of these risks require not only technical solutions but also an organizational culture oriented toward prevention, training, and accountability at the level of all actors involved in agricultural activities (Ghiuleanu et al., 2023) [10].

At the European level, the structure and size of farms directly influence risk exposure: the majority of agricultural holdings are small and medium-sized, managed by farmers with limited resources to implement advanced risk management systems (Arnalte-Mur et al., 2020; Eurostat, 2024) [1, 9]. In Romania, characteristics of the agricultural sector such as land fragmentation, insufficient mechanization, and market volatility further increase farms' vulnerability to risks (Ghiuleanu et al., 2023; Robu et al., 2024) [10, 18]. Moreover, farmers perceive agricultural risks differently depending on their experience, access to information, level of trust in institutions, and perceived barriers to adopting risk management instruments (Duong et al., 2019; Giampietri et al., 2020) [8, 11]. Beyond economic and climatic risks, agricultural activities involve major occupational hazards resulting from the use of machinery, material handling, exposure to extreme weather conditions, or contact with animals. The management of these risks represents a key component of modern agricultural management and is closely linked to the quality of farm-level organization and the competencies of agricultural managers (Culinaru, 2019; Ion & Mocuta, 2020) [6, 12].

Recent studies indicate that the implementation of effective risk management in agriculture contributes not only to the protection of human resources but also to improved economic performance by reducing uncertainties and optimizing decision-making processes (Zhu et al., 2022; Mang'ana et al., 2023; Matei et al., 2025) [20,14, 15]. Modern approaches also include tools such as systematic risk analysis, integrated assessment models, insurance schemes, and advanced monitoring technologies, including phenological data used to mitigate climate-related risks (Dalhaus et al., 2018) [7].

Furthermore, the specialized literature emphasizes that agricultural risk management cannot be analyzed in isolation but must be understood as part of a complex governance system involving multiple actors: farmers, private companies, public institutions, input suppliers, research organizations, and administrative structures (Aven & Renn, 2010; Arnalte-Mur et al., 2020) [2, 1]. This risk ecosystem influences both the perception of risk factors and the actual capacity of farmers and agricultural units to implement effective prevention or mitigation measures. In addition, psychological, structural, and financial barriers identified in recent studies: such as lack of trust in insurance instruments, insufficient technical information, or capital constraints, limit the adoption of modern risk reduction strategies (Smit & Watkins, 2012; Giampietri et al., 2020) [19, 11]. In this regard, the assessment of occupational risks at the level of agricultural units becomes a critical step for understanding real field vulnerabilities and for substantiating managerial decisions, representing a bridge between risk management theory and its practical applicability in agricultural holdings of different sizes.

At the same time, the current context of European agriculture is marked by significant transformations driven by climate change, pressure on natural resources, and increasingly stringent requirements regarding sustainability and food safety. These changes lead to increased exposure to operational and technological risks, as well as to risks associated with workload and working conditions specific to agriculture (Ghiuleanu et al., 2023, Robu et al., 2024) [10, 18]. Concurrently, European agricultural policies

increasingly promote instruments dedicated to risk management, aiming to strengthen farmers' resilience and reduce their vulnerability to market, meteorological, or biological shocks (Robu et al., 2024) [18]. Within this framework, the systematic assessment of occupational injury and disease risks becomes a structural element of modern agricultural management, facilitating not only compliance with relevant legislation but also the development of an organizational culture focused on prevention, performance, and the protection of human resources.

In this context, the assessment of occupational injury and disease risks in agriculture becomes not only a legal obligation but also a strategic management tool essential for the sustainable functioning of agricultural enterprises.

The present study aims to analyze the occupational risks specific to various agricultural activities by applying the INCDPM method in three representative companies from Constanța County, thus contributing to the specialized literature through a practical and comparative approach.

MATERIALS AND METHODS

The present study aims to assess the risks of occupational accidents and diseases in three representative agricultural companies from Constanța County, each carrying out activities specific to the agricultural sector, such as the production and installation of irrigation systems, mechanized agricultural works, grain transportation, and animal care. The research focuses particularly on identifying risk factors characteristic of each job position, determining the overall risk level, and comparing the risk profiles across units with different organizational structures and operational processes.

To achieve this objective, the method developed by the National Research and Development Institute for Occupational Safety (INCDPM) was used. This method is well established at the national level for the analysis of occupational risks and has been adapted for the assessment of workplaces in agriculture. It involves hazard identification, the evaluation of the severity and probability of an undesirable event, and the calculation of the risk level associated with each identified factor. Within the research framework, the INCDPM method was applied directly to the existing job positions in the three analyzed companies, using official assessment documents already developed at the unit level, including risk assessment sheets, prevention and protection plans, internal procedures, job descriptions, and organizational presentations.

The assessment focused on several categories of risk factors, including mechanical risks associated with agricultural machinery, electrical and thermal risks, exposure to chemical substances or biological agents, as well as ergonomic risks, risks generated by environmental conditions, and those related to physical and mental overload. For each identified risk factor, two components were analyzed: the severity of potential consequences and the probability of occurrence, each quantified according to the scale used by the methodology. According to this approach, the risk level results from the multiplication of the two indicators, while the overall risk level of each job position is determined as a weighted average of all identified risks.

Based on these data, overall risk levels were established for each job position and for each company as a whole, with the obtained values placing the analyzed activities within the acceptable risk zone, subject to periodic monitoring and the implementation of recommended preventive measures. At the same time, risk levels were compared across companies to observe how the specific nature of each activity: working with machinery, road transport, or animal care, influences exposure to occupational risks.

The entire analysis process was based on a coherent working procedure that included the examination of documents provided by each company, the extraction of relevant data from assessment sheets, verification of methodological consistency, and the comparative interpretation of results. This approach enabled the rigorous integration of existing data and their use in a synthetic analysis aimed at highlighting the specific

characteristics of occupational risks in agriculture and providing a foundation for the recommendations formulated at the end of the study.

In selecting the investigation method, consideration was given not only to the recognition and applicability of the INCDPM method in the agricultural sector, but also to the need for an integrated approach capable of capturing the real dynamics of work processes. In the context of modern agriculture, where activities take place in a variable and often unpredictable environment, risk assessment must reflect both technical elements and organizational and human factors. Therefore, the analysis conducted in this study included not only technical and procedural data, but also aspects related to work organization, workers' experience, equipment usage practices, climatic conditions, and the specific characteristics of the actual workplace. This holistic approach enabled an understanding not only of isolated risks, but also of the interdependencies among risk factors, contributing to the formulation of relevant conclusions for improving occupational health and safety at the level of agricultural holdings.

The selection of the three analyzed companies aimed to obtain a representative perspective on the diversity of agricultural activities in Constanța County, with each unit displaying distinct characteristics in terms of work processes, types of equipment used, and activity organization. This choice allowed for the identification of a wide range of occupational risks, from those associated with operating complex agricultural machinery to risks specific to road transport of grain and those inherent in animal breeding and care activities. However, the research also presents certain limitations typical of multi-case studies, as the interpretation of results relies on existing company documentation and previously conducted assessments, without the possibility of direct on-site verification of all work processes. Additionally, the degree of generalization of the conclusions is conditioned by the technical and organizational particularities of the three companies, which may not fully reflect the situation of the entire regional agricultural sector.

Moreover, the entire research process was conducted in compliance with ethical requirements and the legal framework governing occupational health and safety, with assessments carried out in accordance with national legislation and current methodological standards, using exclusively official data and documents provided by the companies. This procedural compliance ensures both the integrity of the analysis and the relevance of the formulated recommendations, in line with the principles of a professional and responsible assessment of occupational risks.

RESULTS AND DISCUSSIONS

The analysis of occupational risks in the three investigated companies highlights a complex but relatively homogeneous overall risk profile, reflecting the specific characteristics of the agricultural and related activities carried out. Although the identified risk levels fall within the category of acceptable risks according to the INCDPM methodology, differences between the companies, as well as the structure of the risk factors, indicate distinct priorities in occupational health and safety management. To facilitate comparative interpretation, the values of the overall risk level are presented below (Table 1).

Table 1. Overall Occupational Risk Levels of the Analyzed Companies

Company	Overall risk level
Reinke Europe SRL	2.73
Nyd Agroroute SRL	2.78
Avi Complex Cogealac SRL	2.67

Source: Own calculation based on the data from [17, 16, 3].

The levels presented in Table 1 indicate that Nyd Agroroute SRL records the highest overall risk level (2.78), followed by Reinke Europe SRL with a value of 2.73, while Avi Complex Cogealac SRL shows the lowest value (2.67).

The data illustrated in (Figure 1), show that Nyd Agroroute SRL stands out due to a slightly higher overall risk level, a

phenomenon that can be explained by the nature of its activities, which are dominated by the operation of agricultural machinery, handling of heavy equipment, and road transport of grain. The specialized literature confirms that intensive mechanization, especially when combined with agricultural transport activities, represents one of the main sources of operational risk in farms, with a high potential for generating mechanical incidents, exposure to vibrations and shocks, as well as physical and mental overload (Duong et al., 2019; Komarek et al., 2020) [8, 13]. In addition, psychosocial risks: such as monotony during driving, accumulated fatigue, or time pressure, further increase the likelihood of undesirable events within this company.

In the case of Reinke Europe SRL, the overall risk level value (2.73) is close to that of Nyd Agroroute SRL but derives from a completely different risk structure. Assembly, handling, and maintenance activities related to irrigation systems are associated with technical risks, including contact with moving parts, exposure to electrical installations, working at height, and handling bulky metal components. The relatively small difference compared to Nyd Agroroute SRL suggests the presence of a more controlled working environment, in which standardized procedures and technical training can significantly reduce the probability of accidents. Recent studies show that in agro-technical units, the application of work procedures is one of the most important factors in reducing the overall risk level (Matei et al., 2025) [15].

Avi Complex Cogealac SRL exhibits the lowest overall risk level (2.67); however, this result does not reflect a hazard-free environment, but rather a risk profile characteristic of livestock farming activities. Interaction with animals, exposure to biological aerosols, repetitive handling of feed, and uncomfortable working postures generate a set of predominantly biological and ergonomic risks which, although less severe in terms of immediate consequences, are frequent and may lead to long-term chronic health problems. The lower risk level recorded in this company is influenced not only by the nature of the activities, but also by the fact that the unit is recently established and equipped with modern machinery that complies with international standards. The literature indicates that such risks are often underestimated compared to mechanical risks, although they can significantly affect workers' health (Arnalte-Mur et al., 2020; Ghiuleanu et al., 2023) [1, 10].

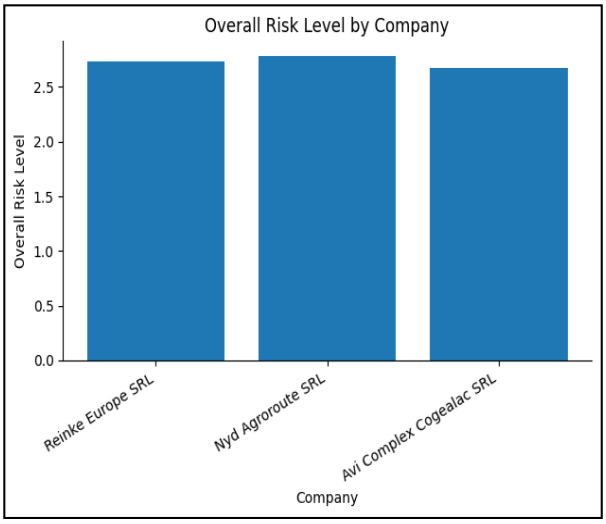

Fig. 1. Overall Risk Level by Company
Source: Own calculation based on the data from [17, 16, 3].

Figure 2, illustrates the linear variation of overall occupational risk levels across the analyzed companies. This visualization highlights the relatively narrow distribution of values, as well as the clear differentiation between companies characterized by mechanized activities and the livestock-oriented company. This pattern is consistent with international studies, which indicate that mechanization is associated with risks of higher potential severity, whereas livestock activities tend to generate chronic risks with high frequency but lower severity (Smit & Watkins, 2012; Giampietri et al., 2020) [19, 11].

Overall, the obtained results allow for the formulation of an important conclusion: the relatively small numerical differences between overall risk values conceal major qualitative differences in risk structure. Thus, while highly mechanized companies are exposed to risks with severe potential consequences, livestock-oriented companies

face risks that are less severe but far more constant and cumulative. This hybrid risk structure is also confirmed by European literature, which suggests that technological and organizational characteristics shape the risk profile to a greater extent than the size or volume of agricultural activity (Mang'ana et al., 2023; Robu et al., 2024) [14, 18].

Therefore, the interpretation of the data highlights not only the numerical differences in overall risk levels, but also the need for a tailored approach to preventive measures, adapted to the specific characteristics of each agricultural activity, an aspect that is detailed in the following section of the article.

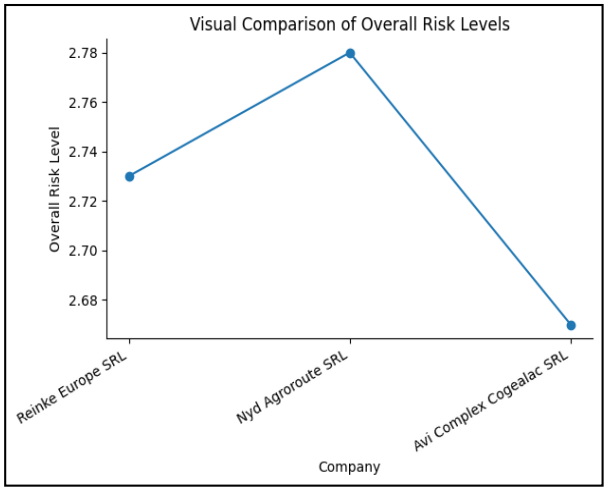

Fig. 2. Visual Comparison of Overall Risk Levels
Source: Own calculation based on the data from [17, 16, 3].

The results confirm the general trend observed in the international literature, according to which mechanical risks are consistently associated with the highest overall risk levels, while biological and ergonomic risks, although less visible in numerical terms, exhibit high complexity and require specific approaches within prevention strategies (Giampietri et al., 2020) [11]. Moreover, factors such as the lack of trained personnel, limited financial resources, and incomplete infrastructure contribute to the vulnerability of agricultural units, issues also highlighted in European and international studies on farm risk management (Robu et al., 2024) [18].

Therefore, the comparison of the three companies reveals a coherent, yet not uniform, picture of occupational risks in agriculture. Although the overall risk levels are relatively similar, the risk structure differs significantly depending on the nature of the activities, which necessitates tailored preventive measures. Overall, the findings confirm that systematic risk assessments, combined with the adaptation of preventive measures to the specific realities of each workplace, remain essential for the effective management of occupational risks in the modern agricultural sector.

Beyond the global risk values, an important contribution of the study lies in the analysis of how risks are distributed across components of the work system: means of production, working environment, work task, and worker. For the first company, Reinke Europe SRL, the risk assessment sheets corresponding to the three job positions: technical and administrative staff (TESA), warehouse/handling worker /commercial worker, and welder/mechanical fitter, provide a detailed overview of the structure of risk factors. The data are synthesized in (Table 2).

Table 2. Distribution of Risk Factors by Work System Components at Reinke Europe SRL

Job Position	Overall Risk Level	Means of Production (%)	Working Environment (%)	Work Task (%)	Worker (%)
Technical and Administrative Staff (TESA)	2.67	19.23	19.23	15.38	46.16
Warehouse / Handling / Commercial Worker	2.80	25.00	13.64	9.09	52.27
Welder / Mechanical Fitter	2.69	26.67	15.56	11.11	46.66

Source: Own calculation [17].

Figure 3 clearly shows that, for all three job positions, risk factors related to the worker account for the largest share in the overall risk structure, ranging from approximately 46% to 52%. This finding is highly relevant from a risk management perspective, as it suggests

that a substantial proportion of risks can be influenced through measures targeting worker behavior, such as training, supervision, the development of a safety-oriented organizational culture, and clearly defined internal rules. This result is consistent with the specialized literature, which emphasizes the central role of the human factor in the occurrence and propagation of undesirable events in agriculture and related activities (Duong et al., 2019; Giampietri et al., 2020) [8, 11].

In the case of the warehouse/handling/ commercial worker position, the share of worker-related risk factors is the highest (52.27%), while the contribution of the work task is the lowest (9.09%). This structure reflects the fact that most risks arise from the manner in which equipment is used and from compliance or non-compliance with procedures, for example, forklift operation, load securing, adherence to access routes, and the use of personal protective equipment. This situation is consistent with findings from studies indicating that agricultural storage and logistics are among the activities in which worker behavior and adherence to work instructions have a decisive impact on overall risk levels (Komarek et al., 2020; Matei et al., 2025) [13, 15].

For the welder/mechanical fitter position, the distribution is similar: 26.67% of risk factors are associated with the means of production, 15.56% with the working environment, 11.11% with the work task, and 46.66% with the worker. This structure reflects the specific nature of welding and metalworking activities, where risks related to equipment (power tools, welding machines, lifting devices) and the working environment (radiation, fumes, noise, extreme temperatures) are balanced by risks generated by the actual manner in which the worker handles and operates this equipment. The literature on risks in welding and metal fabrication highlights precisely this interaction between technical and behavioral risks (Ghiuleanu et al., 2023) [10], which lends additional validity to the obtained results.

It is also noteworthy that, for technical and administrative staff (TESA), whose activities are predominantly office-based, worker-related risk factors remain dominant (46.16%), even though the means of production and the working environment have comparable shares (19.23% each). This structure indicates a combination of “classic” office-related risks: such as improper working postures, eye strain, and prolonged sedentary work, with risks associated with work-related travel and vehicle use, where non-compliance with traffic rules, mobile phone use while driving, or operating vehicles in inadequate technical conditions may lead to serious incidents. Such findings are in line with research showing that, in modern agricultural enterprises, managerial and administrative staff are not exempt from occupational risks, but are exposed to more subtle risks that are often underestimated (Barducz & Jitea, 2024; Matei et al., 2025) [4, 15].

Comparing the three job positions within the same company, it can be observed that the share of risk factors related to the work task is relatively low in all cases (between 9.09% and 15.38%), suggesting that activities are relatively well defined and organizationally structured. In contrast, the means of production and the worker concentrate the largest proportion of risks, indicating a strong dependence on equipment quality, maintenance practices, and the manner in which equipment is used by workers. This conclusion is highly relevant for risk management, as it indicates that investments in safe equipment, training, and supervision have a high potential to reduce overall risk levels.

From a comparative perspective, the data obtained for Reinke Europe SRL support a widely acknowledged idea in the specialized literature, namely that the risk profile in agriculture and related activities is not determined solely by the type of activity (mechanical, technical, livestock-related), but also by the way in which human resources interact with technology and the working environment (Aven & Renn, 2010; Robu et al., 2024) [2, 18]. The dominance of worker-related risk factors across all three analyzed job positions confirms the need to integrate the human dimension into risk management models, not merely as a passive element of

exposure, but as a central actor in the prevention and control of occupational risks. Figure 3 illustrates the percentage distribution of occupational risk factors across work system components for the analyzed job positions at Reinke Europe SRL.

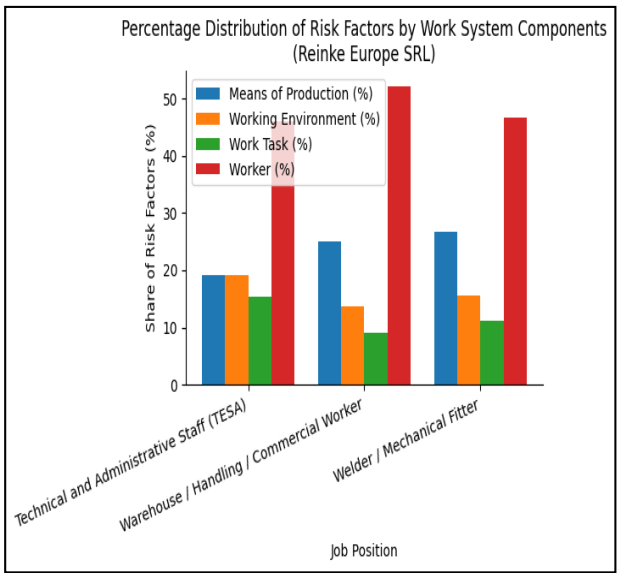

Fig. 3. Percentage Distribution of Risk Factors by Work System Components (Reinke Europe SRL)
Source: Own results [17].

The analysis of the second company, NYD Agroroute SRL, highlights a risk profile characteristic of intensive agricultural operations, where a high level of mechanization and the seasonal pace of activities influence both the frequency and the potential severity of undesirable events. The assessment focused on two occupational categories essential to the technological workflow: drivers and combine harvester operators, both representing positions with a high degree of technical and operational responsibility. The data synthesized and illustrated in Figures 4 and 5 indicate that, although the overall risk level is relatively similar for the two positions (2.80 for drivers and 2.77 for combine operators), the structure of risks differs significantly, reflecting the specific nature of the tasks performed.

For drivers, the high share of risks related to the means of production (29.73%) and to the worker (43.25%) indicates that operational safety is strongly dependent on both the technical condition of the machinery and the operator's skills. Grain transport on agricultural routes, travel over uneven terrain, and the handling of loaded trailers involve significant mechanical risks, such as entanglement, crushing, rollovers, and collisions, which are frequently reported in the agricultural safety literature (Komarek et al., 2020) [13]. In addition, prolonged exposure to vibrations, extreme temperatures, long driving hours, and time pressure during peak agricultural seasons constitute additional risk factors, well documented in studies on agricultural transport (Duong et al., 2019) [8]. Consequently, not only technical conditions but also the psychophysiological resilience of workers becomes a central element in accident prevention.

In the case of combine harvester operators, the risk structure exhibits distinct characteristics. The relatively high share of risks related to the working environment (21.43%) reflects significant exposure to factors such as dust, noise, exhaust gases, whole-body vibrations, and adverse weather conditions. Recent studies show that workers operating combine harvesters face an increased risk of musculoskeletal disorders, respiratory problems, and cumulative fatigue as a result of long operating periods in cabins exposed to environmental stressors (Ghiuleanu et al., 2023) [10]. At the same time, the substantial contribution of worker-related risk factors (45.23%) underscores the importance of continuous attention, anticipatory capacity, and practical experience when operating complex equipment. A momentary lapse in attention, an incorrect distance assessment, or a delayed reaction can lead to serious incidents, given the size, weight, and inertia of modern agricultural machinery.

Compared to drivers, combine harvester operators are more intensely exposed to microclimatic factors and physiological strain, while technical risks account for a lower proportion, suggesting greater structural stability of modern machinery but a more complex exposure to external conditions. This differentiation, observable in both graphical representations (Figure 4) and (Figure 5), is consistent with the literature emphasizing that advanced mechanization does not necessarily reduce risk levels, but rather alters their

structure and modes of manifestation (Aven & Renn, 2010) [2]. Thus, while combine operators are more exposed to environmental and ergonomic risks, drivers are more vulnerable to mechanical, dynamic, and internal traffic-related risks.

Overall, the analysis of activities at NYD Agroroute SRL highlights a work system in which the human factor represents the most sensitive component, regardless of job position, accounting for the largest share of risk in both cases. This finding confirms the conclusions of European studies showing that, in agriculture, worker behavior, practical training, risk perception, and the ability to adapt to variable conditions play a decisive role in accident prevention and risk reduction (Giampietri et al., 2020; Robu et al., 2024) [11, 18].

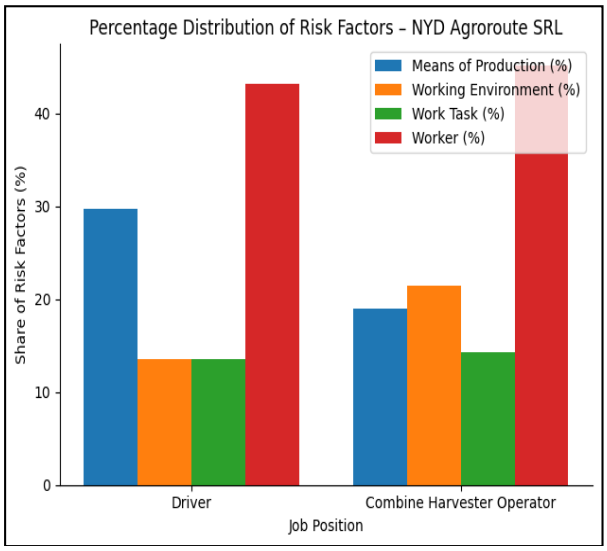

Fig.4. Percentage Distribution of Risk Factors – NYD Agroroute SRL
Source: Own results [16].

At the same time, the percentage differences between the two positions confirm the need for differentiated prevention strategies: for drivers, the emphasis should be placed on technical maintenance and fatigue management, while for combine operators, priority should be given to reducing exposure to environmental factors and optimizing workplace ergonomics.

The third analyzed company, Avi Complex Cogealac SRL, exhibits a distinct risk profile associated with livestock farming activities, where biological, ergonomic, and environmental risks predominate. The assessed job position, animal caretaker, is characterized by a specific distribution of risks, illustrated in (Figure 6). The high share of risks related to the means of production (39.02%) indicates that equipment used in livestock farms: such as ventilation systems, feeding equipment, electrical installations, and automated manure removal systems, represents a major source of risk, confirming findings in the literature regarding the importance of technical infrastructure in livestock operations (Arnalte-Mur et al., 2020) [1]. At the same time, worker-related risk factors (36.59%) highlight the role of worker behavior, animal handling practices, and direct exposure to biological agents, elements well documented as key determinants of occupational risks in livestock farming (Ghiuleanu et al., 2023) [10].

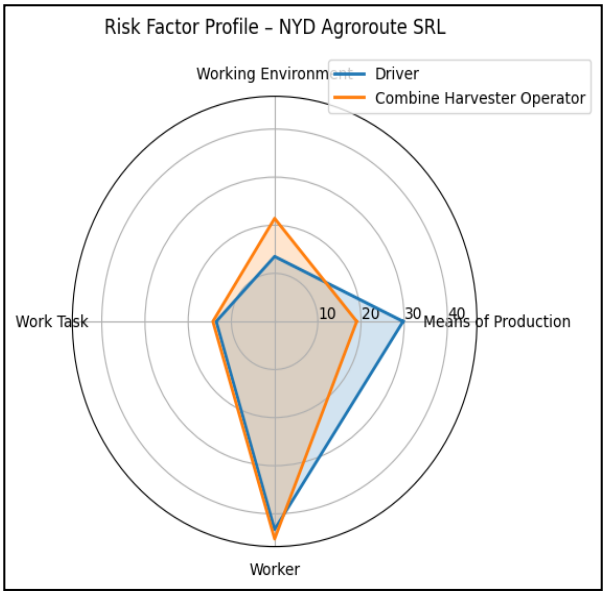

Fig.5. Risk Factor Profile – NYD Agroroute SRL
Source: Own results [16].

The working environment, accounting for 17.07% of the risk factors, reflects conditions specific to livestock farms, including temperature fluctuations, high humidity levels, and the presence of organic dust and microorganisms originating from animal waste factors that influence respiratory health and overall physical condition. Although the work task component has the lowest share (7.32%), it should not be underestimated, as repetitive activities, manual handling of loads,

and movements in confined spaces contribute to chronic ergonomic risks.

Compared to mechanized agricultural operations, risks in livestock farming are less frequently associated with severe accidents but involve continuous and cumulative exposure, which may affect long-term health. The relatively low overall risk level recorded in this company is influenced not only by the nature of the activities but also by the fact that the unit is recently established and equipped with modern machinery that complies with international standards. The use of new technologies, smart agriculture solutions, and digitalized systems contributes to reducing risk exposure and optimizing operational processes, in contrast to situations where activities are carried out using outdated or insufficiently digitalized technologies.

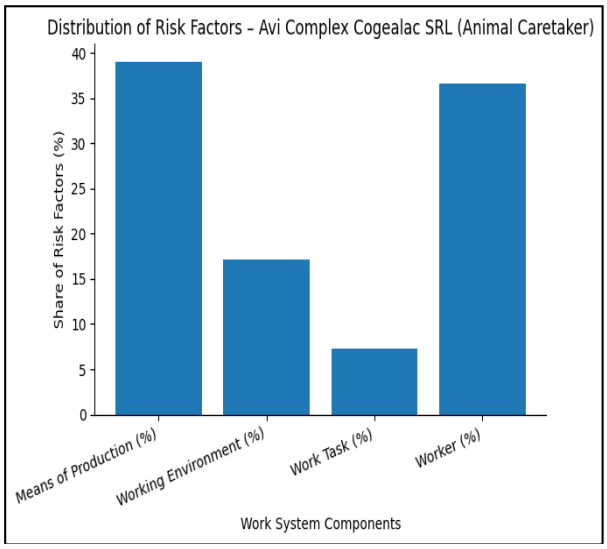

Fig. 6. Distribution of Risk Factors – Avi Complex Cogealac SRL (Animal Caretaker)
Source: Own results [3].

This trend is consistently highlighted in the international literature, which shows that livestock workers exhibit a higher prevalence of musculoskeletal, respiratory, and dermatological conditions, even when the overall risk level is assessed as moderate (Mang'ana et al., 2023) [14].

Figure 6 illustrates the distribution of occupational risk factors across work system components for the animal caretaker position at Avi Complex Cogealac SRL.

The comparative analysis of the three companies reveals significant differences in the structure of occupational risks, mainly driven by the nature of the activities, the level of mechanization, and exposure to specific work-related factors. Although the overall risk levels are relatively similar (2.67–2.80), these values mask important qualitative differences that influence both the probability and severity of undesirable events.

A clear distinction emerges between the mechanized companies: Reinke Europe SRL and NYD Agroroute SRL and the livestock-oriented company, Avi Complex Cogealac SRL. In mechanized operations, mechanical, technical, and operational risks dominate, reflected in higher shares of risks related to the means of production (19–30%) and a consistently strong contribution of worker-related factors (43–52%). These findings are consistent with the literature, which identifies mechanized agricultural activities as a major source of severe accidents, particularly during peak farming periods when work intensity and fatigue increase (Komarek et al., 2020) [13].

In contrast, the livestock-oriented company exhibits a different risk structure, characterized by a higher contribution of risks related to the means of production (39.02%) and the worker (36.59%), while environmental and task-related risks play a smaller role. Risks in livestock farming are less associated with acute accidents and more with cumulative exposure to biological and ergonomic factors, leading to long-term health effects, as documented in previous studies (Arnalte-Mur et al., 2020; Mang'ana et al., 2023) [1, 14].

Across all three companies, the human factor remains the most influential component, accounting for 36–52% of total risk, highlighting the vulnerability of agricultural work systems to human error, fatigue, and insufficient training. Although Avi Complex Cogealac SRL records the lowest overall risk level, this does not imply lower significance of risks, but rather a different risk dynamic, characterized by chronic exposure rather than acute events.

Overall, the results confirm that effective risk management in agriculture must be tailored to the specific operational context of each company. Mechanized operations require a

focus on equipment maintenance, control of mechanical hazards, fatigue management, and continuous training, while livestock operations should prioritize reducing biological exposure, improving ventilation, optimizing ergonomics, and monitoring workers' health. These findings underline the importance of differentiated, context-specific prevention strategies aligned with current European occupational health and safety requirements (Robu et al., 2024) [18].

CONCLUSIONS

The comparative analysis of occupational risks in the three investigated companies shows that, although overall risk levels fall within the "acceptable" range according to the INCDPM methodology, the structure of risk factors differs significantly across units, reflecting the technological, organizational, and operational specificities of each agricultural activity.

In companies characterized by a high level of mechanization: Reinke Europe SRL and NYD Agroroute SRL, the dominant risks are mechanical, technical, and operational, associated with the use of heavy agricultural machinery, electrical equipment, and complex technological processes. Worker-related factors recorded high shares across all analyzed job positions, highlighting the critical importance of training, professional skills, preventive behavior, and fatigue management in reducing accident probability. This finding is consistent with the specialized literature, which emphasizes the central role of the human factor in the causal chain of hazardous events in agriculture.

By contrast, in the livestock-oriented company, Avi Complex Cogealac SRL, dominant risks are biological, ergonomic-postural, and microclimatic in nature, reflecting exposure to biological agents, variable temperatures, organic dust, repetitive physical effort, and interaction with animals. Although the overall risk level is lower, these risks are chronic and cumulative, with potential long-term effects on workers' health an aspect increasingly emphasized in international literature.

The comparison of the three companies reveals a clear relationship between the technological structure of activities and the resulting risk profile: mechanized units are exposed to acute risks with high potential severity, while livestock operations face diffuse risks of lower severity but higher frequency.

These findings underline the need for differentiated, context-specific prevention measures. In mechanized activities, priority should be given to strengthening maintenance programs, standardizing work procedures, and integrating fatigue management into risk management strategies.

In livestock operations, key measures include reducing exposure to biological agents, improving workplace ergonomics, enhancing ventilation, and continuously monitoring workers' health.

Overall, the study confirms that systematic risk assessment, conducted across work system components and complemented by comparative analysis between different entities, is essential for supporting prevention policies and developing risk management approaches adapted to the dynamics of modern agriculture.

The results emphasize that occupational health and safety in agriculture depend not only on technical measures, but also on investments in training, effective organization, and the development of a strong prevention-oriented safety culture among workers.

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THE IMPACT OF SYSTEMIC CRISES ON ACCOUNTING INDICATORS IN AGRICULTURAL FARMS IN ROMANIA: A COMPARATIVE ANALYSIS (2019–2021)

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Abstract

Agriculture represents a strategic sector, essential for food security and sustainable development. Between 2019 and 2021, agricultural farms in Romania were exposed to a series of systemic crises, including the COVID-19 pandemic, energy market instability, and the increasing impact of climate change. These disruptions significantly affected the financial performance of agricultural holdings, as reflected in the changes in both the structure and value of accounting indicators. This study aims to conduct a comparative analysis of the impact of these crises on key accounting indicators, assessing the level of adaptability and the resilience strategies employed by farms in Romania. By analyzing the evolution of key financial indicators in the pre-crisis period (2019) and during the crisis years (2020–2021), the research highlights how these entities responded to external pressures and the consequences on their economic and financial stability. The findings provide valuable insights into the relationship between the macroeconomic context and accounting performance, contributing to the development of support policies tailored to the actual needs of the agricultural sector.

Key words**:** *accounting indicators, adaptability, agricultural farms, COVID-19 pandemic, systemic crises*

INTRODUCTION

Agriculture is widely acknowledged as a strategic economic sector, marked by a high degree of vulnerability to external shocks stemming from economic, climatic, and institutional factors. In recent years, agricultural systems worldwide have faced a series of systemic crises, with the COVID-19 pandemic serving as a major turning point. This crisis had direct repercussions on production levels, supply chains, and the financial performance of farming operations (Mahmood et al., 2024; Saif-Alyousfi, A. Y. H., 2025) [10, 15]. As a vital pillar of the Romanian economy, the inherently volatile structure of agriculture was subjected to intense pressure. This period was defined by what has been termed the "perfect storm": the COVID-19 health crisis, which disrupted logistics networks, and the extreme soil drought in 2020, which severely reduced crop yields in southern and eastern regions of the country (Popescu, 2020) [14, 16, 17]. In Romania, the years 2019 to 2021 were characterized by the overlapping of pandemic-related effects with the severe drought of 2020, fluctuations in agricultural input prices, and rising energy costs. These adverse conditions exerted significant strain on accounting indicators, negatively impacting profitability, liquidity, and the capital structure of farming enterprises.) [11,12, 13].
This article aims to provide a synthesis of the academic literature on the impact of systemic crises on accounting indicators in agriculture, complemented by a descriptive analysis of financial data from representative companies in Romania's cereal sector (Ionescu & Matei, 2021) [9,11].

MATERIALS AND METHODS

This article is grounded in a qualitative review of relevant literature, encompassing peer-reviewed scientific articles, empirical studies, and statistical reports published in internationally indexed journals and national

statistical publications. The selection criteria focused on relevance to the topic of systemic crises, emphasis on the agricultural or agri-food sector, and examination of accounting or financial indicators.) [4,7]. Additionally, the research adopts a mixed-methods approach, integrating qualitative analysis of scholarly sources with quantitative assessment of financial indicators.

Sample selection: Three market-leading companies with distinct business models were chosen for analysis: Agricost S.A. (integrated farming with irrigation infrastructure), Agro Chirnogi S.A. (extensive crop production), and Cerealcom Dolj S.A. (a hybrid model combining production and trading activities).

Indicators examined: Turnover (TO), Net Profit (NP), Total Assets (TA), and Equity (EQ). Furthermore, Net Profit Margin (NPM) was calculated as a measure of efficiency, using the formula:

NPM = (Net Profit / Turnover) × 100.....(1)

The data analyzed were sourced from the companies' annual financial statements submitted to the Ministry of Public Finance, as well as from their sustainability reports.

RESULTS AND DISCUSSIONS

Trends in Accounting Indicators During Crisis Periods

The scholarly literature indicates that profitability indicators such as Return on Assets (ROA) and Net Profit Margin tend to decline significantly during times of crisis, primarily due to rising operational costs and reduced market demand. Liquidity indicators have become crucial for the survival of agricultural enterprises, many of which rely heavily on short-term financing and government support schemes.

Furthermore, some studies report a deterioration in solvency indicators, particularly among small and medium-sized farms. In contrast, larger or more diversified agricultural enterprises have shown greater levels of financial resilience (Tables 1–5).

Resilience and Adaptive Strategies in Agricultural Enterprises

The reviewed literature highlights the critical importance of adaptive capacity in mitigating the financial impact of systemic crises. Frequently cited strategies include cost optimization, production diversification, investment in technology, and enhanced financial management practices. Government intervention through subsidies and targeted support programs has played a key role in stabilizing financial indicators during the pandemic. Research on the economic sustainability of Romanian agriculture emphasizes that farms implementing sound financial management practices demonstrated superior performance under crisis conditions.

The Context of Systemic Crises in Agriculture (2019–2021)

The COVID-19 pandemic intensified existing structural vulnerabilities within the agricultural sector, disrupting labor availability, market access, and the stability of financial flows. Simultaneously, climate change contributed to heightened uncertainty surrounding agricultural output—particularly in 2020, a year marked by severe drought conditions in Romania. These systemic crises directly influenced accounting indicators, leading to significant fluctuations in revenues, increased levels of indebtedness, and mounting pressure on equity capital.

Comparative Analysis of Major Agricultural Enterprises in Romania

Table 1. Sample overview and strategic positioning

Company	Headquarters	Business model	Farm Area
Agricost S.A.	Insula Mare a Brăilei	Integrated crop production with proprietary irrigation system	~56,000 ha
Agro Chirnogi S.A.	Călărași	Grain and legume production, exposed to climatic factors	~9,400 ha
Cerealcom Dolj S.A.	Dolj	Combination of agricultural production and regional grain trading	~25,000 ha

Source: [1, 2, 3].

The comparative evaluation of financial data highlights the uneven impact of these crises across the three selected entities (Table 1).

Table 2 presents the indicators for Agricost S.A., the largest farm in Romania. A notable stability in net profit is observed for the year 2020 (87.3 million RON), despite the challenges posed by the pandemic context.
Furthermore, the farm's financial resilience is reflected in the consistent profit margin maintained during the drought-affected year 2020.

Table 2. Evolution of Financial Indicators – Agricost S.A.

Indicator	**2019 (RON)**	**2020 (RON)**	**2021 (RON)**	**Dina-mica 2021/ 2019**
Turnover	381.633.330	410.804.501	486.288.098	+27.4%
Net profit	91.596.962	87.317.871	97.580.495	+6.5%
Net profit margin(%)	24%	21.1%	20%	-4.0 pp
Total assets	747.763.497	891.638.133	1.151.760.449	+54%
Total Liabilities	261.845.197	324.528.470	439.146.434	-
Equity	468.740.164	556.376.172	703.339.122	-

Source: Own calculation based on the data from [1].

The data presented in Table 2 indicate that Agricost S.A. succeeded in maintaining a strong profit margin above 20%, demonstrating that investments in fixed assets can help buffer the effects of climate-related crises.
This performance highlights the company's high level of resilience, with only a slight decline in profit observed in 2020, followed by a solid recovery in 2021 driven by strategic investments and the use of irrigation systems.
Table 3 illustrates the severe impact of the 2020 drought and the speculative price-driven recovery in 2021.
The data reflect a severe impact of the crisis in 2020, followed by a strong recovery in 2021, correlated with favorable agricultural conditions and rising grain prices.

Table 3. Evolution of Financial Indicators – Agro Chirnogi S.A.

Indicator	**2019 (RON)**	**2020 (RON)**	**2021 (RON)**	**Change 2021/ 2019**
Turnover	662.039.730	456.558.579	1.055.330.096	+59.4%
Net Profit	43.348.773	9.421.632	35.324.375	-18.5%
Net profit margin (%)	6.5%	2%	3.3%	-3.2pp
Total assets	526.158.198	468.723.664	832.608.141	+58.2%
Total liabilities	364.862.826	297.690.434	538.288.038	-
Equity	157.513.596	167.536.851	291.104.344	-

Source: Own calculation based on the data from [2].

Table 4 illustrates an expansion in trading activity, accompanied, however, by a decline in financial stability, as evidenced by the decrease in equity capital.

Table 4. Evolution of Financial Indicators – Cerealcom Dolj S.A.

Indicator	**2019 (RON)**	**2020 (RON)**	**2021 (RON)**	**Change 2021/ 2019**
Turnover	679.187.873	775.397.369	1.251.447.956	+84.2%
Net profit	19.006.341	3.073.857	20.648.070	+8.6%
Net profit margin (%)	2.8%	0.4%	1.6%	-1.2 pp
Total assets	761.020.004	787.231.408	901.513.495	-
Total liabilities	587.575.713	618.220.055	768.150.475	-
Equity	173.609.060	170.939.290	133.739.466	-22.9%

Source: Own calculation based on the data from [3].

The financial structure reveals increased pressure on equity capital.
In contrast to the market leader, the companies Agro Chirnogi (Table 3) and Cerealcom Dolj (Table 4) recorded highly fragile profit margins in 2020 (below 20%), with recovery driven primarily by the favorable price conditions in 2021.
The solvency analysis (Table 5) shows that the financial resilience of these farms was partially supported by higher debt levels particularly in the case of Cerealcom Dolj, where liabilities accounted for over 85% of total assets in 2021.

Table 5 Comparative analysis of solvency and indebtedness level

Company	2019 (%)	2020 (%)	2021 (%)	Risk status
Agricost S.A.	35%	36.4%	38.1%	Low (Resilient)
Agro Chirnogi S.A.	69.3%	63.5%	64.6%	Moderate (Vulnerable)
Cerealcom Dolj S.A.	77.2%	78.5%	85.2%	High (Speculative)

Source: Own calculation based on the data from [1, 2, 3].

Agricost S.A. – Conservative Management

Despite a substantial increase in assets, the company kept its debt ratio below the 40% threshold an indication of strong structural resilience. While other farms resorted to borrowing in order to survive the drought, Agricost relied on internally generated cash flow to finance its investments, thereby maintaining a low-risk profile.

Agricost S.A. consistently pursued a conservative financial strategy, channeling internal cash flow into investment activities.

Agro Chirnogi S.A. – Forced Deleveraging in 2020

A noticeable and unusual decrease in the debt ratio occurred in 2020 (from 69.3% to 63.5%). Coupled with a decline in total assets, this suggests the company was compelled to reduce its exposure—potentially through asset sales or inventory liquidation—to meet urgent debt obligations, lacking the liquidity required to sustain a higher level of indebtedness during a year with no harvest. Agro Chirnogi S.A. underwent forced deleveraging in 2020 in order to settle outstanding debts due to the absence of production.

Cerealcom Dolj S.A. – High-Risk Business Model

This company presents the most concerning financial indicator. A debt ratio of 85.2% in 2021 indicates that nearly the entire operation is financed through borrowed capital. The increase from 77% to 85% reflects a strategy focused on supporting large-scale trading volumes (with record turnover) despite very thin profit margins. This exposes the firm to significant risk in the event of rising interest rates or a sudden drop in grain prices. Cerealcom Dolj S.A. operates under a high-risk model, with liabilities accounting for 85% of total assets leaving the entity vulnerable to interest rate volatility (Tabak et al., 2024) [18].

The Role of Public Policy and International Comparison

The findings of the study indicate that government support particularly through direct subsidies and temporary fiscal measures played a significant role in maintaining farm liquidity during the 2019–2021 period. However, the comparative analysis reveals that the effectiveness of these measures varied, depending largely on farm size and the ability to access available funding mechanisms.

Table 6 provides a summary of the main support instruments implemented in Romania, compared with those applied in other EU Member States.

Table 6. Government support instruments in agriculture during the 2019–2021period

Country	Direct subsidies (€/ha)	COVID-19 measures	Temporary tax facilities	Investment support
Romania	~170 €/ha	Yes (COVID-19 AGRI aid)	Limited (local taxes deferred)	Limited, accessible only to large farms
France	~260 €/ha	Yes (FNSAE, public guarantees)	VAT exemptions for agricultural inputs	Extended access to CAP funds
Germany	~280 €/ha	Yes (COVID aid + climate schemes)	Clear fiscal support (non-taxable subsidies)	Programs for agricultural digitalization
Poland	~215 €/ha	Yes (direct grants)	Reduced VAT for inputs	Funds for small and medium-sized farms

Source: (DG AGRI, Eurostat, FAO Reports 2021–2022) [5, 6, 7, 8].

Romania relied predominantly on direct payments under the Common Agricultural Policy (CAP); however, the absence of permanent fiscal facilities and fast-access investment funds limited the resilience of small-scale farms.

International Comparison of Financial Performance in Agriculture (2019–2021)

To provide a contextualized assessment, an international comparison of net profit margins

in agriculture during the crisis period was included.

The data indicate that farmers in Germany and France managed to maintain, or even increase, their profit margins supported by rapid government intervention mechanisms and better access to agricultural credit.

Table 7. Evolution of the Net Profit Margin in Agriculture (Selective, 2019–2021)

Country	2019 (%)	2020 (%)	2021 (%)	Remarks
Romania	6.5%	2.3%	4.8%	High variability, affected by drought and lack of liquidity
France	7.2%	6.5%	7.8%	Stable public support, extensive digitalization
Germany	5.9%	6.1%	6.3%	Stable profit due to integrated risk management
Poland	5.4%	4.2%	6.3%	Government support tailored to small farms

Source: Eurostat Agricultural Economic Accounts, FAO, National Agri Reports 2020–2022 [6, 8].

This comparison highlights the potential of well-designed public policy to mitigate the effects of systemic crises. Countries that implemented direct fiscal measures, emergency funding, and technological investments demonstrated stronger financial resilience.

CONCLUSIONS

This study demonstrates that the period 2019–2021 represented an unprecedented "stress test" for Romania's agricultural sector, revealing a direct correlation between the adopted business model and the capacity to absorb systemic shocks.

The analysis of accounting indicators shows that the crises had an asymmetric impact. While overall profitability declined across the board in 2020, the extent of recovery in 2021 was largely influenced by the existing technical infrastructure:

Asset-based model (Agricost S.A.): Significant investments in irrigation systems and agricultural technology acted as a natural risk mitigation mechanism, enabling the company to maintain a stable profit margin (above 20%) and a conservative debt ratio (under 40%).

Trading and volume-driven model (Cerealcom Dolj S.A.): Although this approach led to record turnover, it also exposed the company to substantial risk, resulting in a high dependency on borrowed capital, which accounted for 85% of total assets by 2021.

A key finding of the research is that the succession of crises health-related, climatic, and energy-related did not lead to a reduction in farm size, but rather to a concerning restructuring of financing sources.

For farms highly exposed to climate risks, the losses incurred in 2020 eroded equity capital, forcing managers to resort to aggressive financial leverage.

While the favorable price dynamics in 2021 temporarily safeguarded liquidity, long-term sustainability remains fragile due to rising financing costs.

International comparisons suggest that, unlike in countries such as France or Germany where rapid fiscal interventions and digitalization helped stabilize profit margins Romania relied primarily on direct subsidies under the Common Agricultural Policy (CAP).

These ensured short-term survival but failed to secure the structural resilience of small and medium-sized farms, which remain vulnerable to climatic volatility in the absence of better-calibrated emergency funding mechanisms.

The results underscore the urgent need for a shift in Romanian farm management practices from a focus on maximizing gross output to optimizing financial structure.

This study may serve as a foundation for public policy aimed not only at area-based subsidies, but also at encouraging investments in risk-mitigation technologies such as irrigation systems, digital tools, and hedging instruments essential measures for safeguarding accounting performance in the face of future systemic crises.

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DOES FINANCIAL CRIME UNDERMINE ECONOMIC FREEDOM? GLOBAL EVIDENCE ACROSS AGRICULTURE AND INDUSTRIAL ECONOMIES

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Abstract

This study examines the impact of financial crime on economic freedom using panel data for 46 countries over the period 2015-2024, focusing on key dimensions of financial crime: corruption, money laundering, shadow economy activity, and cybersecurity governance. The empirical results confirm a statistically significant negative effect of corruption, money laundering risk, and shadow economy size on economic freedom, while stronger cybersecurity governance is positively associated with economic freedom. The adverse association is more visible in countries where agriculture plays a larger role in the economic structure. These findings suggest that structural characteristics condition the transmission of institutional weaknesses into broader economic outcomes. This study contributes to the comparative institutional economics literature by providing large-scale cross-country evidence on the systemic channels through which financial crime constrains economic freedom, and by demonstrating that sectoral structure conditions the transmission of institutional weaknesses into market outcomes.

Key words**:** *corruption, cybersecurity, economic freedom, financial crime, shadow economy*

INTRODUCTION

In recent years, economic and financial crime has become an increasingly important concern for both researchers and policymakers. This heightened attention is largely driven by the expansion of international financial flows and the rapid pace of digitalization. Practices such as corruption, money laundering, tax evasion, and the shadow economy not only disrupt market functioning but also erode public trust in institutions and limit the state's ability to provide a stable and predictable business environment (Rider, 2015; Achim & Borlea, 2020) [25, 1].

The effects of financial crime are often more pronounced in economies where agriculture, industry, and services contribute unevenly to GDP and develop at different speeds. In such contexts, institutions face additional challenges in enforcing regulations and controlling illegal activities.

A key concept for understanding this relationship is economic freedom. Economic freedom reflects the extent to which a country's rules and policies allow economic activities to take place freely, protect property rights, and encourage competition. It is most commonly operationalised through the Index of Economic Freedom (IEF), published annually by the Heritage Foundation. A higher composite score indicates that economic activities are subject to fewer governmental constraints and that market mechanisms operate more freely (Heritage Foundation, n.d.) [14]. The IEF thus captures not only narrow market liberalisation but also the quality of the legal environment, the predictability of public policy, and the openness of financial and trade systems, precisely the dimensions most exposed to distortion by financial crime.

Cross-country evidence consistently confirms that countries with higher economic freedom scores exhibit stronger long-run economic growth, greater investment, lower unemployment, and higher income levels (Gwartney & Lawson, 2003; De Haan & Sturm, 2000) [12, 7]. De Haan and Sturm (2000) [7] further demonstrated, using panel

data for a large sample of countries, that it is the change in economic freedom, not simply its level, that is most robustly associated with growth performance, implying that the direction of institutional reform matters at least as much as the starting-point. This insight is directly relevant to the present study, which examines cross-country variation in IEF scores over a ten-year panel.

Berggren (2003) [5] provided a comprehensive survey of the empirical literature on the benefits of economic freedom and concluded that economic freedom is not only an outcome of good governance but also a driver of it: economies with more open markets and stronger property rights protection tend to develop more effective anti-corruption systems over time, because competitive markets reduce the rents that motivate corrupt behaviour.

A further strand of the economic freedom literature has examined which specific sub-components are most responsive to institutional change. Heckelman and Stroup (2000) [13] found that property rights, monetary stability, and trade openness are the sub-indices most consistently linked to economic growth, while labour market regulations and government size show weaker and more context-dependent effects. For the purposes of the present study, this granularity matters: corruption, money laundering, and the shadow economy can be expected to affect different sub-components of the IEF through distinct channels.

Thus, research suggests that higher levels of economic freedom tend to coincide with greater institutional capacity to limit informal and illegal economic activity, creating theoretically important feedback between economic freedom and financial crime.

A crucial but underexplored dimension of the financial crime-economic freedom relationship is the structural composition of the economy, specifically, the relative weight of agriculture, industry, and services in national GDP. Economic theory and comparative development evidence consistently show that these three sectors operate under fundamentally different institutional regimes, face different types and intensities of informality, and possess different capacities for regulatory enforcement.

The foundational contribution to understanding structural transformation and its institutional implications is Kuznets (1955) [17], who identified the systematic shift from agriculture-dominant to industry-dominant to service-dominant economic structures as the central feature of modern economic growth. This structural transformation perspective suggests that agricultural dependence may be associated with weaker institutional conditions and lower economic freedom.

The institutional dimensions of agricultural dominance are further elaborated by La Porta and Shleifer (2014) [18], who documented that informal economic activity, measured both as the share of the shadow economy and as the prevalence of informal firms, is substantially higher in low-income, agriculture-dominant economies than in industrialised or service-oriented ones. Their analysis demonstrated that informal firms in agriculture-dominant economies are not simply small-scale versions of formal firms that will eventually formalise as they grow; rather, they operate under fundamentally different cost structures, governance norms, and regulatory expectations. Informal agricultural activity is characterised by poor land titling, seasonal labour arrangements outside formal employment contracts, and cash-based transactions that are structurally invisible to fiscal authorities. These features simultaneously increase the shadow economy share, weaken the rule-of-law foundations of economic freedom, and reduce the administrative capacity available to enforce AML regulations.

Despite these clear structural differences, comparative studies that explicitly examine the role of economic structure remain limited. Thus, the structural conditioning perspective motivates the extended model specifications in this study, which include the shares of agriculture and industry in GDP as additional explanatory variables alongside the financial crime indicators. Rather than simply controlling for sectoral composition, these variables are theorized as moderating

conditions that shape the institutional environment through which financial crime affects economic freedom.

Financial Crime and Its Mechanisms: Channels Linking Crime to Economic Freedom

Many researchers have shown that there is a strong connection between the quality of governance, the level of corruption, and the size of the shadow economy. Countries with weaker institutions and lower governance quality are generally more exposed to informal economic activity and higher corruption (Dreher et al., 2009; Dreher & Schneider, 2010) [8, 9].

Other research has compared the size of the shadow economy across countries at different stages of economic development, examining factors such as fiscal policy, regulatory burdens, and institutional quality (Schneider & Klinglmair, 2004; Williams & Schneider, 2016; Medina & Schneider, 2018) [28, 32, 20].

The factors that drive financial crime are diverse and affect economic freedom in several ways. Institutional factors, such as the quality of legislation, judicial efficiency, governance, and press freedom, are critical not only for preventing and punishing financial crimes but also for maintaining a stable and predictable economic environment, which is essential for the functioning of markets and for attracting investment (Dreher et al., 2009; Kalenborn & Lessmann, 2013) [8, 16]. Technological factors have become increasingly important, with fiscal digitalization, electronic payment systems, anti-fraud mechanisms, and the use of artificial intelligence helping to reduce corruption and fraud while strengthening investor confidence and protecting market integrity (Ryman-Tubb et al., 2018; Achim et al., 2021) [27, 2]. Cultural and social factors, including social norms, tax morale, religion, and business ethics, also play a role by shaping how individuals and firms comply with economic regulations. Taken together, these cultural and social dynamics shape the institutional conditions under which economic freedom may either strengthen or weaken over time (Torgler & Schneider, 2007; McGee et al., 2015) [30, 19].

While these general relationships are well established, a more precise analysis requires differentiating the mechanisms through which each dimension of financial crime affects specific components of the Index of Economic Freedom.

Corruption undermines economic freedom primarily through its corrosive effect on the rule-of-law and property-rights sub-components of the IEF. When public officials exercise power for private gain, whether through petty bribery, regulatory capture, or the diversion of public resources, the predictability of legal and regulatory systems is undermined (Rose-Ackerman, 1999) [26]. Firms facing unpredictable enforcement of contracts or property rights cannot reliably plan long-term investments, reducing both investment rates and the efficiency of capital allocation. Ades and Di Tella (1999) [3] demonstrated that markets with fewer rents, that is, more competitive, open markets, exhibit lower corruption, establishing a direct theoretical link between economic freedom (market openness) and corruption levels. This expected positive relationship between CPI and IEF is formalised as Hypothesis 1 in this study.

Money laundering distorts economic freedom primarily through its effect on financial market integrity and investment freedom. By integrating illicit funds into the formal economy, through real estate, financial instruments, or shell companies, money laundering creates artificial demand, distorts asset prices, and crowds out legitimate economic activity from formal credit markets (Ferwerda, 2009) [10]. A higher AML score is therefore expected to be negatively associated with economic freedom (Hypothesis 2), particularly with the financial freedom and investment freedom sub-components of the IEF. Importantly, the AML channel operates largely through slow-moving structural factors, the quality of financial supervision, anti-corruption legislation, and international cooperation frameworks, that may not be fully captured within a short observation window, a

consideration that informs the interpretation of the empirical results.

The shadow economy undermines economic freedom through a fiscal-integrity and regulatory-compliance channel. A larger shadow economy implies a reduced tax base, which constrains the government's capacity to provide the public goods, legal systems, property registries, infrastructure, that underpin economic freedom (Schneider & Enste, 2000) [29]. At the same time, informal sector activity creates a competitive distortion against formal-sector firms that face the full burden of taxation and regulation, weakening business freedom and eroding the rule-of-law norms that economic freedom requires. Williams and Schneider (2016) [32] showed that shadow economy size is systematically inversely related to tax morale and institutional trust. The shadow economy variable (SE), is therefore expected to be negatively associated with economic freedom (Hypothesis 3), primarily affecting the fiscal health, government integrity, and business freedom sub-components of the IEF.

Cybersecurity governance represents an increasingly critical dimension of the institutional environment for economic freedom in the digital age. Countries with stronger cybersecurity frameworks are better positioned to protect digital financial transactions, reduce exposure to cybercrime-enabled fraud and money laundering, and maintain the integrity of electronic commercial and governmental services (Achim et al., 2021) [2]. Digital infrastructure reliability is a prerequisite for both investment freedom, since foreign investors require assurance that digital assets are protected, and business freedom, since firms increasingly depend on digital platforms for commerce, supply chain management, and regulatory compliance. Higher GCI scores are therefore expected to be positively associated with economic freedom (Hypothesis 4), particularly as financial crime increasingly operates through digital channels.

Research examining the relationship between corruption, the shadow economy, and economic performance helps us understand the complexity of financial crime and highlights the need for studies that combine multiple indicators and data sources. Most existing studies focus either on economic growth or on specific regions, offering fewer insights into economic freedom as a dependent variable or into how sectoral structures influence this freedom at a global level (Borlea et al., 2017; Achim & Borlea, 2020) [6, 1]. In addition, recent evidence points out that financial crime is linked not only to macroeconomic outcomes, but also to corporate outcomes. For example, corruption, money laundering, and the shadow economy are associated with higher risks of business failure and corporate insolvency in European economies (Muntean et al., 2025) [23]. From a corporate-sector stability perspective, weak institutional quality and weak corporate governance, especially when controls are limited, can increase firms' vulnerability and raise insolvency risk, particularly in transition economies (Muntean, 2019) [21]. Finally, cross-country evidence suggests that higher economic freedom is associated with fewer corporate insolvencies across European countries, which supports the idea that a stronger and more predictable institutional environment contributes to firm resilience (Muntean et al., 2021) [22]. Overall, these findings support the motivation of the present study and strengthen the argument that economic freedom should be analysed together with institutional conditions, financial crime, and structural characteristics of the economy.

Research Objective

This study examines the relationship between financial crime and economic freedom using panel data for 46 countries over the period 2015–2024. To capture the complexity of financial crime, four complementary indicators are employed: the Corruption Perceptions Index (CPI), the Basel Anti-Money Laundering Index (AML), estimates of the shadow economy (SE), and the Global Cybersecurity Index (GCI).

The analysis incorporates sectoral composition controls, specifically, the shares of agriculture, industry, and services in GDP, to examine how the structural characteristics of the economy condition the relationship

between financial crime and economic freedom.

The novelty of this study lies in its comparative approach. The analysis incorporates sectoral composition variables, specifically the shares of agriculture and industry in GDP, with services as the omitted category, to examine whether economic structure is associated with cross-country differences in economic freedom. This perspective helps to clarify how institutional weaknesses operate alongside structural characteristics and influence market performance and business activity. Moreover, using multiple indicators for financial crime within a panel framework offers new and valuable insights for public policy, particularly when it comes to strengthening institutional capacity and promoting sustainable economic development.

The central question addressed by this research is: *to what extent does financial crime undermine economic freedom, and how does the sectoral structure of the economy shape this effect?* The findings are relevant to both researchers and policymakers, highlighting the need for differentiated strategies to combat corruption and informality, tailored to the specific structural characteristics of each economy.

MATERIALS AND METHODS

Dataset Description and Panel Structure

The analysis draws on an unbalanced panel dataset covering 46 countries over the period 2015–2024, with a theoretical maximum of 460 country-year observations. The sample includes both developed and developing economies: 34 OECD and high-income economies (Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hong Kong, Hungary, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Singapore, Slovakia, South Korea, Spain, Sweden, Switzerland, United Kingdom, and the United States of America) and 12 emerging and transition economies (Brazil, Bulgaria, China, Colombia, India, Moldova, Morocco, Russia, South Africa, Taiwan, Turkey, and Ukraine). This mix of countries allows the results to reflect differences in institutional quality, financial development, and regulatory environments across the world.

Four separate Pooled OLS models are estimated, each featuring one financial crime indicator alongside two sectoral structure controls. The panel is slightly unbalanced: most countries have observations for all ten years (2015–2024), while missing values in specific country-year cells arise from the differential availability of individual indices. The Global Cybersecurity Index (GCI) is unavailable in 2022–2023, while Shadow Economy data are based on Medina and Schneider (2018) [20] up to 2017 and on FinCrime Platform values 2018-2024 (FinCrime Project, n.d.) [11].

Variable Description

Dependent Variable.

Economic freedom is measured by the Index of Economic Freedom (IEF), published by the Heritage Foundation. The IEF is a score from 0 to 100 built from twelve sub-indices covering rule of law, government size, regulatory efficiency, and market openness. A higher score means greater economic freedom. This index is widely used in cross-country studies as a measure of how freely markets operate (Heritage Foundation, n.d.) [14].

Independent Variables.

Financial Crime Variables. Three direct financial crime indicators and one digital governance indicator are used as main explanatory variables. Corruption levels are measured by the *Corruption Perceptions Index* (CPI), a score published annually by Transparency International on a 0–100 scale, where higher values reflect lower perceived corruption in the public sector (Transparency International, n.d.) [31]. *The Basel Anti-Money Laundering Index* (AML), produced by the Basel Institute on Governance, provides a composite risk score from 0 to 10 that measures a country's exposure to money laundering and terrorist financing risks, with higher scores indicating greater vulnerability (Basel Institute on Governance, n.d.) [4]. *The*

Shadow Economy (SE) is expressed as a share of GDP and reflects informal economic activity, including unreported work and tax evasion, based on data from Medina and Schneider (2018) [20]. It should be noted that the Medina and Schneider (2018) [20] estimates extend through 2015-2017 for most countries; observations beyond this range are not available from this source and therefore the SE variable is based on data up to 2017 from original source, while for 2018-2024 the series were completed with values from the FinCrime Platform comparison module (FinCrime Project, n.d.) [11], these later observations are treated as platform-based estimated values. A larger shadow economy generally means more incentives to avoid formal rules and is linked to financial crime.

Digital Governance Variable. The Global Cybersecurity Index (GCI), published by the International Telecommunication Union (ITU), measures how committed a country is to cybersecurity across five areas: legal measures, technical capacity, organizational structures, capacity development, and international cooperation. The GCI ranges from 0 to 1, where higher values indicate stronger cybersecurity systems (International Telecommunication Union, n.d.) [15]. In this study, cybersecurity capacity is treated as part of financial crime prevention, given the growing link between digital vulnerabilities and financial crime.

Sectoral Structure Variables. Three variables are used to capture the economic structure of each country in the extended model: agriculture value added as a share of GDP (Agr), industry value added as a share of GDP (Ind), and services value added as a share of GDP (Serv), all from the World Bank (World Bank, n.d.) [33]. These variables serve two purposes: they describe the structural environment in which financial crime takes place, and they account for the different institutional pressures found in agrarian, industrial, and service-based economies. Countries with large agricultural sectors tend to have more informality and weaker fiscal capacity. Industrial economies face more complex regulatory environments in manufacturing and trade finance. Service-based economies, especially those with large financial sectors, face more sophisticated financial crime but also tend to have stronger supervisory systems.

Research Hypotheses

H1: *Higher CPI scores (lower perceived corruption) are positively associated with economic freedom across countries.*

H2: *Higher money-laundering risk (higher AML Index) is negatively associated with economic freedom.*

H3: *A larger shadow economy (share of GDP) is negatively associated with economic freedom.*

H4: *Higher Global Cybersecurity Index scores are positively associated with economic freedom.*

Econometric Framework

This study employs a Pooled Ordinary Least Squares (POLS) estimator within a panel data framework. Given the potential for heteroskedasticity across country panels, confirmed by the Breusch-Pagan diagnostic tests reported in Table 4, all regressions use HC1 heteroskedasticity-robust (White-corrected) standard errors. The decision to estimate four separate single-indicator models, rather than a combined specification including all financial crime variables simultaneously, is motivated by the high inter-correlation among the financial crime indicators (notably r = -0.831 between Ln(CPI) and Ln(SE)), which would generate severe multicollinearity and make individual coefficient estimates unreliable.

All continuous variables are expressed in natural logarithms (log-log specification), which allows the estimated coefficients to be interpreted directly as elasticities: a 1% change in an independent variable is associated with a β% change in economic freedom, ceteris paribus. The sole exception is the Basel AML Index, which is entered in levels because its bounded 0-10 scale and near-normal distribution do not warrant logarithmic transformation. The resulting coefficient is interpreted as a semi-elasticity: a one-unit increase in the AML score is associated with a β × 100% change in IEF.

Because sectoral shares (agriculture, industry, and services) sum to 100% of GDP, including all three simultaneously would induce perfect multicollinearity. Accordingly, the services share is excluded from all regressions and serves as the reference category. Coefficients on Ln(Agr) and Ln(Ind) therefore capture structural differences in economic freedom relative to service-dominant economies.

The four estimated models are specified as follows:

Model 1 (Corruption):

$$Ln(IEF_{it}) = \beta_0 + \beta_1 \cdot Ln(CPI_{it}) + \beta_2 \cdot Ln(Agr_{it}) + \beta_3 \cdot Ln(Ind_{it}) + \varepsilon_{it} \quad (1)$$

Model 2 (Shadow Economy):

$$Ln(IEF_{it}) = \beta_0 + \beta_1 \cdot Ln(SE_{it}) + \beta_2 \cdot Ln(Agr_{it}) + \beta_3 \cdot Ln(Ind_{it}) + \varepsilon_{it} \quad (2)$$

Model 3 (Money Laundering):

$$Ln(IEF_{it}) = \beta_0 + \beta_1 \cdot AML_{it} + \beta_2 \cdot Ln(Agr_{it}) + \beta_3 \cdot Ln(Ind_{it}) + \varepsilon_{it} \quad (3)$$

Model 4 (Cybersecurity):

$$Ln(IEF_{it}) = \beta_0 + \beta_1 \cdot Ln(GCI_{it}) + \beta_2 \cdot Ln(Agr_{it}) + \beta_3 \cdot Ln(Ind_{it}) + \varepsilon_{it} \quad (4)$$

where i denotes country, t denotes year, and ε_{it} is the idiosyncratic error term. In all specifications, the dependent variable is the natural logarithm of the Index of Economic Freedom. HC1 heteroskedasticity-robust standard errors are used throughout, as confirmed by the Breusch-Pagan diagnostic tests reported in Table 4. Within-country serial correlation is not explicitly corrected under the Pooled OLS specification and represents a limitation of the current design.

It is important to note that the Pooled OLS specification pools all country-year observations without controlling for unobserved time-invariant country characteristics. This implies that the estimated coefficients capture both between-country structural differences and within-country temporal variation. As a consequence, the results should be interpreted as describing cross-country associations rather than strictly causal within-country effects. Endogeneity, arising from potential reverse causality between economic freedom and financial crime indicators, cannot be fully ruled out under this specification and represents a limitation acknowledged in the Limitations section.

Correlation Analysis

Table 1 presents the Pearson correlation matrix computed on log-transformed variables (except AML, which is in levels). The strong negative correlation between Ln(IEF) and Ln(SE) (r = −0.676) and between Ln(IEF) and AML (r = −0.498) confirms the expected inverse relationship between financial crime and economic freedom. The strongest bivariate association is between Ln(IEF) and Ln(CPI) (r =0.823), consistent with corruption being the dominant institutional constraint on economic freedom.

Table 1. Pearson Correlation Matrix (log-transformed variables; AML in levels)

Variable		1	2	3	4	5	6	7
Ln(IEF)	1	1.000						
Ln(CPI)	2	0.823	1.000					
Ln(SE)	3	-0.676	-0.831	1.000				
AML	4	-0.498	-0.525	0.288	1.000			
Ln(GCI)	5	0.243	0.275	-0.262	-0.212	1.000		
Ln(Agr)	6	-0.665	-0.673	0.593	0.162	-0.184	1.000	
Ln(Ind)	7	-0.144	-0.228	0.139	0.070	-0.017	0.389	1.000

Notes: N = 340 complete observations (listwise deletion). All coefficients computed on logarithmic scale except AML. Bold values indicate |r| > 0.5.
Source: Authors' calculations.

The moderately high correlation between Ln(CPI) and Ln(SE) (r = −0.831) confirms that corruption and informality are strongly co-determined, motivating the decision to estimate separate models for each financial crime dimension rather than including all indicators simultaneously.

RESULTS AND DISCUSSIONS

Table 2 presents the Pooled OLS regression results and a side-by-side comparison of the key coefficients and fit statistics across the four models, facilitating direct comparison of the magnitude and significance of each financial crime indicator's effect on economic freedom. Standard errors are HC1 heteroskedasticity-robust (White correction) throughout, addressing the heteroskedasticity detected in the Breusch-Pagan diagnostic tests (Table 4). All models are jointly significant at the 1% level (F-statistic p < 0.001).

Table 2. Comparative Summary of Regression Results

	Model 1 CPI	**Model 2 SE**	**Model 3 AML**	**Model 4 GCI**
Dependent variable	Ln(IEF)	Ln(IEF)	Ln(IEF)	Ln(IEF)
Financial crime variable	Ln(CPI)	Ln(SE)	AML (levels)	Ln(GCI)
FC variable - coefficient	0.2920 ***	−0.1141 ***	−0.0653 ***	0.0514 **
FC variable - std. error	(0.0143)	(0.0117)	(0.0053)	(0.0199)
Ln(Agr) coefficient	−0.0271 ***	−0.0496 ***	−0.0724 ***	−0.0793 ***
Ln(Ind) coefficient	0.0455 ***	0.0363 **	0.0639 ***	0.0562 ***
R^2	0.7174	0.5746	0.6164	0.4626
Adjusted R^2	0.7154	0.5717	0.6137	0.4580
F-statistic	378.99 ***	254.88 ***	224.65 ***	97.87 ***
Observations (N)	434	435	425	352

Notes: *, **, *** denote significance at the 10%, 5%, and 1% level, respectively. Standard errors in parentheses are HC1 heteroskedasticity-robust. Services share (Ln(Serv)) is excluded as the reference category in all models. AML enters in levels; all other variables are log-transformed. The number of observations varies across models due to missing data in individual indicators.
Source: Authors' processing.

Table 3 reports the Variance Inflation Factors for each model. All VIF values are well below the conventional threshold of 10, and below 5 in all cases, confirming the absence of problematic multicollinearity across all four specifications.

The strategy of estimating separate models for each financial crime variable, rather than a combined specification, was instrumental in achieving these clean diagnostics, given the high inter-correlation between CPI and SE (r = -0.831) observed in the correlation matrix.

Table 3. Variance Inflation Factors (VIF) - Multicollinearity Diagnostics

Variable	**Model 1 (CPI)**	**Model 2 (SE)**	**Model 3 (AML)**	**Model 4 (GCI)**	**Threshold**	**Assessment**
Financial crime variable	1.799	1.558	1.036	1.038	< 10	✓ Acceptable
Ln(Agr)	1.972	1.759	1.176	1.224	< 10	✓ Acceptable
Ln(Ind)	1.152	1.163	1.145	1.184	< 10	✓ Acceptable
Max VIF in model	1.972	1.759	1.176	1.224	< 10	✓ All clear

Notes: VIF = $1/(1 - R^2_j)$, where R^2_j is the coefficient of determination from regressing predictor j on all other predictors. Values below 5 indicate no meaningful multicollinearity. Values below 2 indicate near-orthogonality.
Source: Authors' processing.

Table 4 reports the Breusch-Pagan (BP) test for heteroskedasticity. The null hypothesis of homoskedastic errors is rejected at the 1% level in all four models (BP $p < 0.001$ for Models 1–3; $p < 0.001$ for Model 4). This finding is consistent with the cross-country nature of the panel, where variance in IEF scores is structurally higher among heterogeneous developing economies than among developed ones. To address this, HC1 heteroskedasticity-robust standard errors are applied throughout, ensuring valid inference on coefficients and test statistics.

Table 4. Breusch-Pagan Heteroskedasticity Test

Model	BP Statistic	Degrees of Freedom	p-Value	Decision (α = 0.05)
Model 1: Corruption (CPI)	26.929	3	< 0.001	Reject H_0 - Heteroskedastic
Model 2: Shadow Economy (SE)	37.906	3	< 0.001	Reject H_0 - Heteroskedastic
Model 3: Money Laundering (AML)	46.998	3	< 0.001	Reject H_0 - Heteroskedastic
Model 4: Cybersecurity (GCI)	20.136	3	< 0.001	Reject H_0 - Heteroskedastic

Notes: Breusch-Pagan test: auxiliary OLS regression of squared residuals on the full set of regressors. H_0: homoskedastic errors ($\text{var}(\varepsilon_{it}) = \sigma^2$). BP statistic ~ $\chi^2(k)$, where k = number of regressors excluding the constant. Rejection of H_0 confirms the use of HC1 robust standard errors throughout.
Source: Authors' processing.

Model 1 produces the strongest fit of the four specifications ($R^2 = 0.717$, Adj. $R^2 = 0.715$), with 434 observations. The coefficient on Ln(CPI) is +0.2920 and is highly significant ($t = 20.39$, $p < 0.001$), confirming Hypothesis 1. Interpreted as an elasticity, this implies that a 1% improvement in a country's Corruption Perceptions Index score is associated with a 0.292% increase in its Index of Economic Freedom score, ceteris paribus. The magnitude of this effect, nearly three times larger than any other financial crime coefficient in the study, underscores corruption as the dominant institutional mechanism linking financial crime to economic freedom. This finding is consistent with the institutional economics literature: corruption erodes property rights, generates regulatory uncertainty, and undermines the rule-of-law foundations upon which economic freedom depends (Rose-Ackerman, 1999; North, 1990) [26, 24]. The high explanatory power of this model reflects the deep structural co-determination of perceived corruption and economic freedom across the 46-country sample.

In Model 2 ($N = 435$, $R^2 = 0.575$), the shadow economy coefficient is -0.1141 ($t = -9.75$, $p < 0.001$), confirming Hypothesis 3. A 1% increase in the share of the shadow economy as a proportion of GDP is associated with a 0.114% decline in the Index of Economic Freedom. This negative relationship operates primarily through the fiscal-integrity and regulatory-compliance channels: a larger informal sector erodes the government tax base, reducing its capacity to enforce property rights and regulatory standards; simultaneously, shadow economic activity creates competitive advantages for non-compliant firms, weakening the rule-of-law norms that underpin economic freedom (Schneider & Enste, 2000; Williams & Schneider, 2016) [29, 32]. The somewhat lower R^2 compared to Model 1 reflects the fact that shadow economy size, while strongly correlated with economic freedom, captures a distinct and partially independent institutional channel from perceived corruption.

Model 3 estimates the effect of the Basel AML Index on economic freedom, with the index entering in levels rather than logarithms ($N = 425$, $R^2 = 0.616$). The AML coefficient is -0.0653 ($t = -12.40$, $p < 0.001$), confirming Hypothesis 2. Because AML enters in levels, this coefficient is interpreted as a semi-elasticity: each one-point increase in the Basel AML risk score (on a 0 -10 scale) is associated with a 6.53% decrease in the IEF, holding sectoral composition constant.

Countries with weaker anti-money laundering frameworks face persistent institutional disadvantages in financial market integrity, investment freedom, and rule-of-law enforcement, precisely the dimensions most directly affected by the distortion of capital flows associated with money laundering activity (Ferwerda, 2009) [10]. The agriculture coefficient in this model (-0.0724) is the second largest among all models, suggesting that the AML channel is particularly pronounced in agrarian economies where land-based asset transfers are commonly used as laundering vehicles and where formal financial supervision is weakest. To contextualise the economic significance: the full range of AML risk scores in the sample (approximately 5.5 units) is associated with an estimated difference of approximately 35.9% in IEF scores, underscoring the substantial practical importance of anti-money laundering capacity.

Model 4 estimates the effect of the Global Cybersecurity Index on economic freedom (N = 352, R^2 = 0.463). The coefficient on Ln(GCI) is +0.0514 (t = 2.59, p = 0.010), confirming Hypothesis 4, though with a substantially smaller elasticity than the other financial crime variables. A 1% improvement in the GCI score is associated with a 0.051% increase in economic freedom. The smaller sample (352 observations) and lower R^2 in this model reflect the more limited temporal coverage of the GCI, available for fewer country-years than the other indicators, and the relatively recent integration of cybersecurity governance into the institutional framework supporting economic freedom. The result nonetheless confirms that digital governance capacity constitutes an emerging institutional determinant of economic freedom, operating through its impact on digital financial crime prevention and the protection of investment and business freedom in digital markets (Achim et al., 2021) [2].

The sectoral composition variables, Ln(Agr) and Ln(Ind), with services as the excluded reference, yield remarkably consistent results across all four models. The agriculture share coefficient is negative and highly significant ($p < 0.001$) in all four specifications, ranging from -0.0271 (Model 1) to -0.0793 (Model 4).

These estimates carry a clear interpretation under the log-log specification: a 1% increase in the agriculture share of GDP is associated with reductions in the IEF ranging from 0.027% to 0.079%, depending on the model specification. The agriculture effect is largest in absolute terms in Models 3 (AML: -0.0724) and 4 (GCI: -0.0793), suggesting that the institutional channels through which money laundering risk and digital vulnerability impair economic freedom are particularly severe in agrarian economies.

This is consistent with structural transformation theory (Kuznets, 1955) [17]: countries with large agricultural sectors retain institutional features, fragmented land tenure, high informality, limited administrative reach, that compound the damage caused by financial crime to economic freedom.

The industry share coefficient is positive and significant in all four models ($p \leq 0.029$), ranging from +0.036 (Model 2) to +0.064 (Model 3).

This confirms that industrial economies exhibit higher economic freedom relative to service-dominant economies, other things equal, a finding that, together with the negative agriculture effect, is consistent with the view that structural advancement along the Kuznets development sequence is associated with institutional improvements captured in the IEF.

The persistence of these sectoral effects across all four models, irrespective of which financial crime variable is included, confirms that economic structure is an independent conditioning factor rather than merely a proxy for the financial crime indicators.

Even after controlling for corruption, shadow economy size, money laundering risk, or cybersecurity capacity, the structural composition of the economy retains statistically significant explanatory power for cross-country differences in economic freedom.

Table 5 provides a summary of the empirical results in relation to each hypothesis.

Table 5. Hypothesis Testing Summary

Hypothesis	Financial Crime Variable	Expected Sign	Estimated Coefficient	Result
H1: CPI → IEF	Ln(CPI): lower corruption = higher IEF	+	+0.2920 ***	✓ Confirmed
H2: AML → IEF	AML: higher ML risk = lower IEF	–	−0.0653 ***	✓ Confirmed
H3: SE → IEF	Ln(SE): larger shadow econ. = lower IEF	–	−0.1141 ***	✓ Confirmed
H4: GCI → IEF	Ln(GCI): stronger cybersec. = higher IEF	+	+0.0514 **	✓ Confirmed
Additional findings				
Agr → IEF	Ln(Agr): higher agr. share = lower IEF	–	−0.027 to −0.079 ***	✓ Confirmed (all 4 models)
Ind → IEF	Ln(Ind): higher ind. share = higher IEF (vs Serv)	+	+0.036 to +0.064 ** to ***	✓ Confirmed (all 4 models)

Notes: **, *** denote significance at the 5% and 1% levels, respectively. 'Confirmed' indicates that the estimated sign matches the theoretical expectation and the coefficient is statistically significant at the 5% level or better.
Source: Authors' processing.

CONCLUSIONS

This research examines the extent to which financial crime undermines economic freedom and how the sectoral structure of the economy shapes this relationship. The study uses panel data for 46 countries over the period 2015-2024 and applies Pooled OLS regression with a log-log specification. Four indicators of financial crime are included: Corruption Perceptions Index, Basel Anti-Money Laundering Index, Shadow Economy, and Global Cybersecurity Index, together with sectoral composition variables for agriculture and industry (with services as the reference category).

The results confirm that financial crime has a negative impact on economic freedom. Corruption emerges as the dominant constraint, with a cross-country elasticity of 0.292: a 1% improvement in a country's CPI score is associated with a 0.292% increase in economic freedom. Shadow economy activity exerts a significant negative effect (elasticity = -0.114), operating through fiscal erosion and institutional non-compliance channels. Money laundering risk is also negatively associated with economic freedom (semi-elasticity = -0.065 per AML unit), with the full range of AML risk in the sample implying an approximate 35.9% difference in IEF scores. Cybersecurity governance contributes positively (elasticity = +0.051), confirming that digital institutional capacity is an emerging determinant of economic freedom.

The sectoral analysis reveals that agricultural dependence is the strongest structural constraint on economic freedom across all four model specifications, consistent with structural transformation theory (Kuznets, 1955) [17] and the informality literature (La Porta & Shleifer, 2014) [18]. Industrial composition, by contrast, is positively associated with economic freedom relative to the service-sector baseline, suggesting that structural advancement along the development sequence brings institutional improvements that expand market freedom.

This study makes three specific contributions to the literature. First, it is to the best of the authors' knowledge, the first study to jointly examine four distinct financial crime dimensions as separate but comparable constraints on economic freedom within a unified panel data framework covering 46 economies over a decade. Second, it introduces sectoral structure as a theoretically motivated conditioning variable, demonstrating that the institutional environment through which financial crime operates differs fundamentally across agricultural, industrial, and service-dominant economies. Third, it provides the most recent and geographically comprehensive cross-country evidence on this research question, covering the period 2015-2024 and encompassing both the COVID-19 institutional shock and the subsequent policy adjustments.

The findings present useful lessons for policymakers. Countries are unlikely to

improve economic freedom without addressing the institutional roots of financial crime, especially corruption and informality. Anti-corruption efforts, policies to reduce the shadow economy, and investment in cybersecurity should all be seen as part of a broader strategy to expand economic freedom. These reform priorities should be calibrated to the structural characteristics of the economy. For agrarian economies, where agricultural dependence amplifies the institutional damage of financial crime, reforms targeting land titling, rural fiscal administration, and anti-money laundering capacity in land-based asset markets are most directly relevant. For industrial economies, strengthening trade finance regulation and anti-bribery enforcement in procurement is the priority. For service-dominant economies with large financial sectors, cybersecurity investment and sophisticated AML supervision yield the greatest institutional returns.

This study has several limitations that should be noted. First, the Pooled OLS specification does not control for unobserved time-invariant country heterogeneity, and the results therefore reflect cross-country associations rather than strictly causal within-country effects. Reverse causality, whereby greater economic freedom itself reduces financial crime by strengthening market competition and institutional oversight, cannot be ruled out; future research employing instrumental variable or system-GMM approaches would be valuable in addressing this endogeneity concern. Second, shadow economy data from Medina and Schneider (2018) [20] extend only to 2017 for most countries, while values for 2018-2024 were taken from the FinCrime Platform (FinCrime Project, n.d.) [11], the SE results should therefore be interpreted with this data limitation in mind. Third, the sample is dominated by developed economies (34 of 46 countries), which may limit the generalisability of findings to low-income developing contexts, precisely where the financial crime, agriculture interaction is theoretically most pronounced. Fourth, the slope homogeneity assumption of Pooled OLS, that the effect of each financial crime indicator is identical across all 46 countries, is strong and untested; future research could employ panel threshold models or interaction terms to examine parameter heterogeneity. Fifth, GCI data are missing for 102 country-year observations (22% of the panel), concentrated in 2022-2023, which may introduce selection bias into Model 4 estimates. Future research could analyse sub-groups of countries by development level or dominant sector, extend the panel to more recent years as data become available, and use dynamic panel or fixed-effects specifications to strengthen the identification of causal effects.

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INTER-ANNUAL VARIABILITY OF FOOD INSECURITY – COMPARATIVE ANALYTICAL APPROACH IN AFRICA

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Abstract

Food insecurity continues to be a major challenge for sustainable development, particularly in Sub-Saharan Africa, despite the commitments established under the UN Agenda 2030 and Sustainable Development Goal 2 – Zero Hunger. This study analyses the inter-annual variability of two key indicators of food insecurity, both prevalences of undernourishment and severe food insecurity, by a comparative analysis for Democratic Republic of the Congo and Nigeria. Using FAO data available in the Our World in Data database, the research evaluates both the level and the instability of these indicators by applying descriptive statistical measures, including the mean, standard deviation, coefficient of variation, and annual absolute change. The results reveal two distinct patterns of food insecurity dynamics. In DR Congo, the indicators remain at very high levels but show relatively low variability, indicating persistent structural food insecurity. In contrast, Nigeria exhibits a more volatile trajectory, characterized by rapid increases in severe food insecurity and undernourishment during the last decade. These findings highlight the importance of analysing the variability of food insecurity indicators for designing more effective and resilient food policies.

Key words**:** *food insecurity, undernourishment, inter-annual variability, Africa, SDG 2: Zero Hunger*

INTRODUCTION

Food security remains one of the most persistent global challenges, despite the commitments made in the 2030 Agenda for Sustainable Development. Sustainable Development Goal 2 – Zero Hunger (SDG 2) aims to end hunger, ensure access to adequate food and promote sustainable agricultural systems (UN, 2015) [22]. However, recent assessments indicate uneven progress and even regression trends are observed in some regions, especially in Sub-Saharan Africa, where structural vulnerabilities continue to affect the functioning of food systems and the population's access to sufficient food resources (FAO, IFAD, UNICEF, WFP & WHO, 2023) [9].

Currently, Sub-Saharan Africa stands out as the region with the highest levels of food insecurity globally. This situation cannot be attributed to a single factor, but results from the interaction of multiple determinants, such as accelerated demographic growth, economic instability, armed conflicts, climate variability and low agricultural productivity. In many countries, these pressures are amplified by institutional weaknesses and underdeveloped

social protection mechanisms, which contribute to maintaining high levels of food vulnerability (HLPE, 2020; Maxwell & Smith, 1992; Webb et al., 2006) [12, 14, 23].

Food insecurity is assessed using indicators that capture different dimensions of the phenomenon (Burchi et al., 2011; Gustafson et al., 2016) [3, 11]. Of these, two are frequently used in the literature: the prevalence of undernutrition, which reflects the proportion of the population whose dietary energy intake is insufficient to maintain an active and healthy life, and the prevalence of severe food insecurity, estimated based on the FIES (Food Insecurity Experience Scale), which captures the direct experiences of the population related to major difficulties in accessing food (FAO, 2021) [7].

Most empirical studies focus mainly on the level of these indicators, providing an insight into the magnitude of the phenomenon at national or regional level. In this respect, it deserves to mention the contributions of Chukwu et al (2024) [4] and Shaihu (2021) [19] who analysed food security in Nigeria.

However, the temporal dimension of food insecurity, namely its dynamics and variability, has been analyzed to a lesser extent. Investigating the evolution over time, and in particular inter-annual fluctuations, allows for a more nuanced understanding of how food crises manifest themselves.

In this sense, food insecurity can follow different trajectories: in some contexts, it manifests itself in the form of high but relatively stable levels, suggesting the existence of persistent structural problems, while in other cases, pronounced variations are observed, generated by economic, climatic or security shocks, which affect the functioning of food systems (Barrett, 2010; Béné et al., 2020) [1, 2].

The analysis of inter-annual variability thus becomes relevant for assessing the degree of stability or fragility of food systems. Countries characterized by high but stable levels tend to face long-term structural constraints, while those in which indicators fluctuate significantly are usually more exposed to external shocks or rapid deterioration in food access conditions (Pinstrup-Andersen, 2009; Timmer, 2015) [16, 21].

The Democratic Republic of the Congo and Nigeria are two relevant case studies for analyzing these patterns. Both countries have significant natural resources and significant agricultural potential, and also play an important role in the regional economy. However, they face major challenges related to governance, political instability, demographic pressures and economic vulnerabilities, factors that directly influence the performance of food systems and the population's access to adequate food resources (World Bank, 2022) [25].

In the case of the Democratic Republic of the Congo, high levels of food insecurity are frequently associated with protracted conflicts, underdeveloped infrastructure and major difficulties in realizing agricultural potential. In contrast, Nigeria, although the most populous country in Africa and one of the continent’s largest economies, presents a more complex situation, characterized by the contrast between economic potential and the pressures exerted on food systems by factors such as regional instability, food price volatility and climate change (OWID, 2025; FAO, 2023; Ritchie, 2023) [15, 8, 17].

Although the existing literature frequently addresses the issue of food insecurity in these two countries, comparative studies that analyze the variability of indicators over time are relatively limited. Investigating these developments can help differentiate between the forms of food insecurity and those generated by temporary shocks.

In this context, the objective of this study is to analyze the inter-annual variability of food insecurity in the Democratic Republic of the Congo and Nigeria, using two main indicators: the prevalence of undernutrition and the prevalence of severe food insecurity. Based on data provided by FAO, the analysis tracks both the level of these indicators and their degree of instability, by using descriptive statistical indicators such as the mean, standard deviation, coefficient of variation and annual absolute variation.

By comparing the evolution of these indicators in the two countries, the study aims

to highlight distinct patterns of food insecurity and contribute to a better understanding of the structural and conjunctural components of this phenomenon in Sub-Saharan Africa. The results can also provide useful benchmarks for developing public policies adapted to the specifics of each context and for accelerating progress towards achieving SDG 2 objectives.

MATERIALS AND METHODS

Data sources

The analysis is based on statistical data from the Our World in Data platform, an international database frequently used in global development research, which integrates and harmonizes information provided by major institutions. The indicators used in the study are mainly derived from datasets developed by FAO, which allows for comparability across countries and different time periods (OWID, 2025) [15].

In order to carry out the comparative analysis, two fundamental indicators of food insecurity were selected:

- The prevalence of severe food insecurity, which expresses the proportion of the population facing major difficulties in accessing food and is estimated based on the FIES methodology;
- The prevalence of undernutrition, which reflects the share of the population whose dietary energy intake is insufficient to support an active and healthy life.

For the indicator on severe food insecurity, data for the period 2001–2022 were analyzed, while for undernutrition the available range is 2015–2022. The study focuses on two countries: the Democratic Republic of the Congo and Nigeria, characterized by high levels of food insecurity, but by distinct structural configurations of the food systems.

By using these indicators, the analysis allows capturing both the chronic dimension of food insecurity and the severe difficulties in accessing food experienced by the population.

Analysis methodology

In order to highlight not only the level of food insecurity, but also how it evolves over time, the methodological approach used integrates a set of descriptive statistical indicators, capable of capturing both the central tendency and the variability of the data.

In a first stage, for each indicator and for each country analyzed, the arithmetic mean $\bar{x}$-was determined, used to describe the average level of the phenomenon over the entire observation period. This is expressed by the relationship:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (1)$$

where:

x_i represents the indicator values for each year,

and

n represents the total number of observations.

To assess the degree of dispersion of the values around the mean, the standard deviation was calculated, an indicator that reflects the amplitude of the annual variations of the analyzed indicator. The standard deviation is determined by the formula:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (2)$$

where:

σ represents the standard deviation,

and

$\bar{x}$ represents the arithmetic mean of the analyzed values.

Next, to allow a clearer comparison between the variability of the indicators in the two countries, the coefficient of variation was calculated. This indicator expresses the ratio between the standard deviation and the mean of the indicator and provides a relative measure of the variability of the data. The coefficient of variation, *CV* [%], is determined by the relationship:

$$CV = \frac{\sigma}{\bar{x}} \times 100 \quad (3)$$

where:

σ represents the standard deviation of the dataset.

High values of the coefficient of variation indicate greater instability of the indicator over time, suggesting a volatile evolution of food insecurity, while low values reflect a

relatively stable evolution of the indicator.

To capture the annual dynamics of the analyzed indicators, the annual absolute change was also calculated, determined as the difference between the indicator values in two consecutive years:

$$\Delta x_t = x_t - x_{t-1} \quad (4)$$

where:

Δx_t represents the annual variation of the indicator,

and

x_t and x_{t-1} represents the values of the indicator in the consecutive years analyzed.

By using these statistical indicators, the analysis allows for the simultaneous assessment of the average level of food insecurity and its degree of variability over time, thus facilitating the identification of differences between the patterns of evolution of food insecurity in DR Congo and Nigeria.

Data limitations

The interpretation of the results must be done taking into account certain constraints related to data availability. The dataset used covers the period up to 2022, which means that recent developments in food insecurity are not reflected in the analysis.

Also, for the indicator on the prevalence of undernutrition in the case of the Democratic Republic of the Congo, data are only available for the period 2019–2022. The small size of this time series may influence the results of some statistical indicators, in particular the coefficient of variation, which is known for its sensitivity to the number of observations.

Consequently, the results obtained must be interpreted in relation to these limitations, without affecting the relevance of the methodological framework used.

RESULTS AND DISCUSSIONS

Evolution of severe food insecurity

The evolution of the prevalence of the severe food insecurity indicator highlights clear differences between DR Congo and Nigeria, both in terms of level and dynamics over time. For the period 2001–2022, the data show that DR Congo consistently records very high values of this indicator, maintained within a relatively narrow range of approximately 30%–37% of the population (Table 1).

Table 1. Prevalence of severe food insecurity (%)

Country / Year	DR Congo	Nigeria	Country / Year	DR Congo	Nigeria
2001	30.4	8.8	2012	30.3	10.9
2002	30.9	8.8	2013	30.6	10.8
2003	30.9	8.5	2014	30.9	10.7
2004	31.8	7.8	2015	31.5	10.5
2005	31.7	7	2016	32.1	10.7
2006	31.7	6.6	2017	32.4	11.3
2007	30.9	6.5	2018	32.3	11.8
2008	30.9	6.7	2019	33.8	13.6
2009	30.4	7.9	2020	35	15.1
2010	29.6	9.2	2021	35.7	17
2011	29.5	10.4	2022	37	18

Source: OWID, 2025 [15].

Such a pattern suggests the existence of persistent food vulnerability, characterized by structural continuity rather than significant fluctuations from one year to the next.

In contrast, Nigeria follows a different trajectory. At the beginning of the period under review, the prevalence of severe food insecurity was relatively low, around 8–9%. Subsequently, the indicator records a constant upward trend, which became more pronounced after 2010 and, especially, after 2015. By 2022, the proportion of the population affected reaches about 18%, indicating a significant deterioration in access to food.

The differences between the two countries are also highlighted in Figure 1: while the DR Congo shows high but relatively stable levels, Nigeria is characterized by a clear upward trend, marked by continuous increases in the last years of the period under review.

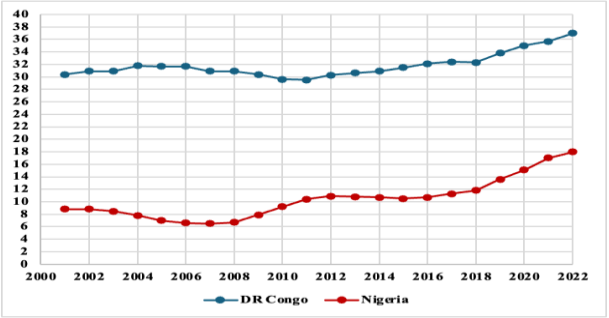

Fig. 1. Evolution of the prevalence of severe food insecurity in DR Congo and Nigeria (2001–2022)
Source: Original by authors based on data from OWID, 2025 [15].

Evolution of undernourishment

The evolution of the prevalence of undernutrition highlights, in turn, significant differences between the two countries analyzed, confirming the existence of distinct patterns of manifestation of food insecurity. This indicator reflects the proportion of the population whose dietary energy intake is not sufficient to maintain an active and healthy life.

According to the data presented in Table 2, in the case of DR Congo, the values of the indicator remain at very high levels, constantly exceeding the threshold of 38% and reaching over 41% in 2022. Its dynamics are relatively slow, with moderate increases from one year to the next, which indicates the persistence of deep structural dysfunctions of the food system and the economy, which limit the population's access to adequate food resources.

Table 2. Prevalence of undernourishment (%)

Country / Year	DR Congo	Nigeria	Country / Year	DR Congo	Nigeria
2015	-	11	2019	38.5	17.3
2016	-	12.3	2020	39.2	19.8
2017	-	13.6	2021	40.3	21.3
2018	-	15.1	2022	41.7	22.6

Source: OWID, 2025 [15].

In contrast, Nigeria presents a much more accelerated evolution of undernutrition. In 2015, the prevalence of this phenomenon was approximately 11%, but in the following years a rapid increase is observed, with the indicator value exceeding 22% in 2022.

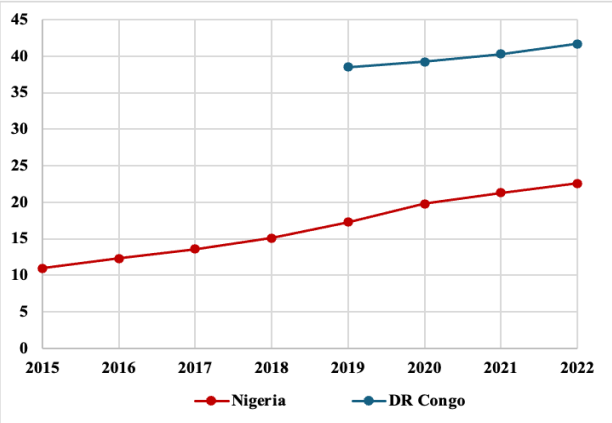

Fig. 2. Evolution of the prevalence of undernutrition in DR Congo and Nigeria (2015–2022)
Source: Original by authors based on data from OWID, 2025 [15].

This evolution suggests a relatively rapid deterioration in food security conditions, possibly associated with factors such as economic instability, rising food prices or regional tensions.

The differences between the two trajectories are also illustrated in Figure 2: DR Congo is characterized by very high but relatively stable levels of undernutrition, while Nigeria highlights a sharp increase in the indicator in the recent period.

Inter-annual variability of food insecurity indicators

In order to assess not only the level of food insecurity, but also its degree of instability, descriptive statistical indicators were calculated, namely the mean, standard deviation and coefficient of variation. The results obtained highlight significant differences between DR Congo and Nigeria in terms of the variability of the indicators analyzed.

In the case of DR Congo, the coefficient of variation for the severe food insecurity indicator is approximately 5.7%, which indicates a low variability over time. Similarly, for the prevalence of undernutrition, the coefficient of variation is approximately 3.6%, suggesting a relatively stable evolution of the phenomenon.

These results reflect the structural and persistent nature of food insecurity in DR Congo. The high levels of the indicators are maintained over long periods, without major fluctuations, which suggests the existence of deep constraints, such as political instability, insufficiently developed agricultural infrastructure and the limited capacity of the economy to ensure the population's access to food (Table 3).

In contrast, Nigeria records considerably higher values of the coefficient of variation. For the severe food insecurity indicator, the coefficient exceeds 33%, and for undernutrition it is around 26%.

These values indicate a volatile dynamics, characterized by significant fluctuations and accelerated increases in the indicators in the last years of the analyzed period (Figure 3).

Table 3. Descriptive statistics and variability of food insecurity indicators

Indicator	Country	Period	Mean	Standard deviation	Coefficient of variation (%)
Severe food insecurity	DR Congo	2001–2022	31.85	1.83	5.74
	Nigeria	2001–2022	10.21	3.45	33.82
Undernourishment	DR Congo	2019–2022	39.93	1.42	3.56
	Nigeria	2015–2022	16.63	4.31	25.91

Source: Own results.

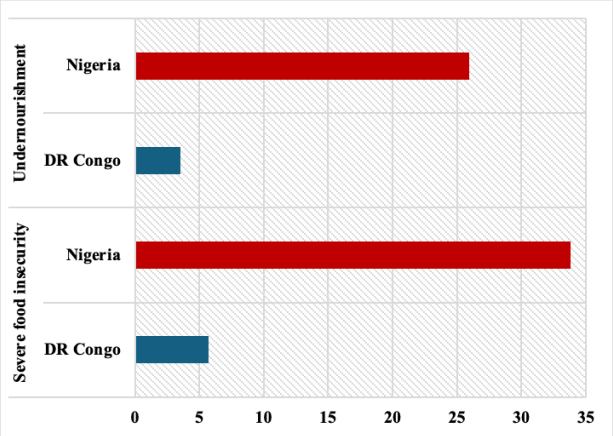

Fig. 3. Inter-annual variability of malnutrition and severe food insecurity (%)
Source: Original by authors based on data from OWID, 2025 [15].

The coefficient of variation represents a relative measure of the dispersion of the data, expressing the ratio between the standard deviation and the mean of a statistical series and allowing the comparison of the variability between different data sets (Stepniak, 2025) [20]. In general, values below 15% indicate low variability, while values exceeding 30% suggest high instability of the analyzed phenomenon.

Therefore, the differences between the two countries are evident: while DR Congo is characterized by persistent food insecurity, with limited variations over time, Nigeria presents a much more unstable evolution, suggesting greater exposure to economic, social or climatic shocks.

The results obtained indicate the existence of distinct trajectories of food insecurity in DR Congo and Nigeria, the differences being not limited only to the level of indicators, but also extending to the way in which they evolve over time. The analysis of inter-annual variability highlights the fact that food vulnerability does not have the same nature in the two contexts. Thus, in DR Congo, relatively constant high values are observed, while in Nigeria the dynamics are more accentuated, with rapid deteriorations in access to food in a relatively short time frame.

This differentiation suggests that food insecurity should be interpreted not only in terms of the level, but also in terms of the stability of food systems. The literature shows that, in vulnerable economies, the persistence of food crises is often correlated with structural factors, such as political instability, underdeveloped agricultural infrastructure, or the limited capacity of institutions to support the functioning of food markets (Barrett, 2010; HLPE, 2020; Willett, 2019) [1, 12, 24]. In this context, the situation in the DR Congo can be associated with a structural form of food insecurity, in which access to food is limited by persistent institutional and economic constraints.

For a clearer interpretation, the results can be analyzed through a conceptual distinction between structural and shock-driven food insecurity. The former is characterized by high levels maintained over the long term, reflecting systemic limitations in the agricultural sector and economic infrastructure. The second category is defined by significant variations over time, generated by disruptive factors of an economic, social or climatic nature, that affect the population's access to food resources (Barrett, 2010; FAO, 2021) [1, 7].

From this perspective, DR Congo illustrates a persistent pattern, while Nigeria falls more into a volatile pattern, characterized by higher exposure to external shocks and economic and climatic instability. Recent developments in indicators in Nigeria, marked by rapid increases in severe food insecurity and undernutrition, suggest an increased sensitivity of the food system to disruptions. Such developments are frequently encountered in economies where mechanisms for adaptation and shock absorption are insufficiently developed (FAO, 2021) [7].

These findings have direct implications for

public policies. In the context of structural food insecurity, such as that identified in DR Congo, interventions need to be geared towards long-term transformations of the food system. These include investments in rural infrastructure, facilitating farmers' access to agricultural inputs and technologies, developing markets and strengthening institutions responsible for agricultural sector governance. Such measures are essential to reduce structural vulnerabilities and improve people's access to food.

In contrast, in situations characterized by high volatility, such as Nigeria, the focus of policies needs to be on increasing the resilience of food systems. Effective measures can include expanding social protection systems, stabilizing food markets and supporting agricultural producers in the face of climate and economic risks. The development of early monitoring and rapid intervention mechanisms can also help limit the negative effects of shocks on food security.

The results also support the need for an integrated approach, based on the concept of the food system. Previous research shows that food security does not depend exclusively on the level of agricultural production, but on the interaction between production, distribution, access and consumption (Ingram, 2011; Fanzo, 2017) [13, 5]. In this sense, food policies must aim not only to increase production, but also to strengthen the sustainability and resilience of food systems as a whole.

In the current context, marked by climate change, economic volatility and demographic pressures, the development of sustainable food systems becomes a major priority. The integration of economic, social and environmental dimensions in agricultural policies is essential to achieve the goals of the 2030 Agenda and to increase the adaptive capacity of food systems to future crises (FAO et al., 2023; Sachs et al., 2023) [8, 18].

Therefore, the analysis of inter-annual variability provides a relevant perspective on how food systems respond to both structural constraints and external shocks. While DR Congo faces a persistent food crisis, Nigeria is witnessing a more rapid and unstable deterioration in food security, driven by the interaction of economic factors, social and climatic.

CONCLUSIONS

The results of this study highlight the existence of significant differences in the dynamics of food insecurity between DR Congo and Nigeria. Although both countries face high levels of food insecurity, the analysis of inter-annual variability shows that the nature and evolution of this phenomenon are different. DR Congo presents extremely high levels of the analyzed indicators, but with relatively low variability over time, which indicates the existence of chronic and structural food insecurity. In contrast, Nigeria is characterized by a rapid increase and significant variability of food insecurity indicators, suggesting a greater vulnerability to economic, social or climatic shocks, an aspect frequently highlighted in the literature on the dynamics of food insecurity in vulnerable economies (Barrett, 2010; FAO, 2021) [1, 7].

This difference is particularly relevant for understanding how food insecurity evolves in different economic and institutional contexts. The analysis of the variability of indicators shows that food insecurity should not be interpreted only in terms of its absolute level, but also in terms of its dynamics and stability over time. In this sense, the study results suggest the existence of two distinct patterns: a structural food insecurity, characterized by high and persistent levels, and a volatile food insecurity, in which the deterioration of food access conditions occurs in a relatively short period of time, a phenomenon often associated with economic instability, conflicts or climate shocks as mentioned by HLPE, (2020) [12].

From a policy perspective, this distinction has important implications. In the case of structural food crises, such as the one observed in DR Congo, interventions must be primarily oriented towards long-term reforms of agricultural and food systems. These may include investments in rural infrastructure,

improving farmers' access to agricultural inputs, strengthening local markets, and developing institutional systems capable of supporting food production and distribution.

At the same time, strengthening institutional capacity and improving governance mechanisms are essential conditions for reducing structural vulnerabilities that affect the food security of the population.

In situations characterized by an unstable evolution of food insecurity, such as that observed in Nigeria, public policies must be oriented as a priority towards increasing resilience and effectively managing shocks. In this regard, measures such as expanding social protection systems, introducing food price stabilization mechanisms and supporting farmers in the face of risks generated by climate variability and economic uncertainties can be considered. Also, integrating early monitoring tools for food crises can help prevent rapid deterioration in food security conditions, an aspect highlighted in numerous analyses of global food security (FAO et al., 2023; Godfray, 2010) [8, 10].

The results of the study have direct relevance to the goals set out in the UN 2030 Agenda for Sustainable Development, in particular SDG 2 – Zero Hunger, which aims to end hunger and ensure universal access to adequate food. However, global progress towards this goal remains uneven, and many countries in Sub-Saharan Africa continue to face major challenges in terms of food and nutrition security. In this context, the analysis of the variability of food insecurity indicators can contribute to a deeper understanding of how these challenges evolve over time and to the identification of policy responses better adapted to the specific context of each country.

Also, the study results emphasize the essential role of developing sustainable food systems, capable of ensuring not only the availability of food, but also the population's equitable access to safe and nutritious food. The transition towards such systems involves correlating the economic, social and environmental dimensions of food production and consumption, as well as supporting resilient and sustainable agricultural practices, considered fundamental for the transformation of food systems at a global level, as also highlighted in the literature of FAO (2020, 2021) and HLPE (2020) [6, 7, 12].

At the same time, the study also presents some limitations related to the availability of statistical data. The dataset used in the analysis covers the period up to 2022, which means that recent developments in food insecurity are not yet reflected in the presented results. In addition, in the case of the indicator on the prevalence of undernutrition for DR Congo, the available data only cover the period 2019–2022, which limits the possibility of conducting a longer-term analysis of this indicator. However, these limitations reflect the current availability of data at the international level and do not affect the relevance of the methodology used.

Looking ahead, future research could expand the analysis by including more recent data series and by analyzing a larger number of countries in Sub-Saharan Africa. Such an approach would allow the identification of regional patterns of food insecurity variability and contribute to a better understanding of the relationship between economic, climatic and institutional factors and the evolution of food security.

Therefore, achieving SDG 2 depends not only on increasing food production, but also on the capacity of food systems to ensure stability, resilience and equitable access to food resources. Analyzing the variability of food insecurity indicators provides useful insight into these dynamics and can contribute to the development of more effective public policies to reduce hunger and malnutrition globally.

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THE USE OF EDIBLE MUSHROOMS AS NON-WOOD FOREST PRODUCTS IN ROMANIA AND SERBIA – CURRENT TRENDS AND FUTURE PERSPECTIVE

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Abstract

Non-wood forest products (NWFPs), particularly edible wild mushrooms, represent important ecological and socio-economic resources in Romania and Serbia. In this context, the paper aimed to comparatively study the current tendencies and future perspective of the use of edible mushrooms as NWFPs products in these two countries. The information and data are sourced from relevant scientific literature, relevant legislation, reports and studies for both countries in the last 15 years and processed using the following research methods: general systems theory, analysis and synthesis, as well as normative and comparative approaches. Both countries possess rich fungal diversity shaped by contrasting forest compositions, ownership structures, and regulatory frameworks. Romania benefits from clearer legislation, established local markets, and significant harvesting of Boletus, Cantharellus and Armillaria species, although regional disparities and climatic fluctuations affect yields. Serbia shows comparable ecological potential but relies heavily on exports of porcini and chanterelles, with domestic value-chain development and processing capacities remaining limited. Complex administrative procedures, insufficient monitoring of fungal populations, and inadequate collector training challenge sustainable management in both contexts. Comparative analysis highlighted the need for adaptive governance, improved data collection, and investment in processing infrastructure. Strengthening education, market integration, and sustainable harvesting practices could enhance rural livelihoods while supporting the long-term ecological resilience of forest ecosystems and advancing the European forest-based bioeconomy.

Key words**:** *non-wood forest products, mushrooms, Serbia, Romania, rural development*

INTRODUCTION

Non-wood forest products (NWFPs) play a critical role in sustainable forest management, biodiversity conservation, and rural economies [2, 4, 7, 13]. Among NWFPs, edible wild mushrooms are particularly significant due to their ecological importance, economic value, and cultural relevance across Europe. Romania and Serbia, with extensive forest cover [27, 28, 37] and high fungal diversity, provide illustrative examples of NWFPs exploitation, yet differ in ecological, regulatory, and socio-economic contexts.

Romania's forest ecosystems, encompassing mountains, hills, and lowlands, host over 120 commercially relevant mushroom species. Key genera include *Boletus*, *Cantharellus* and *Armillaria*, with productivity strongly influenced by forest composition, altitude, and microclimatic conditions. Romanian legislation [35] formalizes NWFPs collection, requiring authorization from forest administrators, while enforcement is managed by the National Forest Guard.

Serbia exhibits similar ecological potential, with thousands of macromycete species documented; however, only a subset attains commercial relevance.

Regulatory frameworks are permit-based, with strict oversight by forestry and nature protection authorities. Despite high biodiversity, overharvesting and seasonal fluctuations highlight the need for sustainable management strategies [32]. Compared to Romania, Serbia's value chains are less developed, with limited local processing and market integration. Export of fresh or semi-processed mushrooms, mainly *Boletus spp.* and *Cantharellus spp.*, represents the main

economic outlet, while domestic consumption and commercialization remain fragmented.
In this context, the present research aimed to comparatively study the current tendencies and future perspective of the use of edible mushrooms as NWFPs in these two countries.

MATERIALS AND METHODS

Research is based on primary data analysis by collecting and processing scientific literature, relevant legislation, reports and studies. The primary scientific methods employed included general systems theory, analysis and synthesis, as well as normative and comparative approaches. The method of analysis and synthesis was applied to examine NWFPs related legislation and draw conclusions based on the collection, processing, and review of literature concerning the mentioned in both countries.
For the purpose of comparative analysis of NWFPs trends in Serbia and Romania, the following criteria were considered: most commonly commercially used mushroom species in both countries, data on the production, purchase, marketing and export of mushrooms, as well as the potential for their management by region, as well as NWFPs-related legislation and regulations. Similarities and differences in forest management in Serbia and Romania were defined, as well as the potential in the future for use of mushrooms as NWFPs. For the comparative analysis, relevant domestic and foreign literature (from Romania and Serbia) sources from the last 15 years were considered.

RESULTS AND DISCUSSIONS

The legal framework regarding the non-wood products in Romania and Serbia

According to the Forestry Code of Romania, Article 99: "*the specific products of the National Forest Fund (NFF) are wood, wood-based products assimilated to wood, and non-wood products*" [35]. Among other ones, truffles and other edible mushrooms from the spontaneous flora within it are the non-wood products specific to the National Forest Fund (NFF) and non-wood products "*are harvested with the consent of the administrator in the case of publicly owned NFF, or with the consent of the owner in other cases, under the conditions established by order of the head of the Authority*" (Article 100 of the same law). Control of the legality of harvesting non-wood products from the National Forest Fund (NFF) is organized and carried out by the Authority through specialized state control through its own personnel with control duties, as well as through personnel with control duties within the National Forest Guard and within the Forest Guards (Article 132 of the same law).
The National Forest Administration manages mushroom exploitation in a sustainable and transparent manner, while contributing to the responsible use of forest resources, with the main species being *Boletus edulis*, *Boletus aureus*, *Cantharellus cibarius*, *Armillaria mellea*, truffles, etc. The National Forestry Administration transfers "*the right to harvest edible mushrooms from the forest fund, depending on the availability of resources and the optimal harvesting period. The recovery process is carried out in accordance with the resource evaluation studies developed annually and respects the principle of sustainable use, with all provisions of the legislation in force being applicable. The allocation of harvesting rights is done through online public auctions, organized according to a calendar established according to the season as well as through direct negotiation*" [30].
The institutions in Serbia responsible for issuing permits for collecting NWFPs are the Ministry of Agriculture, Forestry and Water Management, the Ministry of Environmental Protection, the Serbian Institute for Nature Conservation, the Institute for Lowland Forestry in Novi Sad, and national parks [19]. Relevant institutions which issue the quotas of contingents of wild flora and fauna take into account only the needs of the manufacturers (collectors) and also the documents used in the establishment of enterprises, documents and licenses for the import of raw materials and placement on domestic and foreign markets are too numerous, thus often being a burden in entrepreneurial business [17]. The

laws and regulations that deal with the matter of NWFPs in Serbia are: Law on Forests („The Official Gazette RS“, no. 30-2010, 93/2022, 89/2015 i 95/2018 – other law) [38]; Law on Nature Protection (“Official Gazette of the RS”, N36/2009-76, 88/2010-162, 91/2010-133 (correction), 14/2016-8, 95/2018-267 (other law), 71/2021-3) [39], Regulation on the Proclamation and Protection of Strictly Protected and Protected Species of Plants, Animals and Fungi ("Official Gazette of the RS", 5/2010-46, 47/2011-134, 32/2016-59, 98/2016-97) [40]; Law on Environmental Protection of the Republic of Serbia ("Official Gazette of the RS", 135/2004-29, 36/2009-144, 36/2009-115 (other law), 72/2009-164 (other law), 43/2011-88 (US), 14/2016-3, 76/2018-3, 95/2018-267 (other law), 94/2024-391 (other law) [41]; Regulation on Controlling the Use and Trade of Wild Flora and Fauna ("Official Gazette of the RS", 31/2005-3, 45/2005-110 (correction), 22/2007-26, 38/2008-7, 9/2010-10, 69/2011-9) [42], which controls the collection, use, and trade of wild species of plants, animals, and fungi in the state and private owned forests and determines the amount of the fee; Law on National Parks ("Official Gazette of the RS", 84/2015-15, 95/2018-267 (other law) [43]. In Serbia’s national Forest Law is stated that “*the collection of other forest products may be carried out with the approval of the user, i.e. the forest owner, and in accordance with the project for the use of other forest products*” (Article 62 of Serbia’s Forest Law) [38].

Both Serbia and Romania have a strong legislation regarding the management of NWFPs, although Romania’s management with mushrooms in practice shows greater importance of sustainability, given the up-to-date Forestry Code from the year 2024 and Serbia having numerous documents on the matter, instead of an integrated document that would be less of a burden to entrepreneurs and collectors [35, 17]. It is an open possibility for improving in the future.

Non-wood forest products status

In 2023 forestry products, services and revenues data in Romania, precisely on truffles and other edible mushrooms from spontaneous flora show production of 145.1 tons (398,000 EUR) and in 2024 - 107.7 tons (463,650 EUR) [29].

There is a long tradition of collecting edible mushrooms from the spontaneous flora in Romania, but concrete data regarding the impact of mushrooms collecting on forest ecosystems is lacking [47].

Distribution of NWFPs in Romania is not uniform, due to the different distribution of forests – counties such as Suceava, Caraș-Severin, Hunedoara, Covasna and Neamț have a higher potential for harvesting and marketing of NWFPs, especially in the hilly regions, in favorable conditions of humidity and warmth, as opposed to counties dominated by plains, where mushrooms were the lowest ranked species due to its limited distribution [3, 7, 11, 47]. Even though diversity of the NFWPs in Romania is very high, the decreasing harvested quantities may be determined by the climatic factors, and this trend could be a sign of a lack of interest in these products and a very low degree of marketing [6].

Of the over 250 species of edible higher fungi identified in the spontaneous flora of Romania, only a small part of them are the subject of harvesting and valorization, the highest interest being in truffle species, especially for the white truffle found mainly in forests dominated by oak species, common hazel, hornbeam, linden species, spruce, beech, black pine, poplar species or willow species, and because of the 70% of Romania’s forests being composed of beech, spruce and oaks [25, 28], it is expected to face in the near future grow of harvesting and valorization sector [11].

Based on the FAO Global Forest Resources Assessment from 2025 [14] (Table 1), Serbia showed greater quantity in NWFPs removals and values - 2,714 tons of mushrooms in value of 11,537.21 thousand Euros and Romania 131 tons (value of 606.54 thousand euros). It is to be noted that the Romanian data from this assessment were from 2022 [14].

Results from the Table 1 show greater quantity of NWFPs removals and value in Serbia than in Romania for 2025, which can

be due to Romania's data being from 2022, due to the greater exploitation of *Boletus spp.* in Serbia. There is noticed the absence of an uniform national platform for tracing and evaluating NWFPs in Serbia, while in Romania there are shown the expectations of growth of harvesting and valorization in this sector in the near future, due to global climate changes [14, 11].

Table 1. Non-wood forest products removals and value 2020

	NWFP product	Key species	Quantity (tonnes)	Value (1000 EUR)	NWFP category
Romania	Mushrooms	*Boletus edulis, Armillaria melea, Catharellus cibarius*	131.00	606.54	1 Food
Serbia		*Boletus spp.*	2,714.00	11,537.21	1 Food

Source: FAO [14].

Edible mushrooms - Harvest area, species, marketed quantity, sale price and revenue

The largest amounts of edible mushrooms that are harvested from the Forestry Departments managed by National Forest Administration [30] belong to the following species: *Boletus spp.*, *Cantharellus cibarius* Fr. (chanterelle) and *Armillaria mellea* (Vahl) P. Kumm. (honey fungus), which is harvested mainly in Maramureș, Suceava, Bacău, Mureș and Neamț counties, respectively. The largest amounts of harvested chanterelle and *Boletus* spp. are located in Suceava and Maramureș counties, and in much smaller quantities are also harvested: *Tuber aestivum* Chatin (summer truffle), *Choiromyces meandriformis* Vittad. (Transylvanian Big White Truffle), *Morchella* sp. (True morels), *Amanita caesarea* (Scop.) Pers. (Caesar's mushroom), *Russula alutacea* (Fr.) Fr, *Russula vesca* Fr. (bare-toothed Russula), *Russula virescens* (Schaeff.) Fr. (green-cracking russula), *Russula cyanoxantha* (Schaeff.) Fr. (charcoal burner), *Pleurotus ostreatus* (Jacq. Ex Fr.) P. Kumm (oyster mushroom), *Lactarius deliciosus* (L. ex Fr.) S.F. Gray (saffron milk cap), *Agaricus silvaticus* Schaeff. (Scaly Wood Mushroom), *Ramaria* sp. Fr. ex Bonord. and *Marasmius oreades* (Bolton) Fr (Scotch bonnet) [47].

In 2018, the average value of the annual harvested quantity of edible mushrooms was 560 tons, the highest quantities being for the species: [*Armillaria mellea* (Vahl) P.Kumm], penny bun (*Boletus edulis* Bull.) and chanterelle (*Cantharellus cibarius* Fr.) [6].

There are 5,000 species of macromycetes in Serbia and the Balkans, of which 2,000 have been registered, but research conducted in Serbia in the period 2010-2015 showed that a small number of species (the nine most common) are commercially available on the market in this country: *Agaricus augustus* Fr., *Boletus edulis* Bull., *Cantharellus cibarius* Fr., *Craterellus cornucopioides* (L.) Pers., *Lactarius deliciosus* (L. ex Fr.) S.F. Gray, *Marasmius oreades* (Bolton) Fr., *Russula xerampelina* (Scaeff. ex Secr.) Fr., *Tuber aestivum* Vittad., *Tuber magnatum* Pico [19].

In contemporary times, people are increasingly turning to organic food, and mushrooms originating from the forest, are gaining importance in this regard, as a renewable food source that should be treated responsibly and their habitats should be preserved. And it is important to take to consideration that the quantity and the market of mushroom species varies depending on the environmental conditions – during wet years, large quantities of mushrooms appear, which affects the purchase price to be low, while during dry years, smaller quantities are harvested, which affects the prices to be significantly higher [20].

Serbia is characterized by three climate types and precipitation in the recent decades – flash flooding resulting from extreme precipitation events has proven to be a great threat to human life and a great cause of economic strife [15]. A wide range of biotic and abiotic factors influence fruit body productivity in mushrooms: meteorological variables, local site characteristics, forest stand structure and silvicultural operations, but on the global scale, the main ecological factor affecting fungal distribution are precipitation and temperature [46].

In Prahova County (Romania), it is shown a great potential for NWFPs especially due to its great diversity in terms of forest composition and land forms, and in the terms of mushroom species [*Armillaria mellea* (Vahl) P. Kumm.] and *Boletus* sp. were considered, but the potential could be better emphasized if an adequate infrastructure and

more collection facilities would be established and if favorable normative framework would exist [8, 10]. Bihor County has also great potential in terms of collecting NWFPs. In 2017, Bihor Forestry Department harvested 10.20 tons of *Boletus* sp. and it is renowned for the harvested quantities of truffles even though official statistics do not exist [44]. On the other hand, mushrooms were ranked as products of low interest in Tulcea County, in terms of the quantities that can be harvested and valorized [5]. In Iași County, the most important NWFPs after honey and the common pheasant, were the representatives of genus *Boletus* [1]. In Vâlcea County, the main types of NWFPs that were harvested and/or bought by the local people consisted, in the mean of edible mushrooms – especially penny bun (*Boletus edulis* Bull.) and oyster fungus [*Pleurotus ostreatus* (Jacq.) P.Kumm.] [12]. The diversity of the non-timber forest products in Bertea locality is high and the prices of these products are low, with the main way of harvesting being by family members (most common product being edible mushrooms); with the marketing being almost none considering almost all quantity is used for family purposes, without selling them [10]. Also, the most promising non-wood forest products in Timiș County were the representatives of genus *Boletus* sp. [9]. The selected NWFPs in the mushrooms category for Dolj County were the parasol mushroom [*Macrolepiota procera* (Scop.) Singer] and the milk-caps (*Lactarius* sp.) but did not show great potential for this County – the parasol mushroom being a little bit preferable than the milk-caps, mainly due to its distribution range and market potential [3].

The purchase of chanterelles in the Belgrade region (Serbia) in the period from 2003 to 2014 was characterized by a decreasing trend throughout the entire period, and the purchase quantities ranged between 38-156 tons. The share of mushrooms in the purchase of raw materials in Southern and Eastern Serbia in the period 2003 to 2014 was in third place (after forest fruits and medicinal herbs), with 2,392 tons. The placement of mushrooms on the domestic market in Southern and Eastern Serbia in the period 2003 to 2014 dominates compared to other NWFPs and amounts to 4,329 tons, with a focus on chanterelles and porcini mushrooms. Mushroom purchases in the period 2005-2013 in Šumadija and Western Serbia amounted to 12,400 tons, with a focus on chanterelles and porcini mushrooms, while the placement of these raw materials on the domestic market maintained a decreasing trend during the observed period. The largest share in the quantity of NWFPs exported from the Šumadija and Western Serbia regions belongs to mushrooms (13,367 tons) in the period 2005-2013, namely: fresh, dried, frozen and brined porcini mushrooms, as well as fresh chanterelles. In the observed period in Vojvodina region (2005-2013), there was no recorded placement, distribution on the domestic market, or export of mushrooms, but rather other dominant NWFPs [19, 20]. In Southeastern Serbia, the most represented product in the assortment of the NWFPs companies (besides wild blueberry – 23.1%) was boletus with 19.2%. in business operations [23]. Porcini mushrooms had the biggest share in the purchased quantities of NWFPs in the Kolubara District in the period between 2004 and 2014 and had the largest share in the product placement on the domestic market with 59% [21]. The most important products that companies place on the foreign market from Southern Serbia, when it comes to mushrooms, are *Boletus* sp (Photo 1). Gross revenue of purchased NWFPs for the period 2004-2011: purchased quantity of *Boletus edulis* was 398,100 kg (with the price of 2,40 EUR per kg and gross income of 955,440 EUR) and *Cantharellus cibarius* purchased quantity was 268,500 kg (with the price of 6,30 per kg and gross income of 1,691,550 EUR); gross revenue from placed NWFPs in domestic market for the period 2004-2011: processed chanterelle in the placed quantity of 243,500 kg (with the price of 7,25 EUR per kg and gross income of 1,765,375 EUR) and processed boletus in the placed quantity of 372,400 kg (with the price of 5,4 EUR per kg and gross income of 2,010,960 EUR) [19, 20].

Photo 1. *Boletus aureus*, Fruška gora National Park, Serbia
Source: SE "Fruška gora" website [36].

Romania shows more spatially and species differentiated mushroom production pattern, with counties like Suceava and Maramureș dominating high-yield species, while Tulcea showed low potential; this highlights strong regional contrast. In contrast, Serbia's data indicate a more market-oriented system, with Šumadija, Southern and Eastern Serbia emphasizing trade, export and fluctuating purchase trends rather than localized production dominance. It is to be acknowledged that time frames of the given data does not overlap: for Romania it is more recent (2017-2025) and the majority of Serbia's literature sources on the matter of mushroom production and trade cover years 2003-2014, meaning that there is a demand for analysis of the current trends in this country, in order to focus on the future demands.

NWFPs harvesting versus biodiversity protection

Harvesting should be made so as not to disturb the regenerative capacity and biodiversity especially in the case of endangered species or in fragile ecosystems, in order to assure a low impact on environment. In some areas, mushrooms are traditionally consumed by the local population and therefore their harvest in large quantities may have negative impacts on the lives and habits of the populations concerned, so the environmental impact will be minimal if the organization of the harvest is well done. Considering the consequences resulting from the excessive use of natural resources, the need for their sustainable management and use is very important to both Romania and Serbia. Inadequate collection of NWFPs can have negative consequences for biodiversity conservation through land degradation, which can lead to degradation of forest ecosystems [32, 47]. Also, since a large number of forest owners who have their forests included in several categories of protected areas, hence they have restrictions in terms of wood harvesting, they could find the commercialization of NWFPs as a sustainable solution, which would mean that the forest owners and forest managers will have benefits and the conservation of the forest ecosystems will be guaranteed [7]. Showing where an owner can achieve a competitive advantage with individual assets may foster SMEs, as well as regional livelihoods. It is evident that "*the policy framework affects the potential of NWFPs, and it can be postulated that there is a need to take advantage of the multiplicity of the NWFPs sector, both from a regional resource as well as a stakeholder perspective, and argue for bottom-up governance approaches that respect regional/local conditions but support European policy objectives*" [16].

NWFPs delivery on the domestic and foreign markets

NWFPs in Serbia are marketed mainly as unprocessed raw materials or semi-finished product and most of them do not have their own retails nor do they perform selling through small retail stores or supermarkets in the country.

In terms of export, the most common destination for mushrooms export are Italy and Germany. Although 30 companies in Serbia export mushrooms, the top 10 account for more than 80% of the total export volume, Italy being the largest importer of fresh and semi-processed mushrooms; however, most Serbian exports are sold to bulk importers who further process and often re-export them. Wild mushrooms are generally dried using two types of processes and they represent the highest-value product on the market, the majority being *Boletus sp.* and *Cantharellus* sp. (Photo 2) [18].

For products with a higher degree of processing, marketing is mainly carried out through intermediaries, pharmacies, etc.; it is mostly chosen by companies that do not have the ability or resources to independently carry out distribution [23].

Foreign markets of NWFPs have specific requirements in relation to quantity and quality, which NWFP SMEs from Central Serbia can hardly meet, and in addition, there is competition from other EU countries (Romania, Bulgaria, Poland, etc.), which, because of their EU membership, have easier access to the major markets for NWFPs [33].

Photo 2. *Cantharellus tubiformis*, Mountain Goč, Serbia
Source: Mushroom Society "Šumadija" website [26].

Serbian companies primarily target EU markets, facilitated by the Stabilization and Association Agreement and related trade arrangements that allow Serbian goods to enter the EU while requiring gradual alignment with EU customs and regulatory standards. EU regulations (TFEU Articles 23–30) [45] establish the free movement of goods, removal of customs duties, and rules governing import restrictions. Export procedures for Serbian products require documentation issued by the Customs Administration, the Serbian Chamber of Commerce, and relevant agricultural authorities, with certificates playing a key role in ensuring product quality and safety. Export shipments must also be accompanied by trade, transport, insurance, and customs documents, and undergo customs declaration, inspection, classification, and clearance procedures. For NWFPs, including mushrooms, export documentation requirements are largely the same, with ISO and HACCP standards commonly applied to guarantee product quality [22]. Opposed to Romania, Serbia has to align a lot of its customs and standards to the EU ones, in order to achieve greater options in exporting countries.

Most NWFP SMEs in Serbia have 11-50 employees and operate with mushroom, having a van without refrigerator, weighing and drying machines, machines for processing and cold stores. Working conditions are defined by dependence on weather and inadequate legal framework, stating that financial resources should be invested in fixed assets, as well as the education and formal training of the staff and managers, considering most of them are males, 26-45 years old, with secondary school [34].

Although demand for NWFPs is rising, their market potential remains underexploited. Companies in Central Serbia operate below capacity, with an average utilization rate of only 51%, except for mushroom processors, which use approximately 90% of their processing capacities for species such as *Boletus edulis, Cantharellus cibarius, Agaricus spp., and Pleurotus ostreatus*. Most products are sold domestically, and only 6 of the 15 companies analyzed export semi-products or final products. Exports are dominated by fresh and processed mushrooms, while semi-finished and final products from other NTFP categories constitute a minor share. Exports of final porcini products remain stable, whereas exports of fresh porcini and chanterelles fluctuate. Despite recent growth in fresh mushroom exports, companies remain insufficiently export oriented. The need for favorable financing is evident, particularly for replacing outdated equipment [31]. Serbia has a potential for developing SMEs that can sell the final product, which would contribute to it being competition to countries in the region.

Sustainable management of NWFPs

Serbia's rich wild plant resources can be sustainably utilized only with proper conservation measures, yet limited data on species status and harvesting levels hinder

effective protection planning. Sustainable NWFP management requires regular assessment of population distribution and size to set and revise collection quotas. Inadequate training and the use of improper harvesting tools negatively affect biodiversity, emphasizing the need for education programs, practical manuals, and formal training for collectors. Strengthening control mechanisms across the collection, processing, and export chain aligned with EU standards is essential, as is expanding ex-situ conservation and improving public awareness. Evaluating national biodiversity legislation against EU frameworks is also recommended to prevent further biodiversity loss [32].

Both Serbia and Romania show how important the economy of wild mushroom business is for rural development, especially the case of Romania demonstrates the importance on household welfare where the state often fails to support economically poor segments of the rural society [46].

CONCLUSIONS

This comparative analysis of Romania and Serbia demonstrates that edible wild mushrooms, as key NWFPs, hold substantial ecological, economic, and social importance across both countries, yet their full potential remains largely untapped.

While Romania benefits from extensive fungal diversity, clearer regulatory frameworks, and stronger local market integration, Serbia's NWFP sector is characterized by higher export orientation but weaker domestic value-chain development and lower processing capacity. In both contexts, sustainable management is challenged by insufficient monitoring of fungal populations, climate-driven productivity fluctuations, and regulatory burdens that limit participation of small-scale collectors.

Forest composition greatly influences mushroom productivity, with both countries dominated by beech forests but varying markedly in the distribution of Norway spruce and oak species, which are differences that shape regional harvesting potential. Romania's counties exhibit highly uneven NWFPs availability, with mountain and hilly regions offering the greatest yields of *Boletus, Cantharellus, Armillaria,* and truffle species. Serbia's market shows a strong reliance on porcini and chanterelles, with most exports reaching EU bulk processors. Nevertheless, Serbian SMEs operate under capacity, face financing constraints, and struggle to meet strict quality and quantity standards required by foreign markets.

Across both systems, sustainable harvesting remains a central concern. Limited data on species status, inadequate collector training, and the use of improper tools pose risks to forest biodiversity, while the absence of coordinated monitoring hinders the establishment of adaptive collection quotas.

Strengthening governance through improved regulations, enforcement, ex-situ conservation, and alignment with EU standards is essential for safeguarding forest ecosystems while enabling market growth.

Comparative analysis reveals converging challenges: ecological variability due to climate and forest structure, insufficient monitoring of mushroom populations, and complex administrative procedures limiting small-scale collector participation. However, Romania benefits from more established local markets and clearer legal frameworks, whereas Serbia shows higher export orientation but lower domestic value-chain development. Addressing these issues through adaptive management, collector training, and enhanced processing infrastructure could improve both ecological sustainability and socio-economic outcomes in the region.

Ultimately, expanding processing infrastructure, improving training and certification systems, and supporting local enterprise development could significantly enhance the socio-economic benefits of NWFPs, particularly for rural communities. By integrating ecological safeguards with value-chain modernization, Romania and Serbia can better unlock the potential of wild mushrooms as renewable, climate-resilient resources that contribute to sustainable rural development and a broader European forest-based bioeconomy.

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ORGANIC WINE PRODUCERS BETWEEN PERCEPTIONS, MOTIVATIONS AND CHALLENGES: AN EXPLORATORY ANALYSIS

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Abstract

The aim of this study is to explore the perceptions, motivations and obstacles of these producers, providing an updated perspective on the transition process towards sustainable viticulture. The research is exploratory in nature and is based on an online questionnaire applied to a sample of 51 producers from the main wine-growing regions of Romania. Descriptive analysis of the responses highlights that the main motivation for adopting organic practices is environmental protection (82.4%), followed by access to funds and increased demand for sustainable products. The major barriers identified are the poorly structured internal market (60.8%), bureaucracy (33.3%) and certification costs (29.4%). The results show a sector in a process of consolidation, dominated by small farms and ethically motivated producers, but limited by economic constraints.

Key words**:** *organic viticulture, sustainability, producers' perception, certification, institutional barriers*

INTRODUCTION

The wine industry is undergoing a profound structural transformation, driven by economic, social and climate change, as well as increasing pressure for sustainability. The global organic wine market is booming, reflecting the growing consumer interest in authentic and environmentally friendly products. In this context, organic wine producers in Romania face several specific challenges: high certification costs, excessive bureaucracy, limited institutional support and an underdeveloped domestic market.

The wine industry is currently undergoing a period of profound social transformation, driven by economic, technological and environmental factors. Despite its long tradition, the wine sector faces major challenges: stagnant consumption in some key markets, regulatory pressures, climate change and increasing consumer demands. The global organic wine market, estimated at over USD 11 billion in 2024, is booming and reflects consumer orientation towards products considered sustainable, eco or organic [1, 4, 5, 6]. Wine producers are increasingly required to adopt sustainable winemaking practices, reduce pesticide use and obtain organic certifications. In parallel, they must respond to the need for transparency in terms of traceability and ethical communication [1], [16]. At European level, the agro-ecological transition and the expansion of organic certification are considered strategic priorities, but the degree of adoption varies depending on the economic and institutional context [11], [12], [17]. Thus, organic viticulture is not just a technical choice, but a strategic decision influenced by economic and cultural factors.

A key aspect is consumer perception. Recent research shows that the term organic wine can stimulate preference and willingness to pay, especially among young consumers, who show increased sensitivity to organic certifications [3], [7], [13]. Therefore, the success of organic wine depends not only on sustainable production practices, but also on the effective communication of the ethical and environmental values associated with it [8], [9], [13].

Climate change is increasing the pressures on European viticulture. Changes in temperature and rainfall patterns are causing the expansion of wine-growing areas to the north of the continent and forcing producers to adapt strategies to maintain competitiveness and wine quality. In this context, the transition to organic viticulture represents a strategy for

long-term adaptation and resilience [2], [14], [15].

Compared to other European countries, Romania is at an early stage of integrating sustainability principles into the wine sector. Major challenges relate to the certification process, distribution, consumer education and institutional support. Although the specialized literature has frequently addressed consumer behaviour, research on producers' motivations and perceptions is limited, which outlines an important scientific gap.

The aim of this study is to explore the perceptions, motivations and challenges of organic wine producers in Romania, in the context of the transition to sustainable winemaking practices. Based on an online questionnaire, the research aims to identify the determinants of the adoption of organic viticulture, the main barriers and market dynamics perceptions and sustainability requirements. The study has a fully exploratory character and proposes to contribute to the gaps in the specialized literature, providing data for the development of sustainable policies and practices in the field of organic wine.

MATERIALS AND METHODS

The present study is exploratory in nature and employs a quantitative methodology based on a structured questionnaire aimed at identifying the perceptions, motivations, and barriers of organic wine producers in Romania.

The research instrument was developed using the Google Forms platform and distributed through non-probability sampling techniques, namely convenience sampling and snowball sampling. The questionnaire was disseminated within thematic social media groups and via direct messages to producers identified in the public databases of certification bodies.

Data collection took place over a 24-hour period, resulting in 51 valid responses from the main Romanian wine-growing regions (Moldova, Dobrogea, and Muntenia). The sample includes both certified producers and producers in transition or interested in conversion, most of them operating small-scale vineyards, which reflects the predominantly fragmented structure of the sector.

Although the sample size is limited and cannot be considered statistically representative, it provides a relevant insight into a niche segment characterized by a small number of certified operators. The methodology entails certain limitations, such as self-selection bias, which is specific to online surveys and may favor respondents with a higher level of digital literacy. Additionally, the short data collection period captures a "snapshot" of perceptions, meaning that the results are interpreted in an exploratory context and are not intended to be generalized to the entire industry.

The data were analyzed using descriptive methods and thematic analysis for open-ended questions. The interpretation of the results was conducted through comparative analysis, relating the findings to recent studies on motivations for adopting sustainable practices, barriers to organic certification, and stakeholder perceptions within the wine sector.

RESULTS AND DISCUSSIONS

Based on the data collected through the questionnaire applied to organic wine producers in Romania, the analysis highlights the main trends regarding the structure, motivations and challenges of the national organic wine sector. The purpose of this section is to outline or synthetic image on the current stadium of organic viticulture and on its sustainable development directions.

Participant profile

To begin with, the distribution of respondents provides an image on the level of involvement in organic viticulture. Figure 1 presents the structure of participants according to their status in the organic system.

As can be seen in Figure 1, the majority of respondents (56.9%) are certified organic wine producers, 29.4% come from the conventional segment interested in conversion, and 13.7% are in transition to the organic system. This structure indicates a sector in a consolidation phase, in which experienced producers coexist with those at the beginning of the conversion process. More than half of the participants (52.9%) own small

plantations, under 5 hectares, which reflects the fragmented and predominantly family-based nature of Romanian agriculture. This structural characteristic is also reflected in the literature, where fragmented wine production systems require greater coordination and integration to enhance efficiency and market access [5].

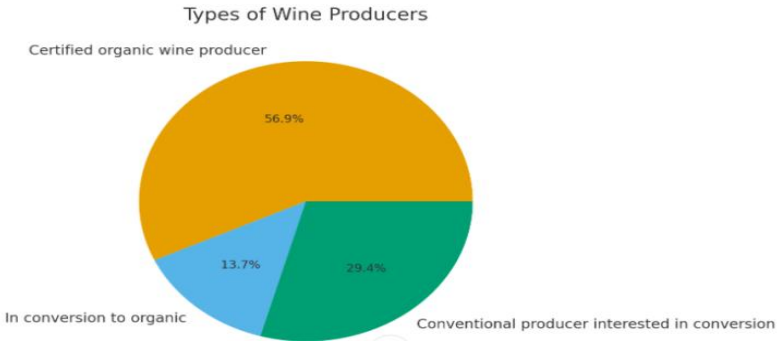

Fig. 1. Type of main activity declared by the respondent
Source: Own data, 2025.

The small size of the holdings constitutes both financial limitations and opportunities for flexibility and adaptation to niche market requirements. Approximately one fifth of producers have been practicing organic viticulture since before 2015, while 19.6% have initiated the conversion after 2020, confirming the dynamic nature of the sector. This trend is consistent with recent studies highlighting the ongoing transformation and adaptation of the wine sector under sustainability and market pressures [2].

Motivations for adopting organic viticulture

After outlining the general profile, the analysis continues with the identification of factors that determine the adoption of sustainable practices. Figure 2 summarizes the main motivations of organic wine producers. According to the data presented in Figure 2, environmental and soil protection is the main motivation for adopting organic viticulture (82.4%), followed by access to funds and subsidies (31.4%) and the ever-increasing demand for sustainable products (23.5%). Similar motivations related to sustainability and environmental responsibility are also identified as key drivers in consumer and producer behavior in the wine sector [15].

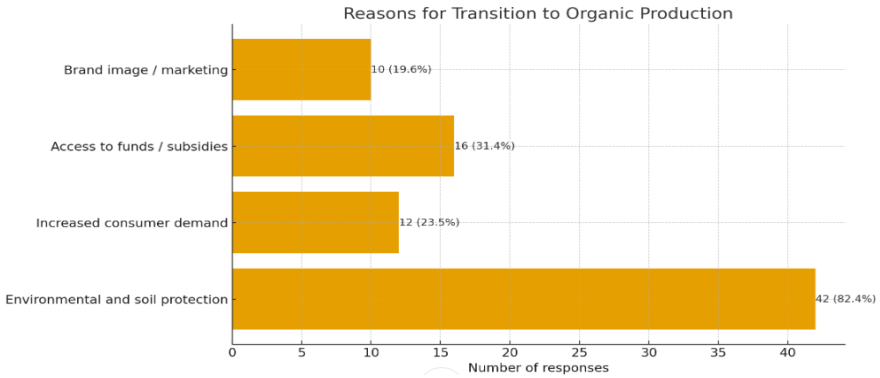

Fig. 2. Main reasons for adopting organic viticulture
Source: Own data, 2025.

This hierarchy confirms the predominantly ethical orientation and an increase in environmental awareness among producers. At the same time, only 19.6% indicated brand image as the main motivation, which shows that sustainable marketing is still underdeveloped in Romania. In contrast, other studies emphasize the increasing importance

of communication and consumer perception in enhancing the market value of sustainable wines [16].Although ethical motivations dominate, many responses about the success of the organic transition also depend on the existence of a financial support mechanism and coherent public policies. This perception directly correlates with the barriers and obstacles analyzed in the next section.

Obstacles and barriers to the development of the sector

Although interest in organic farming is growing, producers face a number of economic and institutional constraints. Figure 3 illustrates the main obstacles identified by participants.

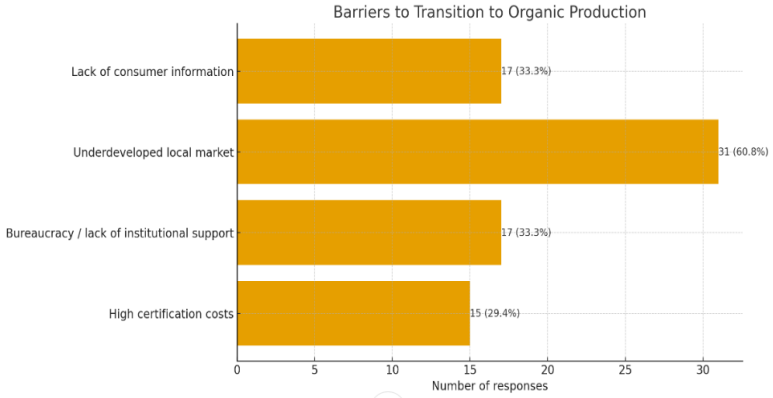

Fig. 3. Perceived obstacles to the production and marketing of organic wine
Source: Own data, 2025

As Figure 3 highlights, the most important barrier perceived by producers is the underdeveloped internal market (60.8%), followed by excessive bureaucracy and lack of institutional support (33.3%) and high certification costs (29.4%). These structural difficulties particularly affect small producers and limit access to competitive markets.Similar structural and regulatory constraints affecting competitiveness in the wine sector are also discussed in the context of legal and institutional frameworks [12].

Correlating Figure 2 and Figure 3, a contrast is observed between the strong ecological convictions of producers and the structural obstacles that hinder the effective application of these principles. This imbalance between sustainability goals and practical constraints is also reflected in studies addressing the complexity of implementing sustainable practices in the wine industry [4]. In addition, the lack of consumer information is perceived as a significant obstacle (33.3%), confirming the interdependence between market education and the economic performance of the sector.

Perception of certification, quality and market

Organic certification is perceived as an essential element of product credibility (average score 3.53/5), although some producers find it a difficult issue due to bureaucracy and costs. In contrast, the organoleptic quality of wine is assessed as the most important factor for success (score 4.65/5), which indicates a maturation of perceptions and an increasingly accentuated orientation towards sensory excellence. This confirms previous research showing that sensory quality remains a fundamental determinant of wine competitiveness and consumer preference [7].

The selling price is considered a moderately important factor (3.86/5), suggesting a mixed strategy between price competition and differentiation through ecological value and authenticity. This balance between price and perceived value is also discussed in relation to consumer willingness to pay for sustainable wines [15]. Labeling and marketing (3.88/5) are recognized as useful tools, but insufficiently exploited, while consumer education is assessed modestly (331/5). This

gap highlights the need for coherent information and communication campaigns on the benefits of certification and sustainable production.The importance of consumer information and awareness is also emphasized in studies addressing the role of knowledge in shaping wine consumption behavior [16].

Market trends and development intentions

Regarding market developments, almost 40% of respondents believe that demand for organic wine is increasing, while 35% perceive it as stable. However, only a third intend to expand in terms of surface area in the coming years, which reflects moderate optimism, tempered by economic and institutional uncertainty.Similar patterns of development in emerging wine regions are highlighted in the literature, where growth is influenced by local market conditions, tourism dynamics and structural characteristics of the sector [3]. Distribution channels are diversified but still limited. Specialized stores (33.3%) and wine tourism (29.4%) host the main marketing methods, followed by online commerce (23.5%). The growing role of wine tourism and alternative distribution channels is also highlighted in recent studies on wine market diversification[1][3].Exports and local sales have low shares, which indicates the high dependence on the domestic market and the need for a more active internationalization strategy [10].

Support measures and development prospects

In the context of these challenges, the participants in the study proposed a series of measures considered priority for strengthening the sector. Figure 4 summarizes the main directions of action.

According to the data in Figure 4, producers and essential increase in subsidies and financial support (47.1%), investments in research and innovation (45.1%), as well as simplification of the certification process for the promotion of organic wines (≈33%).

In contrast, public-private partnerships and the introduction of a unitary organic label are perceived as secondary priorities, although they can contribute to strengthening brand images. The importance of innovation, sustainability strategies and coordinated development policies is also emphasized in studies on improving competitiveness in the wine sector [4] [2].

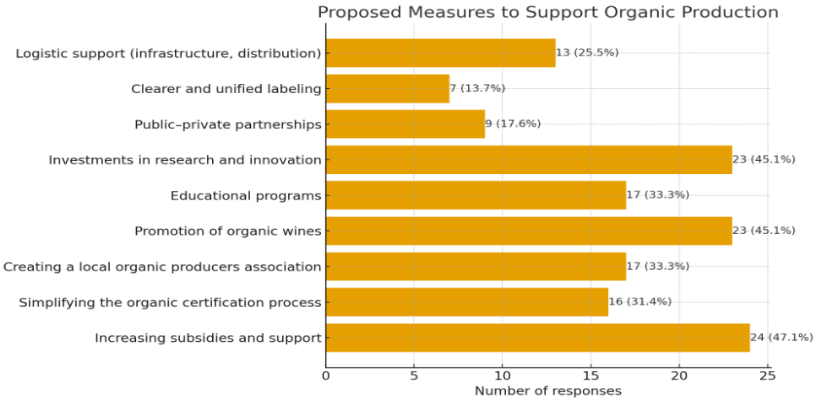

Fig. 4. The main measures that could support the development of organic wine in Romania
Source: Own data, 2025.

Correlating Figure 3 and Figure 4, a coherent vision of producers is observed: the same areas that generate obstacles (bureaucracy, lack of support, poor information) are those for which immediate intervention is requested. Overall, the study reveals an organic wine industry in a process of consolidation, with an active core of producers motivated by ecological values and a desire for professionalization.

The small size of the holdings and limited access to resources remain major challenges, but the positive perception of quality, moderate demand growth and openness to modern distribution channels outline favorable premises for sustainable development.

The results obtained confirm the significant potential of organic vineyards in Romania and provide a solid empirical basis for the formulation of coherent public policies, capable of ensuring the economic, ecological and social sustainability of the sector.

CONCLUSIONS

The study highlights the fact that Romanian organic viticulture is in a consolidation process, marked by a fragile balance between market opportunities and structural difficulties encountered by producers. The results of the questionnaire show that the majority of respondents demonstrate a clear orientation towards sustainable practices, motivated mainly by the desire to protect the environment and a product with superior added value.

However, economic and administrative barriers (high certification costs, lack of financial support and the complexity of bureaucratic procedures) continue to limit the expansion of organically cultivated areas. In parallel, insufficient consumer education and the low visibility of organic products on the domestic market are factors that reduce the growth potential and competitiveness of this segment.

A significant part of producers for public support programs and local partnerships can play a decisive role in stimulating conversion and strengthening trust in the organic label. At the same time, digital marketing and online sales are perceived as key tools for diversifying distribution channels and reaching a wider market, especially among young consumers sensitive to sustainability criteria.

In the medium and long term, the complete transition to a sustainable winemaking model requires not only technological adaptation, but also a change in mentality along the entire value chain, from producers and distributors to consumers and institutions. In this regard, the development of a coherent national strategy on organic farming, complemented by educational and fiscal measures, could accelerate the process of aligning with European trends on the sustainability and resilience of the agri-food sector.

The results obtained demonstrate the existence of significant potential for the expansion of organic viticulture in Romania, together with institutional support, strengthening consumer confidence and promoting a culture of sustainability. This direction is not only an economic opportunity, but a strategic necessity in the context of climate change and the new global demands of the wine market.

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DESIGNING FUTURE-PROOF DIGITAL DECISION SUPPORT SYSTEMS FOR AGRIBUSINESS THROUGH SCENARIO PLANNING

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Abstract

Within the German research project Digital Agricultural Knowledge and Information System (DAKIS), Fraunhofer ISI applied a scenario-based approach to explore how future developments in agriculture may shape farmers' needs for management support tools. Four contrasting future scenarios for agri-business of the future were developed in collaboration with project partners and core stakeholders. These scenarios provided structured future contexts in which the specification of key digital decision support system's (DSS) functions could be derived from a stakeholder perspective. A joint visioning process complemented the scenarios and enabled the identification of different development pathways, research questions, and concrete requirements for the design of DAKIS®. Overall, this contribution demonstrates how future scenarios can serve as a "future-proofing" instrument to identify both scenario-specific and cross-cutting requirements for digital management tools. The approach highlights how DSS development can be aligned with diverse possible agricultural futures, increasing resilience, flexibility, and relevance for farmers and other stakeholders

Key words**:** *Decision Support System, Scenarios, Foresight, Multi-stakeholder Co-creation, Ecosystem Services*

INTRODUCTION

Digital decision support systems (DSS) are increasingly recognized as critical infrastructures for sustainable agriculture because they translate heterogeneous data streams, ranging from in-field sensors and remote sensing to market and policy signals, into actionable, site-specific recommendations [1, 9]. Crucially, future-ready DSS must go beyond commodity optimization and explicitly integrate biodiversity and ecosystem services (ESS) as first-class management objectives so that farm profitability aligns with climate and nature goals [14]. The Germany's Digital Agricultural Knowledge and Information System (DAKIS) exemplifies this shift. In Phase I (2019–2024), the consortium built and tested a modular prototype in two contrasting pilot regions in Germany (Bavaria and Brandenburg) and paired it with foresight to anticipate users' needs under divergent futures. Phase II (from 2025) scales the approach, strengthens advisory and policy interfaces, and extends functionality for landscape-level planning and ESS valorization with a special focus on biodiversity.

Why scenario planning? Agriculture faces deep uncertainties, e.g. climate extremes, volatile markets, evolving regulations, and shifting societal preferences, that limit single-point forecasting [2, 3, 10, 13]. Foresight methods (horizon scanning, multi-stakeholder co-creation of scenarios, and visioning) help 'future-proof' innovation by stress-testing concepts against contrasting but plausible contexts and by identifying robust, cross-cutting requirements. In DAKIS Phase I, four contrasting scenarios for German agriculture were co-developed with stakeholders; these provided structured contexts to derive specification impulses for DSS functions and to frame a joint vision and development pathways.

A complementary strand concerns valorization, that creates practical mechanisms and incentives, beyond mere valuation, that reward the provision of biodiversity and ESS along the agri-food value chain (e.g., voluntary markets, certification, CSR, and tradable permits).

Embedding such options into DSS design ensures that recommendations can transition from 'good practice' to 'bankable practice' for farmers and chain actors.

Building on this rationale, this article (i) details the scenario-based methodology used to elaborate user requirements for DAKIS®, (ii) synthesizes results from stakeholder-driven wind-tunneling of DSS functions with a special focus on biodiversity and ESS valorization, and (iii) outlines implications for a resilient, flexible, and user-relevant DSS ecosystem in German agriculture.

MATERIALS AND METHODS

The optimal provision and promotion of ESS is the focus of the DAKIS project and should be made possible by a new digital decision support system as well as small-scale land management within multifunctional and diversified agriculture. The project adopts a future-oriented vision in which ESS and biodiversity are established as concrete management goals, which can be monitored and managed using digital tools.

DAKIS® is a modular, data-rich decision support system that integrates sensor and model outputs (drones, satellites, in-field sensors, weather and market data) to generate site-specific and landscape-level recommendations aimed at simultaneously improving yields, biodiversity, and ESS (e.g., pollination, water retention, soil protection). Phase I delivered a functioning prototype; Phase II expands automation, advisory integration, and regional scalability [5].

The foundation of all DAKIS activities was a jointly developed vision established before the project began and developed further in the course of the project. Our vision is that novel agricultural management systems will enable an enhanced systems understanding of the complex interactions within the agroecosystem, resulting in spatially as well as functionally diversified cropping systems that are able to harmonise conflicting land use objectives. These could be automated, small-scale cropping systems that are landscape-specific to the needs of society, integrating the provision of ESS and biodiversity conservation from the planning process through production to marketing [11].

To align tool development with this future vision, the DAKIS® proposes an adaptable framework structure to manage complex data connections where the range of included datasets and land management options can easily be extended based on end-user targets, related information needs and data availability [8].

Within this framework we adopted a scenario-based approach based on following steps: (1) framing and horizon scanning across biophysical, technological, market, policy, and societal drivers; (2) co-creation of four contrasting 2035+ scenarios for German agriculture with core stakeholders and project partners; (3) implications analysis to derive DSS design requirements.

Scenarios combined qualitative narratives with indicative quantitative levers (e.g., degree of agri-environmental stringency, carbon price signals, data-sharing openness, advisory system capacity, and climate stress). Iterative workshops and expert interviews refined logics and plausibility. These scenarios were used for 'wind-tunneling' exercises, in which farmers discussed what DSS functions would be needed. By the stress-testing across scenarios the implications for robust or scenario-specific features were identyfied.

User requirement iteration in the second funding phase: Phase II operationalizes continuous feedback loops with farm advisors, farmers, consortium partners, and value-chain actors. Methods include moderated usability sessions on the prototype, value-chain mapping for ESS and biodiversity. Particular attention is given to management needs at the farm and landscape levels, with a focus on biodiversity and ESS valorization. These scenarios were used for 'wind-tunneling' exercises, in which farmers discussed what DSS functions would be needed. By the stress-testing across scenarios the implications for robust or scenario-specific features were identyfied. These scenarios were used for 'wind-tunneling' exercises, in which farmers discussed what DSS functions would be needed. By the

stress-testing across scenarios the implications for robust or scenario-specific features were identyfied.

Valorization evidence base: To ground design options for ESS and biodiversity valorization beyond public agri-environmental schemes, we drew on a peer-reviewed synthesis identifying four clusters of private valorization instruments (voluntary services, labelling /certification, CSR/environmental management, and tradable permits/quotas) and their legal and systems dynamics, including their suitability under different futures [12].

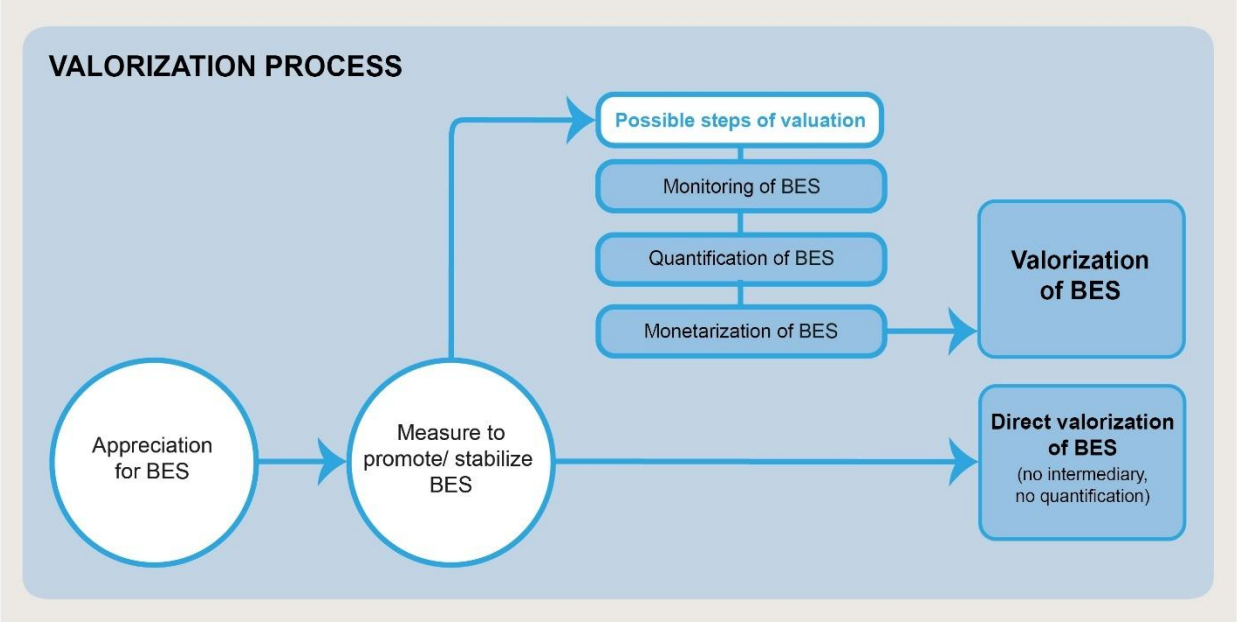

Fig. 1. Delineation of the terms valuation and valorization
Source: [12].

RESULTS AND DISCUSSIONS

Why vision and scenarios belong together?

A vision is intended to provide a team with guidance and motivation in their everyday work while strengthening cohesion. It clearly and inspiringly describes a desirable future for all group members. Depending on the focus, this may encompass internal organizational aspects such as “how we collaborate” or “what defines us”, as well as externally-oriented goals like “what do we want to achieve”. A compelling vision provides shared purpose by articulating an inspiring, desirable future; scenarios complement this by analytically mapping the external contexts in which that future must hold. Together they combine meaning with robustness: the vision aligns people and anchors core principles, while scenarios “wind-tunnel” ideas against contrasting policy, market, technological, and climate conditions to reveal what remains viable when assumptions shift. This pairing turns aspiration into adaptive strategy helping teams prioritize with realism, surface trade-offs early, and sequence actions into roadmaps that can flex as conditions change. It also strengthens engagement: visioning mobilizes imagination and commitment across stakeholders, whereas scenarios supply evidence and options that build confidence in decisions. In short, a vision provides the north star; scenarios chart multiple routes toward it and flag decision points along the way, so organizations can stay true to intent while staying agile in practice [6].

In our vision, DAKIS® is conceived as an IT-enabled, participatorily developed platform where users’ interests are brought together and negotiated transparently. User-friendly, understandable, and transparent interfaces connect primary data capture (remote sensing, in-field sensors, and models) with decision support and information transparency, thereby

intelligently linking supply and demand for both agricultural commodities and ESS. Resource flows and the state of ESS/biodiversity become visible in real time, consolidated on a neutrally governed data backbone (e.g., by an independent public body), and curated into comprehensive, quality-assured knowledge [7]. The platform creates the conditions for verified remuneration of ESS.

The vision also promotes a shared system understanding and cooperative goal achievement: ESS provision is site- and region-specific, data-based, and remunerated via public policy instruments and markets for both commodities and non-commodities; cooperation among farms is explicitly rewarded, and the resource-efficient provision of ESS is strengthened through sensor- and data-supported management.

In line with transparency, societal impact, and the SDGs, DAKIS® acts as a platform for balancing interests among producers, consumers, and nature conservation to foster recognition, mediation between perspectives, and open information. The approach is scalable beyond regions, incorporates external systems and imports in the overall assessment, and contributes to global, intergenerational equity.

The vision further renews urban–rural relationships: agricultural landscapes become attractive places to live and work, enabled by new mobility, communication, and service infrastructures. This encourages greater understanding of rural areas, civic engagement (e.g., forms akin to community-supported agriculture), and regional material cycles.

Finally, the vision addresses production systems and farm structures: arable farming and livestock are better integrated, the tension between labor productivity and socio-ecological goals is reduced, and fine-grained, site-adapted management becomes economically feasible [11].

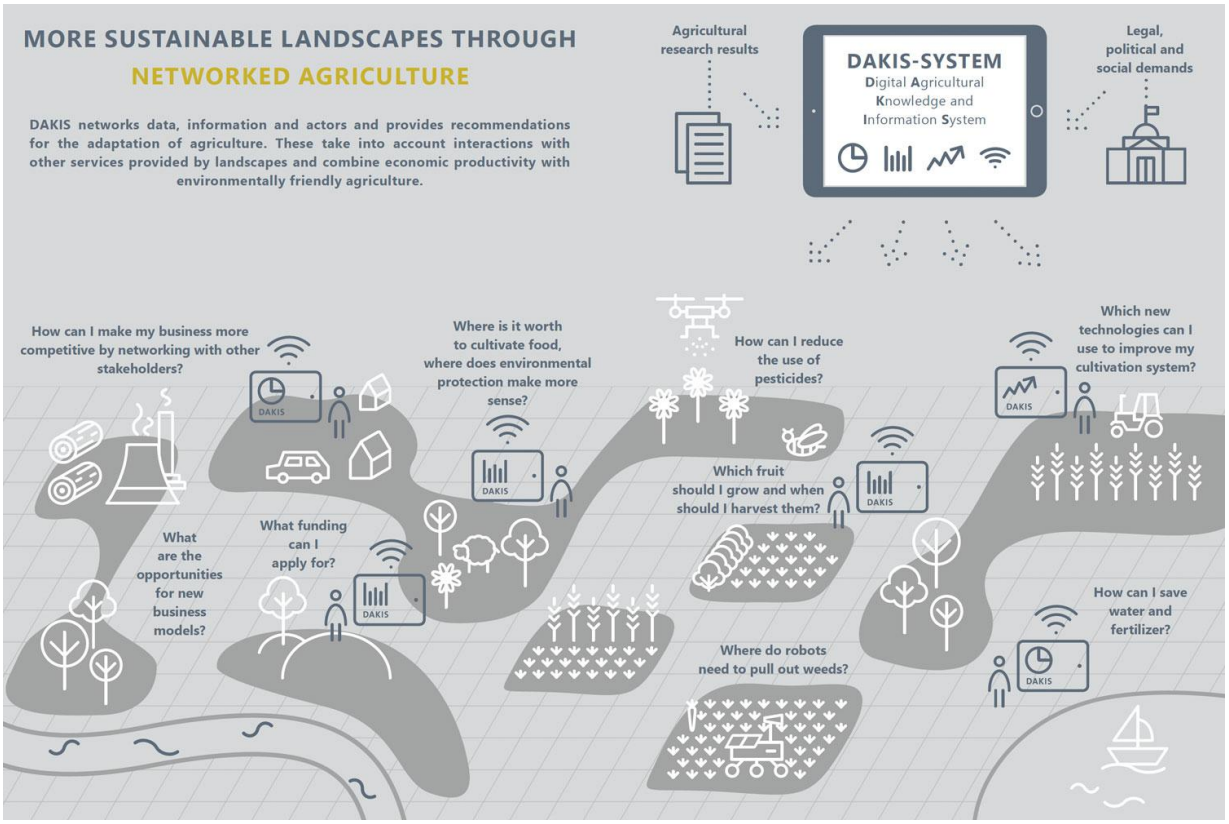

Fig. 2. More sustainable landscapes through networked agriculture
Source: [11].

This vision challenges conventional land-management mental models. Management cooperation among land users is redefined, and rigid separations between

arable land, grassland, and forest are partly dissolved where appropriate.

To "future-proof" DAKIS®, Fraunhofer ISI led a structured scenario process (time horizon 2035) [5] to explore divergent framework conditions for German agriculture and to clarify where a digital decision support system would deliver the most value for farmers. The team identified 15 key factors, formulated 2-3 alternative future assumptions for each, analysed interconnections to detect drivers of change, assembled consistent scenario drafts, and finally wrote four distinctive scenario stories with the farmer as the central user. The process combined literature work with two interactive expert workshops (agriculture, engineering, modelling/simulation, agricultural law). The results of this process show in which situations a decision support system could be of great benefit for farmers and to derive specification impulses for DAKIS® under contrasting external conditions [4].

The four 2035 scenarios and their implications for a DSS:

Environmental protection by global high-tech and regulation

A globalized, tightly regulated world with harmonized legal standards and transparent value chains. The state is a pivotal actor: agricultural land is publicly owned and leased; centralized e-commerce prevails; few harmonized labels exist; and climate change is proactively addressed through coordinated policy. AI-enabled farms and high-tech production dominate; ecosystem services (ESS) are not rewarded on-farm but offset remotely (e.g., rainforest conservation). Consumers are technology-positive, track products end-to-end, and accept reduced consumption in exchange for sustainability.

➔ Implication for DSS: Strong demand for globally interoperable data pipelines, compliance by design, links to state support instruments, and AI-driven recommendations that fit harmonized rules and central marketplaces.

Environmental protection by local food circles and qualitative growth

A decentralized, diverse, and sustainability-oriented system with transparent, local value chains. Consumers are health-conscious, buy locally, and value the cultural role of farming. Regulation shifts to local governments; labels fade ("no labels any more") as face-to-face trust and retailer-mediated information rise; farmers act as shapers of natural landscapes. Production is a hybrid of technologies and practices; decentralized retailers organize flows; climate adaptation is mainstreamed. Growth is qualitative (better, not more).

➔ Implication for DSS: Need for fine-grained, place-based analytics, short-chain logistics awareness, retailer-facing information tools, and co-planning features that help coordinate many small actors at landscape scale.

Event consumption by face-to-face interaction in local food circles

Local networks become social spaces where food shopping is an event; information is rich but often analog, and physical proximity shapes trust and demand. On the production side, technology adoption is strong ("machine farm"), spurred by enabling agri-digital regulation ("enabler for technological transformation"). Markets for ecosystem services can gain traction alongside experiential consumption.

➔ Implication for DSS: Combine high-tech farm operations (automation, sensing) with human-centric interfaces and community touchpoints; provide evidence modules for ESS and tools that translate complex data into intuitive, locally legible signals.

Reduced consumption and de-growth by necessity

A world marked by resource constraints, intransparent/global chains, and law lagging technology. Protection areas expand; land ownership concentrates in a few hands; labels proliferate (high variety), yet there is no functioning market for ESS. Consumer behavior tends to be price-driven; food-shopping retains a social/event character, but with tighter budgets and limited choice.

➔ Implication for DSS: Emphasis on risk-awareness, resource-efficiency modules, offline/low-infrastructure usability, cost-optimization under constraints, and

scenario stress-tests that help farms remain viable despite weak incentives and fragmented governance.

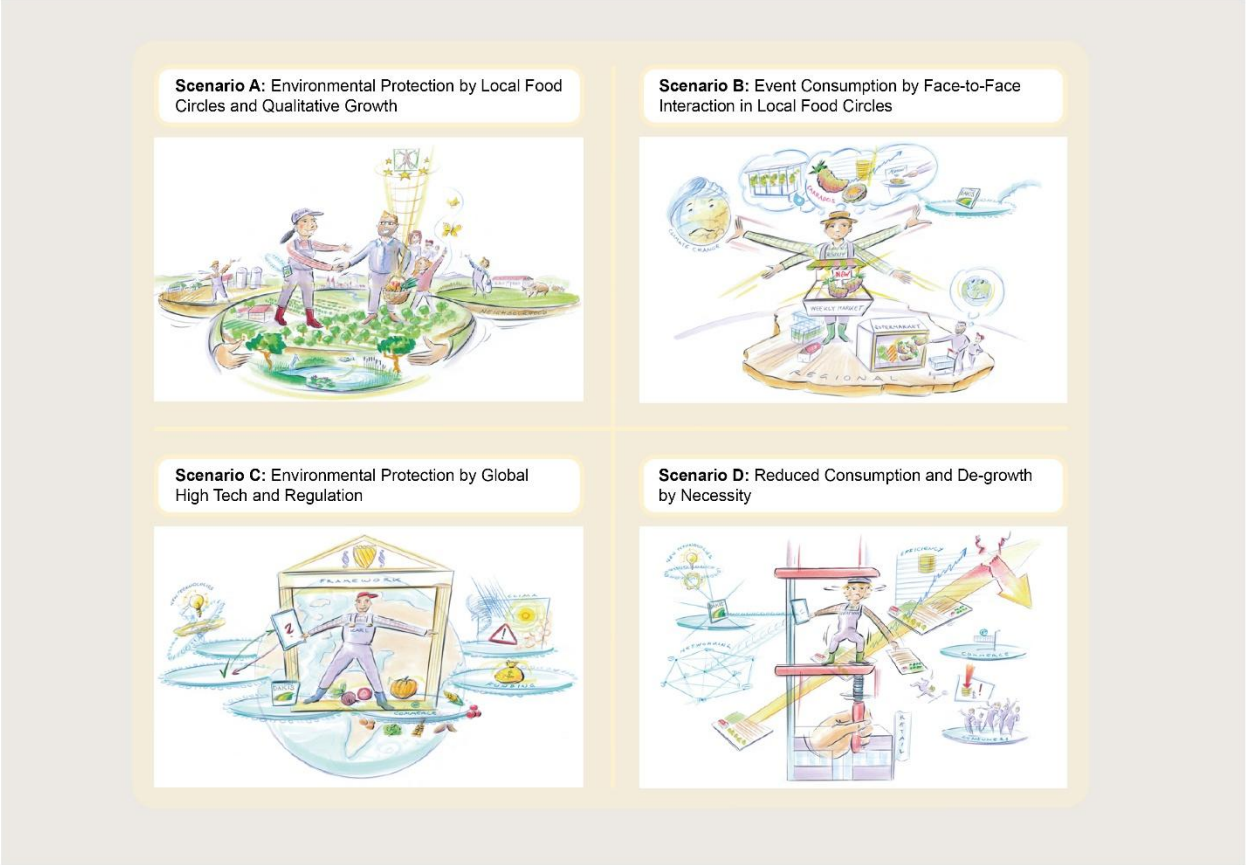

Fig. 3. Future scenarios "Agribusiness in 2035 – Farmers of the Future"
Source: [4].

What the scenarios deliver for DAKIS?

Across the four futures, the scenarios clarify which DSS capabilities are "robust" (e.g., multi-scale data integration, transparent information flows, explainable recommendations, landscape-level coordination) and which are context-dependent (e.g., interfaces to centralized state programs, retailer-centric info hubs, social/analog communication, or ESS marketplaces). In other words, the set enables DAKIS to specify features for different external conditions and to show farmers where and how a DSS is most beneficial.

Cross-cutting, 'future-proof' requirements for an agri-food DSS:

(R1)Modular architecture and open interoperability. A plug-and-play system that integrates with FMIS, advisory platforms, and public portals via open APIs; supports heterogeneous data (sensors, remote sensing, models); and enables feature toggling per user role. Modularity eases evolution under policy and market uncertainty.

(R2) Multi-objective, multi-scale optimization (field vs. landscape). Users need to jointly optimize yield, biodiversity, and ESS under constraints, visualize trade-offs, and understand distributional impacts across stakeholder groups. The DSS should surface equity and multifunctionality metrics explicitly to avoid one-dimensional strategies that increase inequities.

(R3) Explainable, advisory-aligned analytics. Recommendations must be transparent about data sources and sensitivities (e.g., climate or price variability), and they should translate into advisory workflows (checklists, counselling scripts, printable plans).

(R4) Embedded valorization pathways. To convert 'good practice' into 'bankable

practice,' the DSS should expose valorization options and required evidence (indicators, geo-references, audits) across the four clusters and provide tailored data models, document management, and partner integrations.
(R5) Scenario awareness and stress-testing. Configuration presets (policy, price, climate, social preferences) allow users to 'wind-tunnel' plans across futures. For developers, internal scenario packs help prioritize a roadmap of robust features versus scenario-specific modules.
(R6) Governance, data protection, and trust. The system must support granular consent, data provenance, and local hosting options that meet EU data-protection standards while enabling aggregation for landscape-level assessments.
Phase II's of the project DAKIS aims at iterative loops with advisors and value-chain actors surfaced pragmatic adoption levers: explainable recommendations aligned with advisory scripts; incremental onboarding (start with farm-level 'quick wins,' unlock landscape features later); proof-of-benefit through valorization connectors; and robust data-governance options to match varying trust and infrastructure contexts.

CONCLUSIONS

A scenario-based, stakeholder-driven approach can future-proof digital decision support in agriculture by distinguishing robust, cross-cutting functions (modularity, multi-objective and multi-scale analytics, explainability, data governance, embedded valorization) from scenario-contingent modules (e.g., specific certification connectors, cooperative planning features, offline resilience). Results indicate that weaving biodiversity and ESS into everyday farm and landscape decisions is technically feasible and economically actionable when DSS integrate valorization options alongside agronomic and ecological insights.
For DAKIS, next steps include: (i) strengthening landscape-level planning with equity-aware trade-off tools; (ii) operationalizing valorization connectors with selected labels/voluntary markets and public eco-schemes; and (iii) continuing advisory-centric co-design to ensure that each new function fits real decisions on real farms.

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A MODEL FOR THE APPLICATION OF THE ABC COSTING METHOD IN GRAIN PRODUCTION

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Abstract

A major challenge in traditional cost-calculation methods in grain production is the allocation of indirect costs. In all farms examined, indirect costs are distributed on the basis of direct costs, which in some crops—such as rice—distorts the actual cost price by up to two or three times. Improving cost calculation in grain production therefore requires exploring opportunities for applying more advanced costing methods. This study proposes an Activity-Based Costing (ABC) model as one of the most progressive methods in accounting theory and practice. Using empirical data, the research identifies the advantages and limitations of applying ABC in grain production. When implemented correctly, ABC provides significantly more accurate information on crop cost prices, as it ensures a fairer distribution of overhead costs across different cost objects within the farm. Under current conditions in Bulgarian grain production, however, the ABC method remains difficult to apply, as most farms cannot meet its demanding requirements. Large producers face a choice between the lower cost of traditional methods and the additional investment required for ABC, which offers higher accuracy and improved cost control.

Key words**:** *Activity-Based Costing (ABC), grain production, cost allocation, indirect costs, farm management*

INTRODUCTION

Traditional cost calculation methods focus on analyzing the relationship between the cost object and the costs directly attributable to it. A major problem with traditional costing methods is the allocation of indirect costs (Drury, 2007; Drury, 2008; Kumar & Mahto, 2013) [4, 5, 10]. In the farms examined in this study, indirect costs are commonly distributed on the basis of total direct costs. However, for certain types of production — such as rice cultivation — this approach is inappropriate, as indirect costs may exceed direct costs by two to three times, leading to a significant distortion of the actual production cost (Vaisilova, 2004; Zakić, 2013) [17, 18]. Enhancing the accuracy of cost determination in grain production therefore necessitates the exploration and application of alternative costing methodologies. Over the past century, several innovative approaches have been developed, including Activity-Based Costing (ABC), Target Costing, Kaizen Costing, and the Balanced Scorecard, collectively referred to as "progressive" costing methods. Among these, Activity-Based Costing, introduced by Cooper and Kaplan (1992) [3] is widely regarded as one of the most advanced developments in accounting theory and practice. According to numerous scholars (Drury, 2007; Drury, 2008; Lucey, 2009) [4, 5, 11], ABC has ultimately proven to be one of the most significant management accounting innovations of the past hundred years, owing to its enhanced ability to allocate indirect costs more accurately and to support informed managerial decision-making.

The Activity-Based Costing (ABC) method is founded on the principle that activities consume resources, while processes and cost objects — such as products, suppliers, and services — consume activities. Consequently, it is the consumption of resources that gives rise to costs. From this perspective, effective control of activities and processes enables effective control of costs. Moreover, when the resources utilized by individual activities can be accurately measured, it becomes possible to determine actual costs with far greater precision than under traditional cost allocation methods (Carli, Canavari, & Grandi, 2014) [2].

To achieve a sound understanding of cost behavior, it is essential to identify the underlying cost drivers and to clarify their relationships with the relevant cost objects. According to Georgieva et al. (2002) and Georgieva (2014) [7, 8], the core concept of the ABC method lies in the recognition that indirect costs do not arise arbitrarily; rather, they are caused by specific activities and are a direct consequence of the nature and structure of business operations.

Gerganov (2012) [6] and Mihailova and Genov (2004) [14] observe that the emergence and application of the ABC method are driven by substantial changes in modern agricultural enterprises (Markov, 2023) [13]. Vaisilova (2004) [17]further emphasizes that cost information generated by traditional costing methods is often distorted. The rationale for this is that the cost of production at a bigger volume encompasses greater total production expenses, as volume acts as a foundation for cost allocation. Such information misleads the rulers. Simeonova (2012) [16] notes that the use of the ABC technique signifies a pivotal transition from a static cost determination approach to a dynamic model focused on activity and process management, a conclusion supported by recent regional studies on agricultural management and efficiency (Zheleva & Delcheva, 2023) [19]. In this respect, ABC not only increases cost accuracy, but it also functions as a strategic instrument for increasing efficiency and managerial control (Carli et al., 2014) [2].

Despite claims by managers that traditional accounting methods easily pass the benefit test, empirical evidence supporting the benefits attributed to the ABC costing method remains limited and inconclusive (Malmi, 1997; Gosselin, 1997) [12, 9]. In the context of grain production, published studies on the application of ABC costing are particularly scarce and are rarely supported by robust empirical validation, which limits the generalizability of reported benefits (Baird, Harrison, & Reeve, 2004) [1].

At the current stage of development of the method, following the initial period of conceptual expansion, a number of practical difficulties related to implementation complexity, data requirements, and cost–benefit considerations have become increasingly evident (Malmi, 1997) [12]. These limitations have constrained the wider diffusion of ABC, particularly in sectors characterized by biological processes and high production variability, such as agriculture.

Nevertheless, the ABC costing method has made a substantial contribution to the evolution of management accounting. Selected elements of the method have been successfully integrated into various managerial and accounting practices across different economic sectors, improving cost transparency and supporting more informed decision-making (Gosselin, 1997) [9]. However, the application of ABC in agriculture remains limited and fragmented, and its adoption in Eastern European countries, including Bulgaria, is still at an unsatisfactory stage of development (Popescu et.al, 2019) [15].

The objective of the present study is to contribute to making the ABC method a more accessible and practically applicable tool and to define its appropriate role among other widely used accounting methods in agricultural production.

MATERIALS AND METHODS

The main research thesis presented in this study is that traditional accounting methods used for cost calculation in grain production do not provide sufficiently accurate information to support precise managerial decision-making. Therefore, it is necessary to optimize cost accounting practices and improve costing methods.

The subject of the research is cost accounting, with a focus on methods for allocating indirect production costs and calculating the cost of production in grain production across different economic entities.

The empirical data were obtained from analytical accounting records and annual financial statements of several agricultural grain-producing enterprises. In addition, normative documents related to fuel and material costs were used.

Research methods

A system of general logical research methods was applied. In formulating conclusions and interpreting results, comparison, model development, statistical data processing, and analysis of the examined phenomena and processes were employed. The expert evaluation method was used to identify activities related to the cost objects and to determine cost behavior, as well as to consider multiple perspectives on issues that are difficult to assess solely through quantitative indicators.

RESULTS AND DISCUSSIONS

Model for the Application of the ABC Costing Method in Grain Production

The structure of activities in grain production constitutes the basis on which the cost hierarchy is built. Activities are defined depending on the cost objects and the type of products and determine the necessity of incurring costs. Once costs are assigned to activities, specific factors are identified that determine the workload of each activity and, consequently, the behavior of its costs. These factors express the relationship between activities and cost objects and are used as bases for allocating activity costs to products and services; they are defined as cost drivers.

The basis for resource allocation is identified as the main element influencing the flow from resources to activities and from activities to cost objects, namely output (grain), as illustrated in Figure 1. The model demonstrates that the link between resources and products is established through farm activities. Defining the activities related to grain production represents the first step in applying the ABC method. These activities are identified at the beginning of the business year through the preparation of detailed technological maps and budgeting. The ABC method is based on activities directly involved in grain production.

Cost calculation requires a clearer, more precise, and more transparent definition of cost drivers. Activities are classified into value-adding and non-value-adding activities within the production process. For each activity, the relative share of expenses generated by that activity is determined. Under the ABC method, indirect costs are a consequence of the activities themselves and are allocated according to the costs they generate. When the ABC method is applied correctly, more accurate information regarding crop costs is obtained, ensuring a fairer allocation of total production costs.

Considering that the additional costs associated with implementing the ABC method are lower than the benefits achieved in farm management, this methodology can be effectively applied in grain production. A practical activity-based model was developed using data from the agricultural cooperative ZK “Edinstvo”, Kostievo village, Plovdiv region, with the aim of building a cost management system based on the ABC method in grain production. The model includes the stages presented in Fig.1.

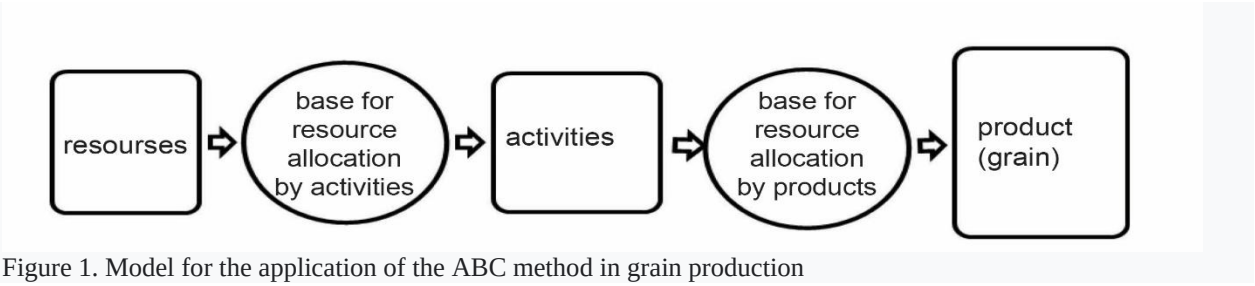

Figure 1. Model for the application of the ABC method in grain production
Source: Adapted from Mihailova (2010) [14].

Defining the activities related to grain production

One approach to defining activities is to compile a list of the main jobs and tasks performed by the production and management units. These activities should complement those described in the technological maps (TM) for crop cultivation. This also provides an appropriate opportunity to assess the relevance and necessity of each activity. The

required activities within each production structure can be categorized as follows. An example of the identification of key activities and their corresponding cost drivers is presented in Table 1.

Table 1. Example of defining activities and their measures

Activities	**Measuring the costs of performing the activity (*cost drivers*)**
Contacts with customers and suppliers	Number of contacts
Preparation of offers and acceptance of orders	Number of offers and orders
Preparation of technologies and TM	Hours worked
Purchase of materials (seeds, fertilizers, pesticides)	Number of purchase orders
Grain production	Number of crops grown (products)
Delivery of materials (seeds, fertilizers, pesticides)	Number of deliveries
Production management and control	Product complexity
Transport of the production to the warehouse	Distance - km (t/ km)
Storage of production	Quantity / time
Sales	Number of payments / number of clients
General management and administration	Activity intensity

Source: Own elaboration.

Determining the Types of Costs (Cost Structure)

As an initial step at this stage, it is appropriate to use accounting data for the grouping of costs (for example, as presented in the turnover statement). As in the first stage, the degree of differentiation of activities and costs is determined by the need for a clearer, more precise, and more transparent definition of cost drivers. If it is possible to apply different measurement bases to a single activity, it is preferable to divide that activity (and the associated costs) accordingly. Excessive detailing does not necessarily provide additional managerial information. The main cost categories and their respective cost drivers, based on accounting data from ZK "Edinstvo", Kostievo village, Plovdiv region, are summarized in Table 2.

For medium-sized production units in grain production (up to 500 ha), the number of activities should be optimized to approximately 10–15 and should not exceed 30 (Georgieva, 2014).

Table 2. Example of determining cost types and their measures based on data from ZK "Edinstvo", Kostievo village, Plovdiv region

Types of costs (category of costs)	**Value (BGN)**	**Cost drivers for the implementation of the activity (cost drivers)**
1 / Administrative and managerial	245,000	Number of contacts
2 / Depreciation	162,000	Number of offers and orders
3 / Rentals and rent	132,000	Hours worked
4 / Maintenance of offices and buildings	53,000	Degree of use of offices and buildings
5 / Transport	65,000	Distance - km, t/km
6 / Interest	42,000	Value of the activity (BGN)
7 / Freight activities	41,000	Weight - kg (t)
8 / Business trips	35,000	Days (number)
9 / Insurance and legal services	33,000	Value of the activity (BGN)
10 / Advertising, samples, exhibitions, etc.	31,000	Profit level (%)
11 / Others	35,000	-

Source: Own elaboration based on authors' data.

Defining the Links between Activities and Costs

The subsequent step involves compiling a table (matrix) in which the activities presented in Table 1 are arranged horizontally, while the cost types from Table 2 are arranged vertically.

Based on accounting data and expert assessments provided by specialists performing the respective activities, it is determined which activities are related to the formation of the costs in each cost category.

Each identified relationship is marked in the cell at the intersection of the corresponding row and column.

In determining the key factors for activity-based calculation, an activity schedule is used in the form of a flow chart illustrating all activities involved in the production process and the formation of value.

This schedule provides a clear overview of the time spent on each activity, which can be classified into four categories: processing time, control time, movement time, and waiting and storage time.

The allocation of total production costs to products under the ABC approach is associated with the introduction of cost drivers, which uniquely express the workload of each specific activity.

The allocation of costs to activities represents the most challenging stage in the application of the ABC method.

It is performed by various specialists; however, according to managers, this process is often highly subjective, which constitutes a significant limitation in the application of the ABC method in grain production.

Table 3 presents the matrix for determining the connections between activities and costs.

Determining the Degree of Correlation between Activities and Costs

The sum of the relative shares in each column of Table 4 must be equal to one. For each activity, the relative share of the costs generated by that activity is determined. Each activity is represented by specific indicators, such as production volume, type and brand of machinery, type of fertilizers and pesticides, sown area (hectares), quantity of seeds applied per unit area, transport distances (kilometres), and the number of orders, suppliers, customers, and employees, all of which influence the level of costs incurred.

Table 3. Matrix for determining the links between activities and costs

Activities / Cost categories	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Contacts with customers and suppliers	**V**		**V**	**V**				**V**		**V**	**V**
Preparation of technologies and TM	**V**		**V**	**V**				**V**			**V**
Purchase of materials (seeds, fertilizers, pesticides)	**V**		**V**	**V**		**V**		**V**			**V**
Production of grain	**V**	**V**	**V**	**V**			**V**				**V**
Delivery of materials (seeds, fertilizers, pesticides)	**V**	**V**	**V**	**V**	**V**		**V**	**V**	**V**		**V**
Production management and control	**V**		**V**	**V**				**V**			**V**
Transport of the production to the warehouse	**V**	**V**	**V**	**V**	**V**		**V**				**V**
Storage of production	**V**	**V**	**V**	**V**		**V**	**V**		**V**		**V**
Sales	**V**		**V**	**V**	**V**		**V**	**V**	**V**		**V**
General management and administration	**V**	**V**	**V**	**V**		**V**		**V**	**V**	**V**	**V**

***Cost category legend:** 1 – Administrative and managerial, 2 – Depreciation, 3 – Rents and leasing, 4 – Maintenance of offices and buildings, 5 – Transport, 6 – Interest, 7 – Freight services, 8 – Business trips, 9 – Insurance and legal services, 10 – Advertising, samples, exhibitions, etc., 11 – Other costs*

Source: Own elaboration based on authors' data and expert assessment.

The allocation of costs to activities through the determination of the degree of correlation represents the most challenging stage in the application of the ABC method. This process is carried out by a multidisciplinary team of specialists and is often characterized by a high degree of subjectivity, as each specialist tends to emphasize the importance of the activities within their own area of responsibility. This subjectivity constitutes a significant limitation to the application of the ABC method in grain production.

Table 4. Matrix for determining the degree of correlation between activities and costs

Activities / Cost categories	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Contacts with customers and suppliers	0.06		0.01	0.18				0.05		0.58	0.10
Preparation of technologies and TM	0.10		0.05	0.10				0.05			0.10
Purchase of materials (seeds, fertilizers, pesticides)	0.10		0.11	0.14		0.60		0.24			0.10
Production of grain	0.13	0.50	0.09	0.03			0.50				0.10
Delivery of materials (seeds, fertilizers, pesticides)	0.04	0.10	0.14	0.06	0.30		0.20	0.16	0.20		0.10
Production management and control	0.21		0.15	0.05				0.16			0.10
Transport of the production to the warehouse	0.05	0.10	0.10	0.10	0.60		0.10				0.10
Storage of production	0.15	0.20	0.10	0.15		0.20	0.10		0.35		0.10
Sales	0.03		0.07	0.08	0.10		0.10	0.14	0.25		0.10
General management and administration	0.13	0.10	0.18	0.11		0.20		0.20	0.20	0.42	0.10

***Cost category legend:** 1 – Administrative and managerial, 2 – Depreciation, 3 – Rents and leasing, 4 – Maintenance of offices and buildings, 5 – Transport, 6 – Interest, 7 – Freight services, 8 – Business trips, 9 – Insurance and legal services, 10 – Advertising, samples, exhibitions, etc., 11 – Other costs*
Source: Own elaboration based on authors' data and expert assessment.

Determining the Value of Activities Based on Information from ZK "Edinstvo", Kostievo Village, Plovdiv Region

The value of each activity is determined using the following formula (Todorov, 2014):

$$\mathbf{TOE} = \sum_{\mathbf{od=1}}^{\mathbf{M}} \mathbf{CP} \text{ x } \mathbf{OD}$$

where:
TOE – total operating expenses of the activity (BGN);
M – types of costs related to the activity;
CP – value of expenses from the respective cost category (BGN);

The calculated value of costs by activities, based on the application of the ABC methodology, is presented in Table 5**.**

The proposed implementation of the non-traditional activity-based costing method aims to provide a more accurate understanding of cost behavior by identifying the factors that determine costs and clarifying their relationship with the produced outputs.

Table 5. Value of costs by activities (BGN x 1,000)

Total costs	**245**	**162**	**132**	**53**	**65**	**42**	**41**	**35**	**33**	**31**	**35**	**Total**
Activities	1	2	3	4	5	6	7	8	9	10	11	**costs**
Contacts with customers and suppliers	14.7		1.3	9.5				1.8		18.0	3.5	**48.9**
Preparation of technologies and TM	24.5		6.6	5.3				1.8			3.5	**41.7**
Purchase of materials(seeds, fertilizers, pesticides)	24.5		14.5	7.4		25.2		8.4			3.5	**83.5**
Production of grain	31.8	81.0	11.9	1.6			20.5				3.5	**150.3**
Delivery of materials(seeds, fertilizers, pesticides)	9.8	16.2	18.5	3.2	19.6		8.2	5.6	6.6		3.5	**91.1**
Production management and control	51.4		19.8	2.6				5.6			3.5	**83.0**
Transport of the production to the warehouse	12.2	16.2	13.2	5.3	39.		4.1				3.5	**93.5**
Storage of production	36.7	32.4	13.2	7.9		8.4	4.1		11.6		3.5	**117.8**
Sales	7.3		9.24	4.2	6.5		4.1	4.9	8.3		3.5	**48.2**
General management and administration	31.8	16.2	23.8	5.8		8.4		7.0	6.6	13.0	3.5	**116.1**

Source: Own elaboration based on authors' calculation.

The agricultural cooperative ZK "Edinstvo", located in Kostievo village, Plovdiv region, carries out a variety of agricultural activities and produces several types of crops, including wheat, barley, maize, sunflower, and rice.

The cooperative operates its own storage facilities and has an on-site grain drying facility. For the analyzed period, indirect costs are allocated to crop types and products on the basis of direct production costs.

Table 6 presents the production volumes by product type and the costs incurred for their cultivation over a three-year period (2015–2018).

Table 6. Production volume by product type and production costs in ZK "Edinstvo", Kostievo village, Plovdiv region (three-year average, 2015–2018)

Indicators	**Types of products obtained**			
	Wheat	**Barley**	**Corn**	**Rice**
Production volume (t) of 100 ha	452.97	339.00	415.60	686.30
Hectares area	744.1	207.6	226.9	353.7
Volume production tons	3,370.5	703.8	943.0	2,427.4
Direct costs per 100 ha (BGN)	75,004.6	63,500.3	86,266.4	138,318.1
Indirect costs per 100 ha (BGN)	41,990.4	32,420.0	65,410.6	89,110.1
Direct costs - total	558,109.2	131,826.6	195,738.5	558,390.1
Indirect costs - total	312,510.9	67,303.7	148,425.0	359,751.2
Total costs	870,620.1	199,130.3	344,163.5	918,141.3
Cost BGN per ton	**258.31**	**282.94**	**364.97**	**378.24**

Source: Own elaboration based on data from ZK "Edinstvo", Kostievo village, Plovdiv region.

Table 7. Allocation of indirect costs by activity centers and types of output

Activity centers	**By types of production**				**Total costs**
	Wheat	**Barley**	**Corn**	**Rice**	
Degree of connection of activities and costs ►	0.18	0.15	0.29	0.38	1.00
Cost determinants ▼					
Contacts with customers and suppliers	8.8	6.8	14.2	19.1	48.9
Preparation of technologies and TM	7.5	6.3	12.2	15.9	41.7
Purchase of materials (seeds, fertilizers, pesticides)	15.0	12.6	24.2	31.7	83.5
Production of grain	27.1	22.5	43.6	57.1	150.3
Delivery of materials (seeds, fertilizers, pesticides)	16.4	13.7	26.4	34.6	91.1
Production management and control	14.9	12.5	24.1	31.5	83.0
Transport of the production to the warehouse	16.8	14.0	27.1	35.5	93.5
Storage of production	21.2	17.7	34.2	44.7	117.8
Sales	8.7	7.2	14.0	18.3	48.2
General management and administration	20.9	17.2	33.7	44.2	116.1
Total	**157.3**	**130.5**	**253.7**	**332.6**	**874.1**

Source: Own elaboration based on authors' calculation.

The next stage of the ABC costing method, as indicated by Mihaylova (2010) for other cereal crops, involves determining costs by cost centers and activity volume. The amount of indirect costs assigned to each cost center serves as the basis for calculating the cost of the cost-determining factors by type of output. The unit cost of each cost driver is defined as the ratio between operating costs and the volume of the corresponding activity. The resulting coefficient is then multiplied by the value of the cost-determining factor, thereby forming the prime cost. The allocation of indirect costs by activity centers and by types of output, obtained through the application of the ABC method, is presented in Table 7.

The indirect costs allocated by activities should be added to the direct tangible and intangible costs incurred in the cultivation and harvesting of wheat, barley, maize, and rice in order to determine their full production cost, as presented in Table 8.

The results clearly indicate significant differences between the costs calculated using the traditional method (Table 6) and those obtained through the application of the ABC costing method (Table 8).

Table 8. Total cost by type of harvested production calculated using the ABC method, based on data from ZK "Edinstvo", Kostievo village, Plovdiv region

Expenses	Wheat	Barley	Corn	Rice
Total production (t)	3,370.55	703.76	942.00	2770.60
Direct costs total BGN.	558,109.2	131,826.6	195,738.5	558,390.1
Contacts with customers and suppliers	8.8	6.8	14.2	19.1
Preparation of technologies and TM	7.5	6.3	12.2	15.9
Purchase of materials (seeds, fertilizers, pesticides)	15.0	12.6	24.2	31.7
Production of grain	27.1	22.5	43.6	57.1
Delivery of materials (seeds, fertilizers, pesticides)	16.4	13.7	26.4	34.6
Production management and control	14.9	12.5	24.1	31.5
Transport of the production to the warehouse	16.8	14.0	27.1	35.5
Storage of production	21.2	17.7	34.2	44.7
Sales	8.7	7.2	14.0	18.3
General management and administration	20.9	17.2	33.7	44.2
Indirect costs total	157,300.0	130,500.0	253,700	332,600
Total costs	715,409.2	262,326.6	458,065.1	890,990.1
Cost calculated by the ABC method BGN per ton	**212.25**	**372.75**	**486.27**	**321.59**

Source: Own elaboration based on authors' calculation.

The discrepancy observed for maize is substantial, as the smaller harvested output compared to wheat and rice results in a higher share of additional production costs.

In contrast, the cost of rice decreases considerably under the ABC approach, since the allocation of indirect costs is more accurate and less dependent on the volume of direct costs. This more realistic distribution of indirect costs can be achieved only through the application of the ABC costing method.

The main benefit of applying the ABC method in grain production lies in the improved accuracy of cost information and in providing managers with a clearer understanding of how production processes can be controlled and, consequently, how costs can be more effectively managed.

CONCLUSIONS

The results of the study confirm that the application of the Activity-Based Costing (ABC) method is effective for grain-producing enterprises characterized by a high share of indirect costs and by the cultivation of crops such as rice, which require substantial production expenditures. The ABC method allows for a more reliable calculation of the cost of individual grain products and increases the objectivity of profitability assessment by providing a more accurate allocation of overhead costs.

At the same time, the research demonstrates that the practical application of the ABC costing method in grain production is associated with significant difficulties. The allocation of costs by activities is complex, time-consuming, and highly dependent on expert judgment, which introduces a degree of subjectivity. The method requires extensive calculations and specialized accounting and management expertise, which are often lacking in small and medium-sized agricultural holdings. Additionally, administrative costs are frequently excluded from cost objects due to measurement difficulties, further limiting the precision of cost allocation.

Under the current conditions of grain production in Bulgaria, the widespread implementation of the ABC costing method remains challenging, as most farms are unable to meet the high requirements imposed on accounting systems and managerial capacity. Nevertheless, for large-scale grain producers, the ABC method represents a valuable alternative to traditional costing approaches, offering improved cost accuracy and

enhanced opportunities for cost control, albeit at higher implementation costs.

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ECONOMIC EFFICIENCY OF HIGH-OLEIC SUNFLOWER HYBRIDS IN SOUTHERN BULGARIA

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Abstract

In recent years, there has been a surge in interest in developing high-oleic sunflower hybrids throughout Europe. This trend is propelled by advancements in plant breeding that have yielded hybrids with an oleic acid content of 85–92%, rendering their oil comparable in value to olive oil. Recent clinical studies have confirmed the important role of oleic acid in human health and have clearly proven its beneficial properties. From an agrobiological and technological perspective, the production and processing of high-oleic sunflower hybrids do not differ from those of traditional linoleic types. These advantages form both the foundation and a challenge for their market introduction. In recent years, high-oleic sunflower seeds have commanded prices 10–15% above those of linoleic-type hybrids, yielding further economic advantages for producers. This article assesses key indicators of economic efficiency to facilitate informed management decisions in the selection of appropriate hybrids. The analysis utilizes empirical data gathered from 2021 to 2023 at the Educational and Experimental Base of the Department of Plant Production, Agricultural University – Plovdiv, encompassing the hybrids Biser, Armada, Oliva, Etik, and Ballistic.

Key words**:** *Sunflower, high-oleic hybrids, yield, economic effect, production cost*

INTRODUCTION

Sunflower is the most widely cultivated industrial crop in Bulgaria. In recent years, interest in the cultivation of high-oleic sunflower hybrids has increased significantly. This growing interest is driven by the achievements of modern plant breeding, which has led to the development of sunflower hybrids with oleic acid content reaching 85–92% (National Sunflower Association, n.d.; Kovalenko & Lysenko, 2023) [31, 19]. Consequently, the oil obtained from these hybrids is considered comparable in value to olive oil.

Recent clinical studies have highlighted the important role of oleic acid in human health, with its beneficial properties being well documented (Zou et al., 2025) [30]. From an agrobiological and technological perspective, the production and processing of new sunflower hybrids with a high-oleic oil profile do not differ significantly from those of traditional sunflower hybrids (Tahsin & Yankov, 2006; Garapova, 2020; Stoev & Tahsin, 2012; Georgiev, 2025) [25, 8, 24, 11].

In addition to its importance as a component of healthy human nutrition, high-oleic sunflower oil is considered the most suitable cold-pressed vegetable oil for use as an alternative renewable fuel (Evtimova-Misheva & Zamfirov, 2008; Todorova & Evtimova, 2017) [7, 28]. These advantages represent both an incentive and a challenge in the commercial trade of high-oleic sunflower hybrids.

In recent years, the purchase price of high-oleic sunflower has generally been 80–130 BGN per ton higher than that of linoleic-type hybrids. This price premium generates an additional economic effect solely through the introduction of high-oleic hybrids into production. To assess the validity of managerial decisions related to the selection of appropriate hybrids, selected indicators of economic efficiency of their cultivation were analyzed.

Economic efficiency represents the economic effect, i.e., the beneficial outcome achieved through the use of a unit of resources or the incurrence of a unit of costs. The beneficial outcome may take the form of revenue, profit,

or other economic results (Hristov et al., 2019) [14]. The economic literature provides extensive coverage of the theoretical aspects of efficiency (Gerganov & Blazheva, 2013; Gerganov et al., 2015; Petkova & Momchilov, 2025; Petrov, 2025) [12, 13, 21, 22]. However, in agriculture, there is a limited number of publications, particularly those evaluating the impact of variety or hybrid quality on economic efficiency (Yankov, 2022; Koteva, 2018; Garapova, 2023; Garapova & Kirchev, 2023; Kovalenko & Lysenko, 2023) [29, 18, 9, 10, 19].

Therefore, the study of high-oleic sunflower varieties and the vegetable oils obtained from them requires a comprehensive analysis of results derived from various empirical studies. Comparative field testing of oil sunflower hybrids under specific regional conditions has revealed significant differences in productivity and quality traits (Delibaltova & Dallev, 2017) [3]. The economic effect represents the monetary outcome of sunflower hybrid cultivation and is determined by achieved yields and market prices. Under otherwise equal conditions, higher-yielding hybrids generate greater revenues (Kljajić et al., 2025) [17], which stimulates the introduction of increasingly productive hybrids into agricultural practice.

The improvement of high-oleic sunflower hybrids and the breeding of cultivars with productivity close to or equal to that of linoleic types, combined with oleic acid content equal to or higher than that of olive oil, has fundamentally changed the concept of sunflower production.

Processors and traders gradually increased purchase prices, thereby shifting the economic effect in favor of high-oleic hybrids. In general, the economic effect can be expressed as additional income generated through higher profits, minimization of material costs, expansion of production volumes, and improvement in product quality, reflected in higher market prices.

MATERIALS AND METHODS

The experiment included the high-oleic sunflower hybrids SI Diego, Tolento, Oliva, Etik, and Ballistic, with the linoleic hybrid San Luka used as a control. The economic analysis was based on empirical data obtained from a three-year study conducted during the period 2021–2023 in the region of the Educational, Experimental and Extension Base (EEEB) of the Agricultural University – Plovdiv, as well as at an off-site experimental location at Agricultural Cooperative ZK "Edinstvo", Kostievo village, Maritsa Municipality.

The trials were conducted using a split-plot design following winter wheat as a preceding crop, with four replications. The experimental plot size was 21 m², and the harvest plot size was 10 m² (Box et al., 2005; Dallev et al., 2016; Jones & Nachtscheim, 2009) [1, 2, 16].

The experimental data were statistically processed using analysis of variance (ANOVA), and mean comparisons were performed using Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSIONS

Economic efficiency measured through the productivity of high-oleic sunflower hybrids

Modern sunflower hybrids exhibit high productivity in terms of both seed and oil yield. Seed yield is used as a primary criterion synthesizing the physiological efficiency of plants and represents an important indicator for the economic evaluation of technologies, varieties, and hybrids cultivated under field conditions. Seed yield is also the main objective of sunflower production.

The results presented in Table 1 summarize the seed and oil yields of the tested sunflower hybrids compared to the linoleic standard hybrid San Luka. The highest average seed yield over the three-year period was recorded for the hybrid Tolento (2,845 kg ha^{-1}), with a high level of statistical significance compared to the other high-oleic hybrids and very high significance compared to Ballistic (2,153 kg ha^{-1}). All tested high-oleic sunflower hybrids exhibited lower seed yields compared to the standard San Luka, with the exception of Tolento, which showed no statistically proven difference relative to the control.

Table 1. Seed yield, oil content, and oil yield of sunflower hybrids (mean values for 2021–2023)

Hybrid	Seed yield (kg ha⁻¹)	Oil content (%)		Oil yield (kg ha⁻¹)	
		Extraction	Cold pressing	Extraction	Cold pressing
San Luka	2,825 ns	42.76 ns	34.72 ns	1,207.1 ns	969.6 ns
SI Diego	2,572 a	42.38 ns	35.73 ns	1,090.0 b	919.0 ns
Oliva	2,324 c	47.41 c	37.91 b	1,101.8 b	881.0 b
Tolento	2,845 ns	46.10 c	37.44 a	1,311.5 ns	1065.2 a
Etik	2,558 a	41.57 ns	34.31 ns	938.7 c	877.7 ns
Ballistic	2,153 c	41.48 ns	34.03 ns	893.1 c	732.6 ns
LSD 5%	238.7	1.79	1.16	124.1	105.4
LSD 1%	330.6	2.48	1.61	171.9	137.5
LSD 0.1%	455.9	3.42	2.21	237.1	23.72

Notes. *Mean values followed by different letters differ significantly according to Duncan's Multiple Range Test: a $p \leq 0.05$; b $p \leq 0.01$; c $p \leq 0.001$; ns – not significant.*
Source: Authors' own calculations and experimental data (2021–2023).

The combined ANOVA revealed highly significant differences among the tested hybrids. Among the high-oleic hybrids, hybrid Tolento demonstrated the highest productivity, exceeding Oliva and Ballistic by 22.4–32.1% ($p \leq 0.001$) and SI Diego and Etik by approximately 11.0% ($p \leq 0.05$).

These results indicate that under the agroecological conditions of Southern Bulgaria, high-oleic sunflower hybrids generally exhibit lower productivity compared to the linoleic standard San Luka. Sunflower hybrid productivity and oil accumulation are strongly affected by agroecological conditions and drought stress (Drumeva & Yankov, 2020; Tanchev & Georgiev, 2025; Tanchev & Kirchev, 2025) [4, 26, 27].

Oil extraction efficiency

Oil extraction was performed using hexane Soxhlet extraction (ISO 659:2009 – Oilseeds Determination of oil content) [15], which provides high extraction efficiency. Among the studied hybrids, the highest total oil content was recorded for Oliva (47.41%) and Tolento (46.10%), with statistically significant differences.

Due to its high seed yield combined with a high oil extraction rate, Tolento ranked first in oil yield per unit area (1,311.5 kg ha^{-1}). Cold pressing resulted in actual oil recovery ranging from 34.03% to 37.91%, with the highest values again observed for Oliva (37.91%) and Tolento (37.44%). Under both extraction methods, Tolento ranked first in total oil yield.

Efficiency of using high-oleic sunflower oil as fuel in diesel engines

Cold-pressed high-oleic sunflower oil (CP-HOSO) can be used as fuel in diesel engines in two ways:

- Direct use of CP-HOSO as fuel;
- Production of biodiesel through oil extraction and transesterification with methanol.

Direct use of CP-HOSO can be economically feasible for small and medium-sized farms, which may utilize part of their oilseed production or waste oils to supply fuel for agricultural operations.

Most diesel engines, particularly tractors, can be relatively easily adapted for operation with sunflower oil (Dulger & Kaplan, 2001; Radu & Zugravel, 1997) [5, 23].

Adaptation is relatively easy, particularly given the wide availability of simplified processing installations on the market.

This would make agriculture significantly more independent of diesel fuel prices on the one hand, and more environmentally friendly and sustainable on the other.

Average annual fuel consumption for agricultural operations ranges from 70 to 100 L ha^{-1}, while in the present study fuel consumption varied between 105 and 118.5 L ha^{-1} across three farms (Figure 1).

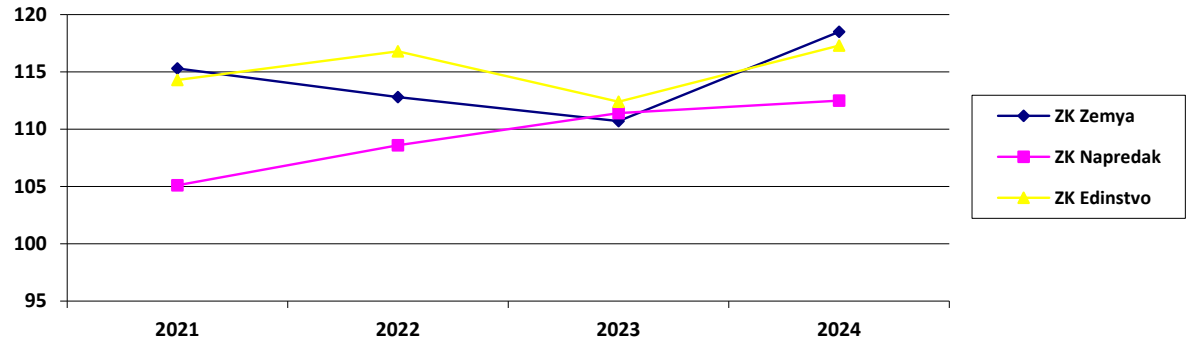

Fig. 1. Average annual diesel fuel consumption per hectare in three agricultural cooperatives: ZK "Zemya", ZK "Edinstvo" and ZK "Napredak"
Source: Authors' own data based on surveys of agricultural cooperatives.

Economic benefits of direct use of cold-pressed sunflower oil

The economic effect of the direct use of cold-pressed high-oleic sunflower oil (CP-HOSO) as fuel in diesel engines was calculated based on the production cost of sunflower seeds and the value of the sunflower oil obtained from them, in comparison with the price of diesel fuel at the time of the experiment. The results are presented in Tables 2 and 3.

Table 2. Production cost of sunflower oil obtained by different extraction methods

Hybrids	Production cost (BGN t^{-1})		Technological costs (BGN t^{-1})		Total production cost (BGN t^{-1})	
	Extraction	Cold pressing	Extraction	Cold pressing	Extraction	Cold pressing
San Luka	1,053.5 ^{ns}	1,272.2 ^{ns}	318.46	378.10	1,371.98 ^{ns}	1,650.3 ^{ns}
SI Diego	1,138.1 ^{ns}	1,350.0 ^{ns}	318.46	378.10	1,456.53 ^{a}	1,728.1 ^{ns}
Oliva	1,057.4 ^{ns}	1,322.3 ^{ns}	318.46	378.10	1,357.82 ^{ns}	1,700.4 ^{ns}
Tolento	967.55 ^{ns}	1,191.3 ^{ns}	318.46	378.10	1,286.01 ^{ns}	1,569.4 ^{ns}
Etik	1,160.9 ^{a}	1,406.4 ^{a}	318.46	378.10	1,479.36 ^{b}	1,784.5 ^{b}
Ballistic	1,227.2 ^{b}	1,496.1 ^{b}	318.46	378.10	1,545.71 ^{c}	1,874.2 ^{c}
LSD 5%	106.7	128.6	-	-	126.4	132.5
LSD 1%	147.8	171.1	-	-	175.1	183.5
LSD 0.1%	203.8	245.5	-	-	241.4	253.1

Notes. *Mean values followed by different letters differ significantly according to Duncan's Multiple Range Test: a $p \leq 0.05$; b $p \leq 0.01$; c $p \leq 0.001$; ns – not significant.*
Source: Authors' own calculations and experimental data (2021–2023).

The production cost was calculated based on planned costs according to the technological card for a yield of 2,500 kg ha^{-1}, using cost norms provided by the Agricultural Cooperative ZK "Edinstvo", Kostievo village, Plovdiv region.

As shown in Table 2, the lowest production cost of sunflower oil obtained by extraction was recorded for the Tolento hybrid (967.55 BGN t^{-1}), while the highest value was observed for the Ballistic hybrid (1,227.2 BGN t^{-1}). In addition to the production cost, processing costs for oil recovery were included, adjusted for revenues from by-products (sunflower cake or meal). The calculated processing cost amounted to 318.46 BGN t^{-1} for extraction and 378.10 BGN t^{-1} for cold pressing. As a result, the total production cost of sunflower oil obtained by extraction ranged from 1,286.01 BGN t^{-1} (Tolento) to 1,545.71 BGN t^{-1} (Ballistic), whereas for cold-pressed sunflower oil the corresponding values ranged from 1,569.4 BGN t^{-1} to 1,874.2 BGN t^{-1}.

Economic benefits of the direct use of cold-pressed sunflower oil in diesel engines

The economic viability of the direct use of cold-pressed sunflower oil (CPSO) in diesel engines is primarily determined by the relationship between the market price of diesel fuel and the production cost of sunflower oil. When diesel prices are high and the purchase price of sunflower seeds, and consequently the cost of sunflower oil, is relatively low, a strong economic incentive emerges for the direct substitution of diesel fuel with sunflower oil. The economic evaluation presented in Table 3 is based on empirical data obtained from experiments conducted at the Department of Crop Science, Agricultural University of Plovdiv. The diesel fuel price applied in the calculations corresponds to the average market price for 2023, ranging between 2.55 and 2.89 BGN L^{-1}.

Table 3. Economic efficiency of the direct use of cold-pressed sunflower oil (CPSO) in comparison with diesel fuel

Hybrid	Average diesel price (BGN L^{-1})	Excise refund (BGN L^{-1})	Real diesel price (BGN L^{-1})	CPSO cost (BGN L^{-1})	Profit (BGN L^{-1})	Profit (%)
San Luka (control)	2.55	0.42	2.13	1.514 ^{ns}	0.616 ^{ns}	40.68 ^{ns}
SI Diego	2.55	0.42	2.13	1.586 ^{ns}	0.544 ^{ns}	34.30 ^{a}
Oliva	2.55	0.42	2.13	1.560 ^{ns}	0.570 ^{ns}	36.54 ^{ns}
Tolento	2.55	0.42	2.13	1.440 ^{ns}	0.690 ^{ns}	47.92 ^{a}
Etik	2.55	0.42	2.13	1.638 ^{b}	0.492 ^{b}	30.04 ^{b}
Ballistic	2.55	0.42	2.13	1.720 ^{c}	0.410 ^{c}	23.84 ^{c}
LSD 5%		-	-	0.18	0.08	5.81
LSD 1%		-	-	0.25	0.11	8.04
LSD 0.1%		-	-	0.34	0.15	11.10

Notes. *Mean values followed by different letters differ significantly according to Duncan's Multiple Range Test: a $p \leq 0.05$; b $p \leq 0.01$; c $p \leq 0.001$; ns – not significant. Calculations based on average diesel prices for 2023.*
Source: Authors' own calculations and experimental data (2021–2023).

The data presented in Table 3 confirm the assumption that the direct use of cold-pressed sunflower oil (CPSO) as fuel in diesel engines provides a significant economic benefit. This benefit is expressed as profit in BGN per liter. The potential for the direct use of sunflower oil as an alternative fuel in diesel engines under Bulgarian conditions has been previously demonstrated (Evtimova-Misheva, 2006) [6].

The highest profit was achieved for the Tolento hybrid, amounting to 0.69 BGN L^{-1}, followed by the standard hybrid San Luka with a profit of 0.616 BGN L^{-1}. The conducted study also showed that the average annual fuel consumption ranged from 105 to 118.5 L ha^{-1}, depending on the operating conditions of the respective farm (Figure 1). The price analysis indicates that the use of sunflower oil as fuel results in a profit ranging from 64.68 to 81.77 BGN ha^{-1}.

It should be noted that the direct use of crude sunflower oil in diesel engines may be associated with additional technical costs and potential engine damage, which are not included in the present price-based economic analysis.

Economic efficiency assessed through the oil quality of the studied sunflower hybrids

Sunflower oil is primarily intended for food purposes. Its use as an alternative fuel is acceptable only in exceptional cases, mainly for low-quality oils or oils derived from waste products.

The results of the experiments conducted at the Department of Crop Science, Agricultural University of Plovdiv, indicate that the obtained cold-pressed sunflower oil (CPSO) is of high quality and, therefore, should not be preferentially used as an alternative fuel.

The data from the analysis of the tested sunflower genotypes during the study period are presented in Table 4.

Table 4. Fatty acid composition of oil from sunflower hybrids and olive oil

Fatty acids	Total fat (%)	Palmitic acid	Stearic acid	Linoleic acid (Omega-6)	Oleic acid (Omega-9)	Others
Hybrids						
Olive oil	15.72 ^{c}	10.30	2.39	9.96	75.06	2.29
San Luka	42.76 ^{ns}	6.50	4.00	51.03	37.81	0.66
SI Diego	42.38 ^{ns}	3.37	2.47	4.91	87.86	1.39
Oliva	47.41 ^{b}	4.19	2.16	6.69	85.87	1.09
Tolento	46.10 ^{a}	2.45	1.43	5.09	89.81	1.22
Etik	41.57 ^{ns}	4.42	2.40	2.96	88.33	1.89
Ballistic	41.48 ^{ns}	4.47	3.09	4.39	86.40	1.65
LSD 5%	1.79				2.06	
LSD 1%	2.48				2.86	
LSD 0.1%	3.42				3.94	

Notes. *Mean values followed by different letters differ significantly according to Duncan's Multiple Range Test: a $p \leq 0.05$; b $p \leq 0.01$; c $p \leq 0.001$; ns – not significant.*
The high oleic acid content of the studied sunflower hybrids further confirms their suitability for food purposes rather than for energy use.
Source: Authors' own calculations and experimental data (2021–2023).

The data presented in Table 4 confirm the findings reported by other authors that the use of cold-pressed sunflower oil (CPSO) as a renewable fuel, despite the demonstrated economic benefits (Tables 2 and 3), is not practically justified. All studied hybrids exhibited high contents of linoleic acid (Omega-6) and oleic acid (Omega-9). The hybrids SI Diego, Tolento, Oliva, Etik, and Ballistic showed higher oleic acid contents than olive oil, which makes the oil obtained from these hybrids more suitable for culinary purposes than olive oil. These findings are consistent with previous reports on genetic variability in oleic acid content among sunflower genotypes, highlighting the importance of genetic potential for obtaining high-quality oil suitable for premium market segments (Kurt & Baloch, 2023) [20].

This qualitative advantage of the studied hybrids cannot be adequately evaluated solely through calculations of production costs of sunflower seeds or crude oil. When assessing the economic efficiency of production results, additional indicators based on specific quality parameters may also be applied. For high-oleic (HO) sunflower hybrids, the most important quality indicator is oleic acid content. The purchase of HO sunflower hybrids is directly linked to their high oleic acid content, with an additional price premium of 8.25 BGN per ton paid for each 1% increase above the threshold of 82% oleic acid.

Table 4 presents the main quality parameters of the studied HO sunflower hybrids. All hybrids exhibited oleic acid contents exceeding 82%. On average over the three-year study period, the highest oleic acid content was recorded for the Tolento hybrid, reaching 89.81%. The conversion of quality parameters into higher prices and corresponding economic benefits is presented in Table 5.

The specificity of high-oleic sunflower production is associated with the presence of a price premium resulting from the high oleic acid content of the oil. The results presented in Table 5 indicate that under the conditions of Southern Bulgaria, where agrometeorological conditions are more frequently unfavorable, high-oleic sunflower hybrids can be successfully and efficiently cultivated. The economic efficiency of production was assessed by the level of profit per unit area (hectare) and per unit of output (ton).

The highest profit was obtained from the high-oleic hybrid Tolento, amounting to 378.95 BGN ha^{-1} and 133.2 BGN t^{-1}.

This hybrid has proven to be highly productive and is characterized by a very high

oleic acid content compared to the Oliva and Ballistic hybrids. Very good economic performance was also recorded for the SI Diego and Etik hybrids.

Table 5. Economic evaluation of high-oleic (HO) sunflower hybrids based on production cost, profit, and return on costs

Hybrids	**SI Diego**	**Tolento**	**San Luka**	**Oliva**	**Etik**	**Ballistic**
Indicators	**HO**	**HO**	**(St, linoleic)**	**HO**	**HO**	**HO**
Average yield (kg ha^{-1})	2,572	2,845	2,825	2,324	2,558	2,153
Total revenue (BGN ha^{-1})	1,774.68	1,963.05	1,949.25	1,603.56	1,765.02	1,485.57
Production costs (BGN ha^{-1})	1,105.3	1,144.5	1,131.0	1,097.0	1,092.0	1,037.0
Additional costs (BGN ha^{-1})	425.3	439.6	439.25	435.4	435.3	425.3
Total costs (BGN ha^{-1})	1,530.6	1,584.1	1,570.2	1,552.4	1,557.3	1,462.3
Production cost (BGN t^{-1})	595.10	556.80	555.82	667.98	608.80	679.19
Profit (BGN ha^{-1})	244.08	378.95	379.05	51.16	207.72	23.27
Profit (BGN t^{-1})	94.90	133.20	134.18	22.02	81.20	10.81
Oleic acid (%)	87.86	89.81	37.81	85.87	88.33	86.40
Premium (8.25 BGN t^{-1} per 1% above 82% oleic acid)	48.34	64.43	–	31.93	52.22	36.30
HO premium (BGN ha^{-1})	124.34	183.31	–	74.20	133.17	78.15
Total profit incl. HO premium (BGN ha^{-1})	368.72	552.26	379.05	125.36	340.89	101.42
Rate of profitability (%)	24.08	34.86	24.14	8.07	21.89	6.94

Notes: *HO - high-oleic sunflower hybrids; St – standard (linoleic type).* *A price premium of **8.25 BGN t^{-1}** is applied for each **1% oleic acid content above 82%**.*
Source: Authors' own calculations and experimental data (2021–2023).

An important tool for evaluating economic efficiency and the return on invested resources relative to generated revenues while accounting for the specific quality characteristics of the product and the applicable market premiums is the rate of profitability. This indicator represents a key measure for assessing the economic efficiency of cultivating high-oleic sunflower hybrids. It integrates the effects of yield level, price premium, and cost structure, thereby allowing for a well-grounded evaluation of economic feasibility. Unlike indicators such as income or gross margin, the rate of profitability reflects the relative economic effect and thus provides a more objective basis for comparison among different hybrids. The analysis of empirical data obtained from a three-year field experiment shows that all studied high-oleic hybrids exhibited high profitability rates. In descending order, the hybrids were ranked as follows: Tolento (34.86%), SI Diego (24.08%), Etik (21.89%), Oliva (8.07%), and Ballistic (6.94%). According to literature and practical assessments for sunflower production, including high-oleic hybrids, a profitability rate above 20% is considered very good. Accordingly, the hybrids Tolento, SI Diego, and Etik fall into this category, whereas the Oliva (8.07%) and Ballistic (6.94%) hybrids can be classified as having a satisfactory (acceptable) profitability rate.

CONCLUSIONS

The main conclusion derived from the conducted analysis is that under the conditions of Southern Bulgaria, high-oleic (HO) sunflower hybrids can be successfully cultivated. Some newly developed HO hybrids, such as Tolento, have demonstrated higher productivity compared to linoleic-type hybrids. The HO hybrid Tolento achieved a high profit of 378.95 BGN ha^{-1} and 133.2 BGN t^{-1} and is characterized by a high level of reliability combined with a very high oleic acid content of 89.81%.

The economic analysis indicates that under conditions of high diesel fuel prices and low purchase prices of sunflower seeds (below 800 BGN t^{-1}), the direct use of cold-pressed sunflower oil (CPSO) as fuel in diesel engines provides a significant economic benefit. This benefit is expressed as profit in BGN per liter. The highest profit was obtained for the Tolento hybrid (0.69 BGN L^{-1}) and for the standard hybrid San Luka (0.616 BGN L^{-1}). The price analysis further shows that the direct use of sunflower oil as fuel results in a profit ranging from 64.68 to 81.76 BGN t^{-1}.

Among the studied hybrids, the highest total oil content in seeds was recorded for the Oliva (47.41%) and Tolento (46.10%) hybrids. When oil extraction was performed by cold pressing, the actual oil yield ranged from 34.03% to 37.91%, with Oliva (37.91%) and Tolento (37.44%) again showing the highest values. The combination of high seed yield and high oil recovery through extraction places the Tolento hybrid in first position in terms of oil yield per unit area, reaching 1,311.5 kg ha^{-1}.

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TRENDS IN RISK MANAGEMENT IN THE AGRICULTURAL SECTOR IN BULGARIA

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Abstract

The present study aims to analyze trends in risk management in the agricultural sector in the Republic of Bulgaria, to identify the main prevention factors and challenges and to formulate conclusions for increasing the sustainability of the sector. The relevance of the topic is determined by the need for a changed awareness and attitude towards the problems of risk management related to environmental protection, which are capable of guaranteeing stability and competitiveness of Bulgarian agriculture in conditions of high uncertainty. We make the clarification that we consider only certain types of risk from the point of view of the human factor and conscious behavior and responsibility related to the management of agricultural holdings in terms of biodiversity protection.The aim of the study is to present the main trends in risk management, specifically external environmental risks, in the agricultural sector of the Republic of Bulgaria, focusing on prevention measures through eco-effective strategies and the change in the behavioral approaches of entrepreneurs based on environmental ethics. In the study, we draw attention to the factors necessary for successful prevention, assessment and adequate solutions in risk management in the agricultural sector, namely - the implementation of eco-effective strategies and the priority of environmental ethics. The trend related to the need for ecological-ethical thinking and care on the part of agricultural entrepreneurs to deal with the unpredictability and consequences of external risks in the agricultural sector in the Republic of Bulgaria stands out as a problem. The research methods used in the study include: general scientific research methods, summary and synthesis, logical method, questionnaire survey, tabular and graphical presentation of characteristics and trends. The results of the study formulate guidelines and conclusions related to the awareness of the need for change in the direction of environmentally friendly thinking and behavior of the human factor in the agricultural sector and can be systematized in the following areas: assessment of the impact of using eco-efficient strategies in agricultural activities and the influence of environmental ethics on the managerial approach of agricultural producers. In conclusion, the summarized studies create an idea of the trends in the changed consciousness and attitude of the human factor towards the environment and outline future directions for research in the field of human resources in modern agriculture, related to the prevention of environmental risks.

Key words**:** *agricultural sector, environmental risk, eco-effective strategies, environmental ethics*

INTRODUCTION

The combined efforts and measures of national strategies and policies and the Common Agricultural Policy [10, 3, 5, 6] are of decisive importance for the prevention, management and management of risks in the agricultural sector and ensuring the future of agriculture in the Republic of Bulgaria. A key factor for the successful implementation of the intended goals set out in the CAP and the state policy towards the agricultural sector are human resources [4, 19, 11, 22, 7]. In this presentation, we draw attention to the need for entrepreneurial, environmentally friendly, strategic behavior and thinking of agricultural producers to deal with the unpredictability and consequences of external risks (climate change and environmental pollution), as well as ecological and ethical awareness to prevent or minimize environmental risks arising in the agricultural sector in the Republic of Bulgaria. The legislation, in force since January 1, 2023, establishes during the period a fairer, more humane and more environmentally friendly CAP, which is realized by the changing self-awareness of agricultural producers in their practical activity of managing risks in agriculture. [18, 17, 8, 9].

The study focuses on key trends in risk management within the agricultural sector of the Republic of Bulgaria, with particular

attention to external environmental risks. It emphasizes preventive approaches based on eco-effective strategies and highlights the importance of changes in entrepreneurs' behavior grounded in environmental ethics. The analysis considers the main factors contributing to effective risk prevention, assessment, and response, especially the adoption of environmentally responsible strategies and ethical priorities. A central issue identified is the growing need for ecological-ethical awareness among agricultural entrepreneurs as a response to the uncertainty and impacts of external environmental risks in the sector. The research methods used in the study include: general scientific research methods, summary and synthesis, logical method, questionnaire survey, tabular and graphical presentation of characteristics and trends.

The results of the study formulate guidelines and conclusions related to the awareness of the need for change in the direction of environmentally friendly thinking and behavior of the human factor in the agricultural sector and can be systematized in the following areas: assessment of the impact of using eco-efficient strategies in agricultural activities and the influence of environmental ethics on the managerial approach of agricultural producers. The summarized studies create an idea of the trends in the changed consciousness and attitude of the human factor towards the environment and outline future directions for research in the field of human resources in modern agriculture, related to the prevention of environmental risks.

The care and emphasis on the leading priorities in modern agriculture, in our opinion, namely – the human factor and the environment, as well as the balanced and reasonable combination of effective management and moral attitude, humanity, ethics and environmentally friendly behavior, responsibility for the environment and care for society, necessary for modern agriculture, we can unite and consider in the following main focuses of this work: implementation of eco-effective strategies and promotion of environmental ethics in the agricultural sector for the prevention and minimization of environmental risks in the practical activity of Bulgarian farms.

The main trends characterizing the guidelines for sustainable risk management in Bulgarian agricultural holdings emphasize the leading role of the human factor, with priorities focused on prevention and adequate management of unforeseen risks in the agricultural sector in the Republic of Bulgaria, based on an ecological and ethical component in the strategic plans in the agricultural sector, leading to success in the development and management of the local economy. A significant challenge identified in the study is the shortage of sufficiently qualified entrepreneurs who are oriented toward ecological and ethical principles and capable of effectively applying eco-efficient strategies to manage risks in the agricultural sector. The research focuses on the intersection of key factors required for successful prevention and for achieving a balance between the management of major external and internal risks and the implementation of appropriate measures in the agricultural sector of the Republic of Bulgaria. Particular attention is given to changes in human behavior and awareness in relation to two main categories of risk. External environmental risks include climate change and environmental pollution, which require environmentally responsible attitudes and protective actions. Internal risks are associated with human resources and involve the need for behavioral and mindset shifts grounded in ecological and ethical principles.

The study proposes and emphasizes the main trends and measures that, in our opinion, would contribute to the prevention and minimization of the negative consequences of environmental risks in the agricultural practice of Bulgarian farms, namely:

Environmentally friendly behavior to protect the environment and human health and measures by agricultural producers to achieve these goals by implementing eco-effective strategies (external environmental risks);

-Priority of the ecological-ethical component in the management approach (internal risks) by applying the principles of ecological ethics

to minimize environmental risks in the agricultural activities of producers in the agricultural sector.

This combination of factors makes it possible to successfully manage the main external and internal risks arising in the agricultural activities of agricultural entrepreneurs in the Republic of Bulgaria. The study of scientific literature on the topic confirms its relevance and the need for future research related to environmental protection and risk management in the agricultural sector [1, 2, 13, 16, 12]. Analysis, preventive measures and the managerial approach and self-awareness could reduce or even neutralize adverse effects and serious crisis situations.

The study aims to identify key strategic and behavioral factors, in the author's view, that are associated with the analysis of environmental risks and the development of relevant strategies. These factors are considered essential for achieving balanced and environmentally sustainable management of the agricultural sector in the Republic of Bulgaria. To meet this objective, the study examines the application of eco-effective strategies and the integration of environmental ethics as a guiding principle in management practices within the agricultural sector.

MATERIALS AND METHODS

The methods used to study trends in risk management in the agricultural sector include: general scientific research methods, surveys, observation, review of scientific literature, summary and synthesis of statistical data from official sources, logical method, survey method, graphical presentation of characteristics and trends.

The surveys collect information on the main characteristics of the types of risks and eco-effective strategies, observational and survey studies provide information for analyzing farmers' behavior and judgment for action in different conditions and situations of environmental risk. The literature review provides an opportunity to analyze existing research and new directions of reasoning about the impact of environmental strategies and environmental ethics on agricultural practices. With a combination of these methods, researchers can gain a deeper understanding of how the implementation of effective strategies and the application of environmental ethics enhance the influence and give a determining role to the human factor in risk management in the agricultural sector.

RESULTS AND DISCUSSIONS

According to the Program for Risk and Crisis Management in the Agriculture Sector [5, 20], they are classified as external and internal, focusing on those to which we direct our attention in the presentation:

External risks:

- climate change (eco-effective strategies)
- environmental pollution (environmental ethics)

Internal risks:

- risk related to human resources (behavior and self-awareness).

The main ways and measures for prevention and minimization of environmental risks are most directly related to the purpose of our study, namely - the role of the human factor and the change in consciousness, behavior, actions, decisions arising from the most important problem of modern society - environmental protection for future generations. All strategic documents on a regional and global scale affirm the care and necessary measures and changes to neutralize and minimize environmental risks and the consequences of human activity on nature [6, 17, 22].

Analysis of changes in the behavior and consciousness of the human factor related to external environmental risks - climate change and environmental pollution (environmental attitude and measures for environmental protection) and internal risks - risk related to human resources (behavior and consciousness based on ecological-ethical behavioral change):

The study proposes and emphasizes the main trends and measures that, in our opinion, would contribute to the prevention and minimization of the negative consequences of

environmental risks in the agricultural practice of Bulgarian farms, namely:
(i)Environmentally friendly behavior to protect the environment and human health and measures by agricultural producers to achieve these goals through the implementation of eco-effective strategies;
(ii)Implementation and priority of environmental ethics in the strategies and agricultural activities of producers in the agricultural sector.

Environmentally friendly behavior for the protection of the environment and human health and measures by agricultural producers to achieve these goals through the implementation of eco-effective strategies.

Through the use of eco-effective strategies, emphasis is placed on an important part of the general conscious efforts of humanity to protect and preserve the environment, namely - the protection of biodiversity in the implementation of the economic activities of agricultural producers. We draw attention to basic eco-effective strategies and the necessary measures aimed at minimizing risks and negative impacts on the environment through the implementation of the principles of sustainable development, with the main conclusion in the study being that eco-effective strategies for environmental protection help to achieve a balance between the needs of economic development of agricultural holdings and the vital goals of biodiversity protection [21]. The development of modern agriculture is directly linked to the principles of sustainable development and we draw attention to a relevant part of the specifics of the strategic management of agribusiness. Eco-effective strategies are crucial for minimizing negative impacts on the environment by applying the principles of sustainable development. These strategies aim to reduce risks and harms by taking both preventive and subsequent measures to prevent or minimize the impact of human activity on the state of the environment. They include measures such as avoidance, mitigation, compensation, net gain from biodiversity. It is important to specify that all actions of agricultural entrepreneurs in the listed eco-effective strategies are based on a conscious ecological-ethical awareness and intention and should be carried out after expert assessment, assistance and monitoring of specialists with scientific training, competence and precision and in accordance with European and global directives for the protection of biodiversity and the environment.

Eco-effective strategies for mitigating environmental impacts in environmental protection

The main types of strategies for mitigating environmental impacts, as we have emphasized, include:
- avoidance (trying to preventively specify, correct and not develop economic activity in sensitive and risky ecological areas);
- mitigation (aims to reduce the risk and adverse effects of the functioning and development of agricultural organizations on the flora and fauna);
- compensation (when unavoidable impacts occur, compensatory measures are applied, guided by environmental assessments);
- net gain from biodiversity (involves improving or restoring biodiversity beyond what originally existed in the affected area).

By demonstrating and implementing environmental awareness and responsibility for preserving and improving biodiversity, agricultural producers can contribute to the long-term protection of ecosystems and support the provision of vital environmental services.

A summary of the main types of eco-effective strategies that agricultural producers, the objectives and measures related to the prevention and minimization of environmental risks related to biodiversity conservation, as well as the expected results and benefits, can be synthesized in Table 1.

By implementing a combination of the listed eco-effective mitigation strategies, agricultural entrepreneurs can effectively reduce the risks and environmental impacts of their agricultural operations, while promoting the implementation of sustainable development principles for biodiversity conservation at the national and global levels.

When examining the impact of eco-effective strategies on biodiversity conservation, we

obtain the statistical result presented in Figure 1.

Table 1. Main eco-effective strategies for biodiversity conservation

Basic eco-effective strategies for biodiversity conservation			
Eco-efficient strategy	***Main goal***	***Example measures***	***Expected result***
Avoidance	*Preventing impacts on sensitive ecosystems*	*Environmental assessments, selection of suitable location, restriction of activities in risk areas*	*Minimizing habitat disturbance*
Mitigation	*Reducing the negative impact on nature*	*Pollution reduction, ecological corridors, limiting habitat fragmentation*	*Limiting environmental damage*
Compensation	*Restoring biodiversity losses*	*Creating new habitats, restoring ecosystems*	*Balancing the damage caused*
Net gain from biodiversity	*Improving the state of nature*	*Restoring ecosystems, increasing habitats, conserving species*	*Increase in biodiversity compared to the initial state*

Source: Author's contribution.

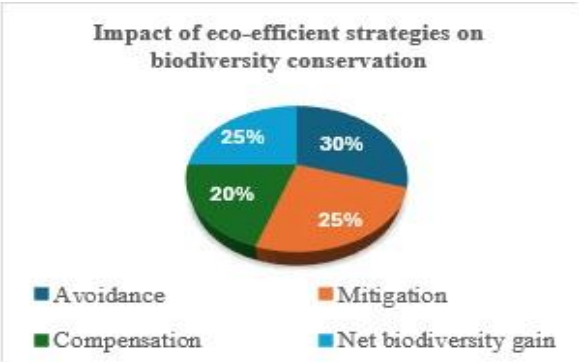

Fig. 1. Impact of eco-effective strategies on biodiversity conservation
Source: Authors' contribution.

Fig. 1 reflects the relative contribution of different strategies to reducing ecological risk and improving biodiversity status. The preventive approach (avoidance) is of greatest importance, as it prevents damage from occurring already at the planning stage.

Main challenges and characteristics of the measures in implementing the strategies for mitigating the environmental consequences

Of crucial importance for the implementation of eco-efficient strategies is the emphasis on the main measures and challenges that exist in mitigating the impact, because by overcoming them, the successful integration of the goals of development and environmental protection is guaranteed (Fig. 2).

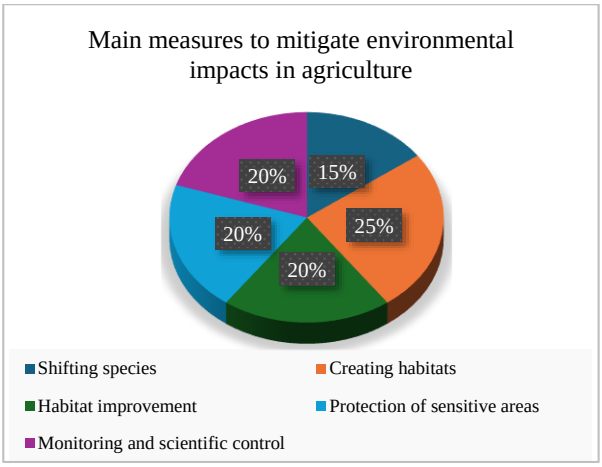

Fig. 2. Main measures to mitigate environmental impacts in agriculture
Source: Author's contribution.

In summary, integrating eco-efficient strategies into the management of agricultural enterprises enables a balanced approach that supports both economic progress and long-term environmental sustainability.

In order to continue and deepen research on the identified trends in the use of eco-efficient strategies for the prevention of environmental risk, we highlight the main challenges in the implementation of the strategies in Table 2.

Table 2. Challenges in implementing eco-efficient strategies

Challenges in implementing eco-efficient strategies		
Challenge	Characteristic	Necessary actions
Insufficient scientific data	Lack of sufficient empirical evidence for the effectiveness of some measures	Conducting more research
Insufficient expert support	The implementation of the measures requires specialists and monitoring	Cooperation with scientific institutes and experts
Legal restrictions	Some policies do not sufficiently incentivize sustainable practices	Updating of environmental legislation
Lack of coordination	Insufficient information sharing between institutions and farmers	Improving data exchange and good practices
Economic constraints	Some of the measures require investments	Financial support and European programs

Source: Authors' contribution.

Based on the analyzes made, the conclusion can be summarized that the implementation of eco-efficient strategies in the management of agricultural holdings is a key factor for prevention and minimization of the consequences of environmental risks in the agricultural sector. Through the combination of preventive, mitigating and compensatory measures, the negative impact on biodiversity is reduced and conditions are created for the restoration and improvement of ecosystems. The effectiveness of these strategies depends on scientifically based decisions, expert monitoring and integration of ecological principles in management practice. In this way, a balance is achieved between the economic goals of agricultural holdings and the long-term protection of the natural environment.

Priority of the ecological-ethical component in the management approach by applying the principles of ecological ethics to minimize environmental risks in the agricultural activity of producers in the agrarian sector

The transition to sustainable agriculture is also related to a behavioral change in the attitude towards the environment. In all European strategic documents related to agriculture, the requirement for humane and ethical treatment of animals and, in general, the environment in general, makes an impression, because only in this way can there be a complete change in the way of cultivating the land, producing food, preserving nature, as well as handing over to future generations a new understanding and attitude towards the common home of humanity.

The ecological-ethical component in the management of risks in modern agriculture finds its application in the concept of ecological ethics.

The basis of the principles of sustainable development is ecological ethics, because the priorities and goals it sets have moral and ethical characteristics. Environmental problems require an ethical and humane attitude, their solution is related to moral dilemmas and moral choices [20].

Environmental ethics are the principles, values, and beliefs that guide individuals and organizations in their efforts to preserve and protect the environment. This ethic often centers around the idea that people have a moral obligation to care for the natural world and to minimize the harm they cause to the environment.

The key components of environmental ethics include:

-*Sustainability* - the belief that human activities should not deplete resources or harm the environment in a way that prevents future generations from meeting their needs;

-*Respect for nature* - recognition that nature has intrinsic value and that people have a responsibility to protect and preserve it;

-*Equity* - ensuring that the benefits and burdens of environmental protection are shared fairly among different population groups and communities;

-*Responsibility* - taking personal and collective responsibility for one's actions and their impact on the environment;

-*Transparency* - being open and objective about the impact of your activities on the environment and holding yourself and others accountable as well.

Environmental ethics is fundamental because it helps guide environmental decision-making and action and ensures that people and organizations act in a way that is environmentally responsible and sustainable. The interaction between environmental ethics and agricultural activity is a fundamental moment and an important trend in the management of risks in agriculture.

As the object of the present study, related to the identified problems and trends regarding the behavioral change in environmental risk management, as well as the analysis of the obtained data, we are targeting agricultural holdings from the Veliko Tarnovo region. The idea is to study agricultural organizations of different types, larger, medium and small farms, and to summarize the opinion of those employed in them about the current reality and the vision of their future development, directing our attention specifically to the determining importance of the human factor in risk management, to people in production activity and their thinking, consciousness and behavioral change in the direction of

responsibility for environmental protection, greening of production, care for human health, in order to prove that the changes and trends in the development of the agrarian sector also have an ethical-ecological nature. The respondents in the questionnaire provide information according to which it becomes clear whether the human factor and its awareness and responsibility are decisive for the successful management of environmental risks in the activity of the agricultural holding (Figure 3).

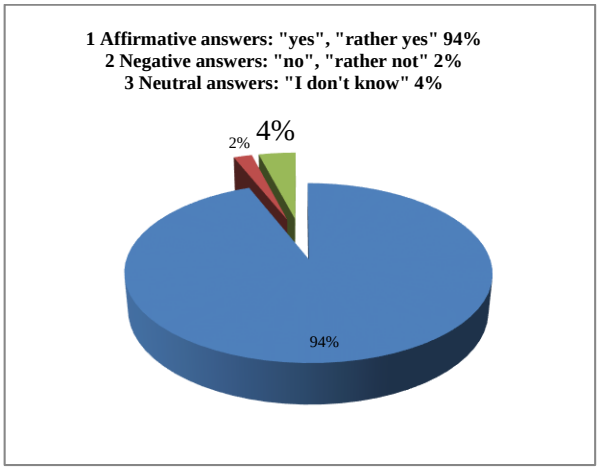

Fig. 3. Importance of the human factor for the successful management of environmental risks
Source: Author's contribution.

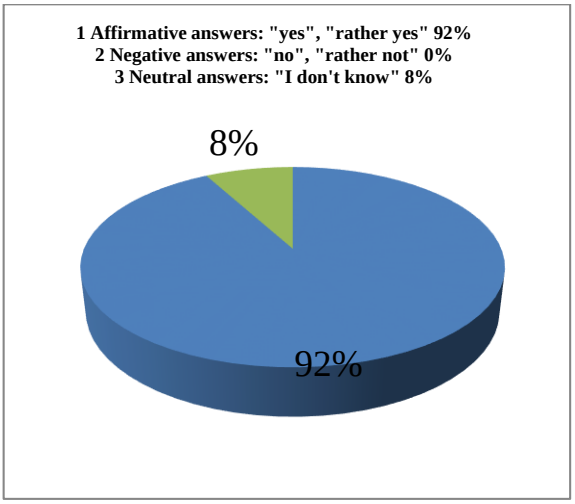

Fig. 4. Importance of environmental ethics in environmental risk management
Source: Author's contribution.

The results, according to which higher environmental ethics, responsibility and self-awareness should be promoted in the agricultural sector, confirm the thesis that the prevention and minimization of environmental risks, however unpredictable and difficult to manage, depend on the reasonable attitude and behavior of agricultural producers towards the environment.

Here the answers are unanimously in the affirmative, which matches our assumption. (Fig. 4).

The fact that the ecological-ethical behavior of those employed in the agrarian sector is influenced by the managerial approach stands out. According to the respondents, the approach of the entrepreneur in the management process should be based on ethics and a responsible and reasonable attitude to the environment, and we can summarize that the proposed risk prevention factors (eco-efficient strategies and environmental ethics) are accepted by the respondents as useful for the effective management of risks (Fig.5).

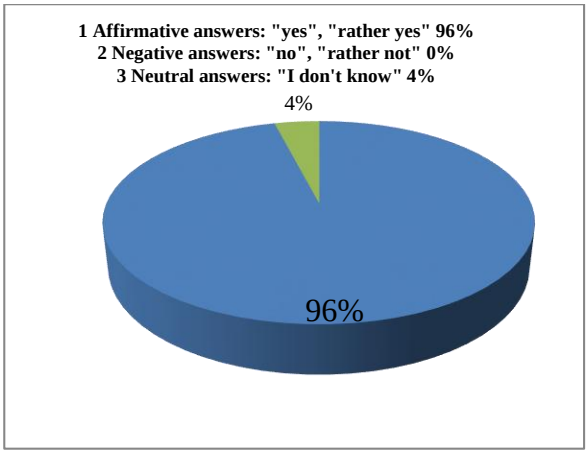

Fig. 5. Importance of ecologically-ethical attitude and behavior in environmental risk management
Source: Author's contribution.

It is interesting that the respondents in a management position estimate the environmental-ethical level of behavior of the management team as very high, but have certain reservations regarding the environmental-ethical level of behavior of the employees. Conversely, respondents who are employees rate their environmental-ethical level highly, but expect more from the management team. Apparently, the divergence of opinions is not accidental and is a clear manifestation of the problem of the contradiction between different value systems, different priorities, different viewpoints

regarding ethics and ecological self-awareness.

As already mentioned, the practical study in the selected agricultural holdings, made through a survey method, is mainly aimed at environmental-ethical behavior and risk management in the agrarian sector. The results of the survey highlight that respondents' views reflect the current level of awareness and attitudes toward environmental issues and ethical practices in agricultural enterprises. One of the key positive findings is the growing integration of ecological and ethical principles into the strategic development of farms included in the study. The participants generally recognize the importance of teamwork, report partial implementation of eco-efficient strategies along with awareness of their advantages, and show readiness to adopt such approaches more widely to improve environmental performance. Furthermore, there is a clear acknowledgment of the need to incorporate environmental ethics as a fundamental element in management practices and strategic decision-making within the agricultural sector. The main conclusions obtained from the practical study establish that the respondents have a certain positive attitude towards the ecological-ethical managerial approach related to the direction of behavior and management.

We can summarize that the interaction between humans and ecology is critical to the success and sustainability of agro-organizations and requires careful management to ensure that modern agriculture remains productive for generations to come. Ecological agriculture means a new responsible attitude towards the natural environment and requires new management solutions.

The formation of environmental awareness and environmental responsibility is a long and slow process because it is related to a change in thinking and behavior. In the essence of ecological consciousness, the ethical component is dominant and defines its character. Ecological awareness is the awareness of responsibility for human actions towards the environment, and this responsibility is associated with the presence of the so-called ecological conscience, and ecological awareness is an indicator of the degree of humanity of the respective society. This degree of consciousness is determined by ethical manifestations towards the surrounding world. Man is faced with the enormous moral responsibility to make a choice that is above all moral and to be realized and accepted as the only possible, reasonable and expedient version of ecological morality. We can summarize that environmental morality is a major factor in improving the modern environmental situation and dealing with environmental risks.

CONCLUSIONS

The lines of reasoning indicated in this presentation confirm the thesis that the further development of humanity is possible only within the framework of ecologically sound and sustainable development, which requires that ecological and economic interests are interdependent in the content of the ecological strategy, which is related to the ecologically sound management of risks in the agrarian sector.

The conclusions of the study on the main trends in the management of environmental risks in the agricultural sector of the Republic of Bulgaria and the influence of the factors of eco-efficient strategies and ecological ethics in the attitude of agrarian entrepreneurs to the environment can provide valuable insight into the practices and behavior of agricultural producers:

-The main conclusion of the study is that the role of human resources in risk management in the agricultural sector is decisive. The change in consciousness and behavior in the direction of ecologically-ethical management of environmental risks is crucial for the prevention and minimization of their negative consequences;

-Eco-efficient environmental protection strategies help to balance the economic development needs of agricultural holdings with the vital objectives of biodiversity conservation;

-We summarize the relationship between management aspects emphasizing and affirming the ethical component in the management process and current environmental problems related to the management of environmental risks in modern agriculture in the concept of environmental ethics. The basis of the principles of sustainable development is ecological ethics, because the priorities and goals it sets have moral and ethical characteristics.

Environmental problems require an ethical and humane attitude, their solution is related to moral dilemmas and moral choices, leading to an innovative managerial approach, uniting economic profitability and ecological sustainability in agricultural practices to achieve balance in agrarian management, which is built on the foundations of ecological ethics. A reasonable and balanced attitude towards the environment gives rise to judgment and conscious choice, and hence appropriate behavior, which we define as rational behavior towards the environment.

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DEMOGRAPHIC DYNAMICS AND AGRARIAN TRANSFORMATION OF RURAL AREAS IN BULGARIA: ANALYSIS OF CHALLENGES, TRENDS, AND STRATEGIC PERSPECTIVES (2024-2030)

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Abstract

The present study aims to examine the relationship between the deepening demographic crisis and the structural transformation of the agricultural sector in Bulgarian rural areas. Through an analysis of statistical data from the National Statistical Institute, Eurostat and the Ministry of Agriculture, the cyclical dependence of the processes has been deduced, expressed through the economic framework of subsidies, which encourages mechanized grain production, which in turn leads to a reduced need for labour. This, combined with better economic alternatives in urbanized centres, accelerates migration and leads to a permanent shortage of human capital, with employment in agriculture falling by 44%. The established "monoculture model" is economically rational for producers, but socially and environmentally unsustainable. By the end of 2024, the share of people over 65 years of age reaches 24.0%, creating a critical labour shortage, most pronounced in areas such as Vidin, Montana and Gabrovo. The study proves that the outflow of people follows a clear economic logic, not a paradox. In conclusion, it recommends policies aimed not simply at subsidies, but at creating vibrant communities through improved transport and digital connectivity, which would revitalize the social fabric of the periphery.

Key words**:** *rural areas, demographic crisis, agrarian transformation, employment in agriculture, smart villages*

INTRODUCTION

The Republic of Bulgaria is at a critical stage of its modern development, characterized by profound and interconnected structural changes in demography and the agricultural sector. This report provides a detailed and multi-layered analysis of the processes taking place in the rural areas of the country, considering the demographic crisis not as an isolated statistical phenomenon, but as a consequence of changes in the agricultural sector. The interaction between the declining and aging population and the restructuring of agricultural production creates a complex feedback loop that defines the socio-economic reality of large parts of the country.

By the end of 2024, the demographic picture in Bulgaria reveals a continuing trend of population decline, accompanied by drastic aging, which is particularly pronounced in rural municipalities [23]. This process is not just a statistical phenomenon, but represents a fundamental change in the human capital necessary to maintain vibrant rural communities. The relationship between this demographic collapse and agriculture is circular. The shortage of labour, combined with the economic logic of subsidies, paved the way for the monoculture model during previous EU CAP planning periods. This in term led to a transformation from labour-intensive horticulture to highly mechanized grain production, which required significantly less labour resources and was economically rational for farms, but socially destructive, as it further accelerated the migration of the population to cities due to lack of employment [6].

In this context, the paper aimed to study the connection between the demographic crisis and the structural transformation of Bulgaria's agriculture and rural areas.

MATERIALS AND METHODS

The conclusions drawn in the report are based on a thorough review of statistical databases from the National Statistical Institute (NSI) and Eurostat, as well as research by the

Institute for Market Economics (IME), the Ministry of Agriculture and Food (MAF), as well as academic studies and strategic documents, including the Strategic Plan for the Development of Agriculture and Rural Areas 2023-2027. The analysis covers not only the quantitative dimensions of the crisis, but also changes in the quality of life of the rural population, access to services, transport connectivity and the emergence of innovative revitalization models such as "smart villages" and social farming.

RESULTS AND DISCUSSIONS

The demographic collapse – National and regional dimensions

National demographic profile by 2024

The demographic situation in Bulgaria as of December 31, 2024 continues to deteriorate, following the long-term negative trends established in recent decades. According to NSI data (2024) [23], the country's population has decreased to 6,437,360 people, which represents over 8,000 people in just one calendar year. This decline is the result of the sustained effect of the so-called "triple negative" – negative natural growth, an aging age structure and ongoing net migration from rural to urban areas and abroad.

The age structure of the population is a key indicator of the future potential of the country. The share of the population aged 65 and over is already 24.0%, while children under 15 make up only 14.0% of the country's population [23]. This ratio creates an extremely high age dependency ratio (61.3% by the end of 2024), which means that for every 100 people of working age, there are over 61 dependents (children and the elderly) [23]. For the economy of rural areas, where the tax base is low and the needs for social and health services are high, this poses a huge challenge.

Urban-rural typology and territorial imbalances

Aggregated national data conceal the deep gap between urban centres and rural periphery. According to Eurostat's (2024) typology, Bulgaria is characterized by some of the largest regional imbalances in the European Union. While the population in predominantly urban regions (such as Sofia-city, Plovdiv and Varna) remains relatively stable or even slightly increases thanks to internal migration, predominantly rural areas face an existential threat [13].

The analysis of age pyramids by the typology "urban-rural" reveals that in predominantly rural areas the pyramid is "inverted". There is a critical deficit of young people in the age groups 20-29 and 30-39 years – the periods of most active economic activity and reproduction [13]. This phenomenon is explained by the mass departure of young people who migrate to large cities or abroad for the purpose of education and professional realization. As a result, rural areas lose their demographic reproductive potential, which leads to a spiral effect of depopulation.

An interesting and worrying aspect of rural demography is the gender imbalance. Eurostat data (2024) show that in predominantly rural areas, in the age groups up to 50-54 years, men predominate [13]. This is a consequence of the so-called "female migration" - women are more likely to leave rural areas in search of education and work in the service sector, which is concentrated in cities. Men, on the other hand, more often remain in their hometowns, engaged in the agricultural, construction or mining sectors. This imbalance leads to persistent social loneliness and lack of partners for men of working age, which erodes the social fabric of the community and accelerates depopulation, turning villages into territories of single households. This imbalance is not an isolated phenomenon in Bulgaria. A report by the EU CAP Network (2025) highlights that at EU level there is a significant gender gap in farm managers, with women representing only 23% of farmers in 2020, and for young farmers (under 39) this share drops to 19.5% [10].

The term "demographic desert" is increasingly used by demography experts to describe territories where population density has fallen below a critical minimum (usually below 10 people per sq. km), with this process currently most pronounced in North-western Bulgaria, the Kraishte and Strandzha-Sakar regions. According to recent analyses, the

districts of Vidin, Montana and Gabrovo are among the most affected, with Vidin often cited as the first district to fall completely into this category, closely followed by parts of the districts of Lovech, Kyustendil and Pernik, where entire municipalities remain almost depopulated and with a highly aging structure (Table 1). According to the analysis "Horizon 2030: Demographic Trends in Bulgaria", by 2030, 60% of the country's territory is expected to become a demographic desert. Bardarov and Ilieva (2022) predicted that by 2040 this share would increase to 69-70% [4].

Table 1. Comparative demographic indicators by region (2023-2024)

District	Share of population 65+ (%)	Natural increase (‰)	Economic profile	Demographic forecast
Vidin	31.4%	-18.7	Grain production	Critical / Depopulation
Montana	29.8%	-15.5	Grain / Industry	Critical / Depopulation
Gabrovo	30.5%	Negative	Industry / Aging Village	Severe aging
Smolyan	30.0%	Negative	Tourism / Small-scale agriculture	Population decline
Sofia (capital)	19.2%	-1.9	Services / Technologies	Stability / Growth
Varna	21.6%	- 6.8	Tourism / Transportation / Grain	Moderate decline
Dobrich	28.5%	-10.7	Industrial grain production	Accelerated aging
National average	24.0%	- 6.8	-	Decline

Sources: Own calculations based on the data from National Statistical Institute, 2024 [23], Eurostat, 2024 [13], Institute for Market Economics, 2024 [18].

"The Vidin Syndrome"

Vidin district has become a byword for demographic catastrophe not only in Bulgaria, but also in the entire European Union. It illustrates the final stages of the depopulation process and the consequences for the local economy and social structure. According to Eurostat data (2024), for the period 2012–2022, Vidin district recorded the largest population decline among all rural regions in the EU—nearly 27% [13]. This statistic shows a loss of over a quarter of the region's human capital in a decade. By the end of 2024 (NSI), Vidin is the district with the highest share of the population aged 65 and over – 31.4% [23]. In practice, every third resident of the district is a pensioner. At the same time, the share of children is among the lowest (11.4%), which guarantees that the labour force will continue to shrink in the future. The natural growth rate in Vidin is extremely negative, reaching an average of -18.7‰ per year (Eurostat, 2024) [13]. Mortality exceeds birth rate at a ratio that makes natural population recovery impossible. This pattern is reproduced, albeit with varying intensity, in other districts such as Gabrovo (30.5% adults), Smolyan (30.0%) and Lovech. In these areas, entire villages are completely depopulated or reduced to a few dozen inhabitants. Statistics report 199 settlements in Bulgaria without a single inhabitant by the end of 2024, and the number of villages with a population of less than 50 people ("ghost villages") is growing annually [23].

Migration patterns

Migration is a two-way process, which in the case of Bulgarian rural areas acts almost entirely as a "pumping" mechanism. In terms of internal migration, the main flow is directed from villages to regional centres and from regional centres to the capital Sofia. Sofia-city is the only region with a share of the elderly population below 20% (19.2%) and continues to attract young people [23]. This leads to a concentration of economic activity and innovation potential in one point of the country, while the periphery remains without human resources for development. Although Bulgarian agriculture at certain times and sectors experiences difficulties in providing labour resources, thousands of rural residents continue to choose seasonal migration to Western Europe every year. This process is not paradoxical, but follows a clear economic logic. Bulgarian workers choose the better economic alternative, since wages abroad exceed many times those in the agricultural sector in the country. The problem is not only the lack of people, but also the low competitiveness of wages in the Bulgarian agricultural sector, which makes working abroad a preferred survival strategy. Higher wages abroad are an irresistible "pull" factor and lead to "labour drain", which deprives local producers of an experienced

workforce and forces them to look for alternatives [12].

Transformation of the agricultural labour market

The demographic collapse has a direct impact on the agricultural labour market. The lack of people is not just a statistical fact, but an operational constraint that is changing the way business is done in the sector.

The disappearance of the workforce

The data is clear: the workforce in Bulgarian agriculture is melting away at an unprecedented pace. According to OECD and CEIC data (2025), employment in agriculture has fallen from a peak of over 251,000 people in 2008 to a historic low of 141,875 people in December 2024 [5]. This represents a contraction of nearly 44% in less than two decades (Table 2).

Table 2. The collapse of agricultural employment (2008-2024)

Year	Employed in agriculture (thousands of people)	Trend
2008	251.05	Peak value before the crisis
2015	~200.00	Moderate decline
2023	166.38	Accelerated decline
2024 (Dec)	141.88	Historical low

Source: Own calculations based on the data from CEIC Data / OECD (2025) [5].

It is recognized as the result of the intensive mechanization and digitalization of the sector, which allowed for higher productivity with fewer human resources, in parallel with the consolidation of farms. Eurostat data (2025b) confirms this trend, noting that Bulgaria recorded the sharpest decline in labour input in agriculture in the entire EU for the period 2009-2024 – by an average of 7.7% per year [15].

Farmer Profile: Aging and Lack of Continuity

According to Kabadzhova (2022), generational renewal is more likely in farms that are more profitable and have a stable market share, while smaller farms face the risk of going out of business due to a lack of successors [20]. Additionally, the ratio of young to older farmers in the EU remains critically low, with countries such as Bulgaria and Portugal reporting this problem as one of the most acute according to the indices of the severity of the demographic problem in agriculture [10].

The profile of those employed in agriculture reflects the general demographic picture, but is even more skewed towards older age groups. Only 11.9% of farm managers in the EU are under 40, and in Bulgaria this share is among the lowest in the union. The majority of farmers (56%) are over 55 [14]. The problem with the "young farmer" is structural. Due to the low prestige of the profession, difficult working conditions and better opportunities for employment and social life in cities, farmers' children are increasingly less likely to take over the family business. This leads to land consolidation and specialization after the owners retire, as small farms often cease to exist or are absorbed by larger structures.

Labour Import: The New Normal

To compensate for the deficit, farmers, especially in labour-intensive sectors and in regions such as North-eastern Bulgaria (the country's breadbasket), are forced to import workers from outside the EU. Workers from Ukraine, Moldova, Kyrgyzstan, Uzbekistan and Turkey are increasingly being hired [12]. This process is accompanied by administrative burdens, but it is the only way to save the harvest at peak work periods. The labour shortage is most acute in the North-western and South-Central regions, where it coincides with the highest levels of depopulation [6]. In these regions, farmers are faced with a dilemma: to mechanize production completely or to stop it.

Structural changes in agricultural production – Monoculture in Bulgaria

One of the most important conclusions of this analysis is that the relationship between rural areas and agriculture is circular, leading to a change in the structure of crops grown. The lack of labour is forcing the sector to reorient itself from the traditional Bulgarian production of fruits and vegetables to the cultivation of cereals and industrial crops.

From the "Garden of Europe" to the export of raw materials

Historically, Bulgaria was known for its vegetable and fruit growing – sectors that

require a lot of manual labour for pruning, picking, sorting and processing. Today, these sectors are in deep decline. Over the past 20 years, tomato production has halved – from 240,000 tons to around 120,000 tons. Pepper production, an emblematic crop for the country, has also decreased by 50%. The viticulture sector has reported a 60% decline in recent years [24]. Today, the situation has changed radically and the main reason is not only the lack of labour, but also the loss of competitiveness. The modern consumer expects fresh products all year round, which necessitates greenhouse production. The seasonality of the climate in Bulgaria and high energy prices make year-round cultivation too expensive compared to imports. Bulgarian products have become uncompetitive in price, and producers have abandoned them for better economic alternatives in grain production. However, reorienting towards organic farming could reverse this trend. As Agapieva-Aliosman and Dirimanova (2021) point out, organic production is not only an environmental necessity but a vital economic instrument for generating employment in rural areas, offering higher added value than conventional monocultures [1].

The rise of monoculture grain production

The transition to monoculture farming is a direct result of the economic framework of the Common Agricultural Policy (CAP). The unified area payment supported the production of food products with radically different factor requirements at the same level despite the huge differences in production costs. Since grain production has much lower costs and a high degree of mechanization, the subsidy covers a significant part of the inputs, making it the most economically efficient choice for farmers. This naturally pushes out labour-intensive production and drastically reduces the need for labour, which, left without a livelihood, migrates to the cities. This model is economically rational for farms, but socially destructive for villages, as it does not retain the population. As of 2019, grain and technical crops occupy 62% of the utilized agricultural area and form 53% of the value of production [6]. In regions such as Dobrudzha, these crops cover over 90% of the arable land. One operator with a modern combine harvester can process hundreds of hectares of land, replacing the labour of dozens of people. This model is economically efficient for landowners, but socially inefficient for rural areas, as it creates minimal employment. A 1,000-hectare grain farm can provide employment for 3-5 people, while the same vegetable farm would employ hundreds [6]. This specialization makes the sector dependent on international commodity prices and weather conditions, while leading to soil impoverishment and a decrease in biodiversity.

The hidden social network

In the shadow of large-scale industrial agriculture, a parallel, informal structure exists. It is not measured in stock market indices, but in human connections, survival and solidarity. This "hidden social network" functions through mechanisms that often remain invisible to official statistics, but are vital to Bulgarian society.

In small towns and villages, money often gives way to in-kind exchange. The "hidden social network" is activated when the formal market is inaccessible or too expensive. For the elderly population in villages, the home economy is not just a source of additional income to low pensions, but a mechanism for providing fresh, high-quality products that would otherwise be unavailable to them on the market. The main goal is the food security of the household – a kind of "social safety net" that guarantees access to nutritious food even with minimal financial resources. About half of households in Bulgaria grow some form of food for their own consumption [16, 32]. This creates a mutual aid structure that allows people with minimal cash income (low pensions) to maintain a higher standard of living than their finances allow.

This in turn is an integration link between generations. One of the most powerful channels of this network is the transfer of food from rural areas to urban centres. This is a phenomenon that connects the aging population in depopulated areas with their children and grandchildren in large cities. As for the elderly, food production gives them a sense of usefulness and social significance.

They are not just a "burden" for the health system, but active sources of wealth for the family. For young people, usually living in the city, this transfer of products acts as a support, reducing their food costs and increasing the quality of consumption (organic/eco products, although without certification).

As Fredriksson et al. (2021) [16] and Yoveva et al. point out (2000) [34], these farms are "invisible" to GDP but critical to food security. In periods of economic turmoil (high inflation, pandemic, unemployment), this hidden network expands. The household farm becomes a guarantor that even in the absence of cash, physical survival is ensured. The network captures vulnerable households with low levels of food security, which the state's social system would otherwise not be able to compensate for.

At the same time, it is reported that the concentration of agricultural land in Bulgaria is among the highest in the European Union. According to an analysis by the World Bank (2021), the statistics show a startling disproportion: about 1.5% to 2% of individuals and legal entities control and cultivate over 80-85% of the agricultural land, a process that is most clearly expressed in the "breadbasket" of Dobrudzha [33]. This model, which according to the report is mainly powered by the mechanism of direct European subsidies per area, has created a class of super-powerful tenants who have imposed monoculture agriculture (wheat, corn, sunflower) at the expense of labour-intensive productions such as fruits, vegetables and livestock. The enormous financial resources concentrated in the hands of a few provide them with disproportionate lobbying influence, with which they not only dictate the allocation of the agricultural budget, but also have the potential to destabilize the political situation through large-scale protests with agricultural machinery, speculation on the prices of basic foods, and pressure on any government that tries to change the status quo [3].

Land concentration is not the only problem. According to a large-scale study by the EU CAP Network (2025), access to land has been identified as the most serious barrier to the entry of young farmers into the sector in almost all Member States, with high prices and speculation further complicating the situation for new entrants [10]. One of the most sustainable mechanisms for counteracting the concentration of land and capital is the unification of small and medium-sized owners in modern cooperatives. According to the analyses of Doychinova (2020) on the sustainability of agrarian structures, this is a successful European model, which in Bulgaria still faces a serious psychological barrier due to the historical trauma of forced collectivization (Labor Cooperative Farms - TCZS). Through cooperation, small producers can overcome the impossibility of economies of scale by investing jointly in modern equipment, storage facilities and processing plants, which would allow them to close the production cycle and retain added value in the local community. This approach would not only create a real market alternative to large grain producers, restoring the diversity of crops (fruits, vegetables) and livestock, but would also increase their negotiating power vis-à-vis retail chains, guaranteeing fairer purchase prices and social stability in small settlements [7, 8].

Socio-economic infrastructure and quality of life

People's decision to stay or leave a rural area depends not only on the availability of jobs, but also on access to basic services – transport, healthcare and education. In Bulgaria, the degradation of this infrastructure acts as a powerful "push" factor for migration.

Transport connectivity

Research (2023) focused on the Stara Zagora region clearly shows that transport accessibility is the main divider between "living" and "dead" villages [26]. The specific dimensions of this process can be traced through the example of the Stara Zagora municipality, which serves as a representative model for the region. The data illustrate the mechanism by which temporal distance to the economic centre acts as a major factor for demographic sustainability:

Table 3. Transport accessibility: The example of Stara Zagora municipality (Travel time to the centre)

Travel time (car)	Number of villages	Demographic status
0 - 10 min	16	Stable / Periurbanization
11 - 15 min	14	Relatively stable
16 - 20 min	12	Risky
21 - 30 min	8	Depopulated

Source: Transport Development Study (2023) [26].

In the villages close to the regional centres (10-15 min. of transport accessibility), rural communities of a new type are being formed – young families and economically active people who work in the city but live in the countryside [26]. In these areas, there is even a process of "periurbanization" - the relocation of city dwellers to nearby villages [30]. This leads to the flourishing of local services – kindergartens, courier offices, shops and insurance agents. These people are not employed in agriculture, but they revitalize the social community of the village, making good transport connectivity the most important factor for demographic stability. Beyond the 30-minute travel zone, depopulation accelerates dramatically. Public transport in these areas is irregular or absent. Over 30% of the municipal road network has not been repaired for more than 30 years, which physically cuts these settlements off from the world [22]. The decline in population makes bus lines unprofitable, carriers are thus discontinuing them, which forces more people to leave because they can't get to work or access medical services.

Health and social "desert"

According to data from the Institute for Market Economy (2024, 2025), regional profiles reveal dramatic disparities in access to healthcare. In Dobrich district, one general practitioner (GP) serves an average of 1,455 people, but this figure is averaged. In many remote villages, there is no doctor's office at all, and the doctor visits the village once a week or less [18, 19]. In Kyustendil, for example, despite the high number of general practitioners (GPs) per capita, there is a lack of specialist doctors, which necessitates a trip to Sofia for more serious treatment. The same applies to Pernik, Montana and Vratsa. The doctors and nurses themselves in rural areas are of pre-retirement and retirement age, which portends an even more severe crisis in the near future.

Education

The education system in rural areas generates inequalities. Students in rural areas show significantly lower results in the National External Assessment (NEA). In Kyustendil, the average score in mathematics after the 7th grade is 35.8 points, compared to the national average of 42.9, and in Dobrich it is 33.8 [18]. The optimization of the school network has led to the closure of many educational institutions in rural areas. Children are forced to travel daily to secondary schools in municipal centres, which lengthens their day and disconnects the school from the local community. The lack of a local school is often the final signal for young families to leave the village.

Policies, Innovations and Development Strategies

How are the state and the EU responding to these challenges? The main instrument is the Common Agricultural Policy (CAP), in which new, innovative approaches are also emerging. For example, the CAP Strategic Plan 2023-2027 for Bulgaria. This plan has a budget of over €5.6 billion and attempts to address structural problems. The plan allocates €436 million specifically to support young farmers [11]. The aim is to stimulate generational renewal. The effectiveness of these measures depends on the correct linking of result indicators, such as the number of young farmers starting with CAP support, to specific generational renewal targets [20]. However, the EU CAP Network analysis shows that while instruments such as start-up aid (INSTAL) and supplementary income support (CIS-YF) are widely used and necessary, they alone cannot address structural barriers such as access to land and administrative burden [11]. A more comprehensive approach is needed, which also includes national instruments to facilitate inheritance and access to financing.

A report by the European Commission notes that access to land (controlled by large grain producers) is a greater barrier than the lack of subsidies. Payments targeted at small and medium-sized farms are being introduced,

with a cap on subsidies for the largest, to reduce inequality. Over €600 million is allocated for "coupled support" for vulnerable sectors such as fruit and vegetables production, as well as livestock farming [11]. The rationality is focused on the need to support production that creates employment in order to prevent it from diminishing. For the sustainable development of these areas, it is crucial that support is not limited to agriculture alone, but encourages diversification into non-agricultural activities that can reduce socio-economic disparities between regions [2].

The Smart Villages concept

Smart villages are a new development paradigm that relies on digitalization and local initiative. The village of Kurtovo Konare (Plovdiv region) is an example of a successful implementation of a smart village strategy. The local community, known for its tomato and pepper production, uses cultural heritage (the Pepper and Tomato Festival) and digital marketing to create a brand and develop tourism [29]. The strategy involves cooperation between the community centre, local businesses and the administration. The national strategy emphasizes broadband internet in villages and the digitalization of agriculture (precision farming), but the administrative capacity of small municipalities to win projects remains an obstacle [31].

Social Entrepreneurship and "Baba Residence"

Initiatives such as the Baba Residence demonstrate an innovative approach to revitalization. The project connects young urban people with older people in depopulated villages to exchange knowledge and provide help. This not only brings life to the villages, but also creates networks of solidarity and potential for new economic activities (cultural tourism, crafts) [25].

Social farming ("Green Care") is also gaining momentum as a model for integrating vulnerable groups through agricultural labour, providing new social value to rural areas [9, 28].

In parallel, the model of rural coworking and co-living spaces is developing, transforming depopulated mountain regions into international hubs for digital nomads. The example of Bansko, which has transformed from a seasonal ski resort into a year-round destination for remote professionals, demonstrates how attracting "global talent" can stimulate local microeconomies beyond traditional agriculture [27].

At the level of cultural revitalization, art residencies also play a key role in revitalizing community life. Associations such as the "Old School" in the village of Gorna Lipnitsa use abandoned buildings to attract artists from all over the world, whose presence not only enriches the environment but also restores a sense of identity among the local population [17].

CONCLUSIONS

The analysis of demographic and agrarian transformative processes in Bulgaria paints a picture of a profound change, in which the depopulation of villages is not an easily reversible process due to the strong demographic inertia. However, complete collapse is not inevitable if state policies refocus from attempts to mechanically save everything to adaptation and strategic support. The key to the viability of these areas lies in the understanding that they should not be just places to live, but centres of economic activity. This requires moving beyond narrow agricultural production and stimulating an environment that encourages entrepreneurship and innovation.

The most effective measures for rural revitalization are aimed at stimulating alternative employment and economic activities not directly related to agriculture. Investments in transport and digital infrastructure are fundamental, as good connectivity with urban centres allows villages to develop as vibrant peripheries. New value chains, such as renewable energy, the bioeconomy and ecotourism, offer significant growth potential. Only through improved connectivity and specific support models for isolated areas (such as mobile services) can these new sectors unlock real employment and retain the population.

In parallel with alternative employment, the state should aggressively support labour-intensive agricultural sectors – fruits, vegetables, and organic farming – not only for food security reasons, but also as a tool for preserving jobs. While grain production is economically successful, it remains socially neutral due to its low need for manpower. To make the sector attractive to young people, serious investments are needed in vocational education focused on high-tech and digital agriculture. Without this modernization, agriculture will continue to rely on aging personnel and imported labour.

Effective rural governance requires moving away from one-size-fits-all policies, as the needs of regions like Vidin are fundamentally different from those of Plovdiv. As Marinov (2019) points out, the rural areas in the country are diverse in terms of geostrategic location, physico-geographic, socio-economic and ecological features, which constitutes one of Bulgaria's biggest resources [21]. Therefore, decentralization of resources and local decision-making are critical to the success of initiatives like "smart villages". By delegating authority, local communities can better identify their specific strengths, whether they are in industry, services or crafts, turning regional differences from a handicap into a strategic advantage for economic diversification.

Ultimately, the future of the Bulgarian village depends on society's ability to recognize that these areas are complex living spaces, not just food production sites. Their preservation requires integrated efforts in healthcare, education, and transportation, combined with a modern economic vision. When rural areas offer quality infrastructure and opportunities for diverse professional realization outside of traditional agriculture, they will cease to be fading functions and will become a sustainable part of the national economy.

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