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ASSESSING THE DEGREE OF INNOVATION IN THE EUROPEAN RURAL ENVIRONMENT THROUGH A MULTI-INDICATOR COMPARATIVE ANALYSIS

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Abstract

The present research aims to analyze the relationship between innovation and sustainable economic development in the rural areas of the European Union, in the context of the transition towards a knowledge-based economy and territorial balance. The main aim of the paper was to identify to what extent factors such as education, employment, logistics infrastructure and economic structure influence the innovation capacity of European rural regions. The methodology applied was based on a comparative quantitative analysis, using official statistical data for the period 2018–2023, extracted from Eurostat sources, and focusing on five relevant indicators: gross domestic product per capita, employment rate, share of the population with tertiary education, employment in industry and agriculture, and volume of road freight transport. The analysis included both comparisons between Member States and correlations between indicators, applied to annual series and multi-annual averages, in order to capture both recent dynamics and structural patterns. The research results show the existence of clear differences between the European Union Member States regarding the conditions that support rural innovation. Western and northern European countries are distinguished by high GDP per capita, high levels of tertiary education, dynamic labour markets and an efficient logistical infrastructure, which favour the rapid adoption of modern agricultural technologies. Southern and eastern countries present structural imbalances: a high employment rate in agriculture, a low level of skilled human capital and low economic performance, which limit the diffusion of innovations and maintain vulnerabilities. Correlational analysis confirms these findings and leads to the conclusion that rural innovation depends on a combination of economic performance, human capital and infrastructure, which requires differentiated policies to reduce the gaps. The overall conclusions indicate the need for integrated European strategies, able to capitalise on the advantages of developed regions and mitigate the structural deficits of those lagging behind, in order to ensure innovative convergence and the sustainability of European agriculture.

Key words: *innovation, rural environment, multi-indicators, economic development, E.U.*

INTRODUCTION

In recent decades, the European rural area has undergone a complex transformation process, in which the dynamics of globalization, demographic developments, climate change and digital transition have profoundly influenced its functions, structures and development prospects. If in the past the rural environment was perceived almost exclusively through the lens of agriculture, today it is recognized as a multifunctional space, in which economic, social and ecological activities interact in an increasingly complex way [2, 15]. In this context, innovation – in its multiple forms – has become an essential pillar for economic revitalization, territorial cohesion and the sustainability of rural development [23, 25].

The theme of innovation in the rural areas of the European Union is today at the heart of public policy and scientific research concerns, in response to multiple challenges: depopulation of rural areas, population aging, decline in economic competitiveness, vulnerability of infrastructure and regional inequalities [4, 16]. At the same time, these spaces are also sources of untapped potential:

natural resources, social capital, biodiversity, productive traditions and resilient local communities. In this framework, innovation is perceived not only as a technological process, but as a systemic transformation involving new forms of organization, digitalization, participatory governance and reconfiguration of relationships between local actors [1, 13, 24].

The European Union has explicitly recognised the central role of innovation in rural development through policies such as the Farm to Fork Strategy, the European Green Deal or the long-term vision for the EU's rural areas 2021–2040 [14, 17]. Also, initiatives such as Smart Villages, the European Funding from the Horizon Europe Program or the Innovation Partnership in Agriculture are tangible tools for fostering innovation in rural regions [18]. In addition, Pillar II of the revised Common Agricultural Policy include support measures for innovation, digitization, and collaboration among farmers, SMEs, and research facilities. Accordingly, the European Commission's 2024 report on rural finance highlights that innovation sits at the intersection of social cohesion, technological advancement, and participatory governance rather than being reduced to traditional economic measurements [11]. The long-term vision for rural areas highlights the objectives of transforming them into stronger, more connected, more resilient and prosperous communities, and financial instruments such as EAFRD, LEADER/CLLD and EIP-AGRI partnerships directly contribute to achieving these targets through projects aimed at digitalisation, economic diversification and social innovation [3]. Recent territorial analyses indicate that the gaps between western and northern regions, on the one hand, and southern and eastern regions, on the other, are not only explained by differences in GDP, infrastructure or human capital, but also by the level of integration of public policies and the degree of community participation [21]. Thus, Member States that have developed holistic national strategies and have used European funds (CAP, ERDF, ESF, EMFAF) in a complementary manner perform better in absorbing innovations and strengthening rural resilience, compared to countries where policies remain fragmented and sectoral.

Therefore, rural innovation should be understood as the result of the interaction between economic performance, human capital, logistical infrastructure, digitalisation and social capital, and reducing territorial disparities requires differentiated policies, sensitive to local specificities, but also strategic coordination of European and national funds [20]. Such an integrated approach not only supports innovative convergence, but also contributes to the long-term sustainability of European agriculture and rural economies.

However, the literature and European reports show that territorial differences in the innovation capacity of rural regions are still significant [5, 12, 19, 22]. Western and northern European regions benefit from high-performance infrastructure, consolidated innovation ecosystems and access to skilled human capital, while rural regions in the eastern and southern EU often face structural constraints that limit the absorption and generation of innovation. In addition, there is a lack of integrated data and analyses that correlate the level of innovation with indicators such as education, employment, economic structure or transport infrastructure – essential factors in shaping a clear picture of rural development.

Therefore, the present research aims to contribute to this analytical effort, starting from the following central question: What are the relevant correlations between innovation and sustainable economic development in the rural environment of the European Union in the period 2018–2023?

From a theoretical point of view, the research is anchored in the concept of systemic innovation, which goes beyond the classical understanding of innovation as a technological result and proposes an integrative vision, in which the interaction between institutions, knowledge, practices and economic and social structures generates sustainable transitions. In recent literature, rural innovation is conceptualized in close connection with the notions of human capital, social capital and multiscalar governance, highlighting the role of local communities, partnerships and

knowledge networks in stimulating development. Thus, sustainable rural development becomes not only a matter of material investments, but also of collective learning capacity and institutional adaptability.
In addition to the scientific purpose, the present research also has a practical stake: supporting the formulation of differentiated public policies for the European rural environment, based on clear empirical evidence whose results can contribute to: identifying rural regions with high innovation potential, but economically underperforming; supporting investments in education and infrastructure as accelerators of sustainable transition; strengthening the arguments for an integrated approach to innovation in rural development policies post-2027.
The research topic aligns with a major challenge for the European Union: how can innovation be stimulated in territories characterized by economic fragility, structural dependence and geographical exclusion, without reproducing the urban-industrial development model? The answer requires not only complex statistical analyses, but also a rethinking of dominant paradigms, in favor of an inclusive, territorial and sustainable vision of development.
Thus, the present paper aims to contribute to this endeavor through a solid empirical analysis, offering a comparative and updated picture of the role of innovation in shaping the present and future of the rural environment in the European Union.

MATERIALS AND METHODS

The study, which used a quantitative-comparative methodology, sought to examine the connection between the level of innovation and sustainable economic growth in EU rural regions between 2018 and 2023. To capture both temporal dynamics and structural patterns, the analysis is cross-sectional and multi-annual, utilizing both yearly series and multi-annual averages. The European Union's member states, seen at the national level, serve as the analytical unit.
The data were collected exclusively from the official Eurostat database, which guarantees comparability and statistical accuracy. The annual values available for the period 2018–2023 were used, an interval chosen because it provides a recent framework, but sufficiently extensive to capture both the effects of the crisis generated by the COVID-19 pandemic, and the economic recovery trends. The statistics are national averages based on Eurostat's established territorial typologies and classifications, with the EU Member States serving as the territorial units of reference.
In the absence of direct measures of innovation in rural areas (such as research and development expenditure or the number of patents, which are not available at an updated level), proxy indicators were selected, with demonstrated relevance in the specialized literature:
Gross domestic product per capita, as a measure of economic performance and resources available for innovative investments
Employment rate, as an indicator of the integration of human resources and the capacity of the labor market to absorb innovative activities.
The share of the population with tertiary education, for the purpose of locating highly qualified human capital, which is essential for the development and dissemination of innovations.
The share of the population employed in agriculture and industry, as a measure of the rural economic structure, between dependence on traditional sectors and diversification towards innovative activities.
The volume of road freight transport, as a way of measuring the logistics infrastructure and economic connectivity, crucial factors for the dissemination of innovations.
These indicators provide a complex picture of the structural conditions that can favor or limit innovation in the European rural space.
The statistical analysis was carried out in several stages:
Descriptive analysis consisting of calculating means, extremes and standard deviations, to highlight differences between countries.
Multinational comparative analysis that was the basis for identifying groups of countries with similar profiles based on the five indicators.

Correlation analysis by applying the Pearson coefficient for normally distributed variables and Spearman for asymmetric distributions, with the interpretation of the results according to statistical significance ($p < 0.05$) and the intensity of the relationship.

The analysis is subject to inherent limitations. First, the lack of direct indicators of rural innovation (research and development spending, patents, organizational innovations) reduces the degree of precision of the assessment. Second, the use of national averages can mask intra-state disparities (between rural and urban regions or between peripheral and central areas). Despite these limitations, the selection of indicators is validated by the scientific literature, and the proposed methodology allows for a coherent comparative analysis, highlighting the structural differences between states and the conditions that determine the degree of innovation in the European rural environment.

RESULTS AND DISCUSSIONS

In order to emphasize the variations among Member States, the research examined the link between innovation and sustainable economic growth in rural regions of the European Union using a set of similar metrics
and allowing the identification of rural development models associated with innovation.

Table 1. Evolution of GDP/capita in the European Union member states during 2018-2023 (euro/capita)

Country	2019	2020	2021	2022	2023
Austria	115,685.86	111,280.91	116,626.55	130,648.94	:
Belgium	23,389.00	23,004.00	25,565.77	29,018.73	30,586.00
Bulgaria	3,435.71	3,657.05	4,176.46	4,591.78	5,074.81
Croatia	21,275.52	19,126.08	22,206.12	25,925.24	30,015.00
Czechia	41,720.11	40,770.16	44,967.84	51,514.97	58,764.68
Denmark	45,566.48	45,945.05	48,513.34	49,356.38	52,031.97
Estonia	3,880.48	3,686.51	4,166.91	4,769.25	4,904.53
Finland	42,271.04	41,786.89	44,133.19	48,416.41	49,743.78
France	478,315.00	467,997.00	506,212.00	530,692.00	554,375.00
Germany	387,890.00	382,752.00	403,943.00	439,946.00	:
Greece	43,553.22	39,033.44	42,632.43	48,996.00	:
Hungary	17,537.03	16,559.81	18,116.00	19,884.93	22,396.00
Ireland	165,549.16	175,102.25	209,299.79	244,614.70	229,939.00
Italy	127,088.11	118,061.44	129,013.00	138,275.52	:
Latvia	4,684.71	4,947.58	5,518.07	6,194.79	:
Lithuania	2,348.71	2,407.59	2,662.82	3,155.71	3,343.90
Netherlands	4,232.38	4,238.89	4,556.11	5,119.00	4,834.00
Poland	151,640.46	152,282.00	164,440.67	186,497.77	:
Portugal	:	:	56,018.00	61,058.35	66,739.00
Romania	68,308.51	67,301.39	72,934.69	82,979.79	94,813.00
Slovakia	37,787.45	37,541.29	40,082.64	42,940.20	49,800.00
Slovenia	23,134.98	22,359.78	24,656.99	27,030.46	29,936.33
Spain	29,251.70	26,412.20	29,550.60	32,770.00	:
Sweden	26,497.02	26,190.73	29,826.25	30,693.91	28,653.14

Source: own processing [6].

This approach attempted to capture both recent dynamics and structural trends, and the statistical interpretation is complemented by comparative elements, useful for formulating relevant conclusions from a territorial and strategic perspective.

Comparing the Member States of the European Union, we can see the existence of persistent economic disparities between the west and north of the continent, on the one hand, and the east and south of Europe, on the other. Countries with consolidated economies, characterized by diversified productive sectors and developed infrastructures, consistently record higher levels of GDP per capita (Table 1). These countries have superior financial and institutional resources to support innovation in rural areas, through investments in digitalization, advanced agricultural technologies and related services. However, the GDP per capita of the economies of Central and Eastern Europe and several Baltic republics is far lower. This gap reflects both dependence on low-productivity sectors and delays in the process of European economic convergence. In these cases, innovation in rural areas is often limited by insufficient financial resources, poor logistical infrastructure and a higher share of traditional occupations.

GDP per capita thus remains a sensitive indicator of the capacity of states to transform economic growth into innovative and sustainable development of rural areas.

Table 2. Population employed in industry and agriculture in the European Union member states in the period 2018–2023 (Thousands)

Country	2019	2020	2021	2022	2023
Austria	1,457.9	1,430.5	1,457.9	1,495	:
Belgium	312	309	315.55	321.67	322
Bulgaria	337.9	339.47	332.4	268.09	:
Croatia	691	744.16	760.12	772.62	785
Czechia	1,112.12	1,083.6	1,092.29	1,107.03	1,116.73
Denmark	472.45	467.53	478.84	492.97	496.96
Estonia	112.08	108.85	109.72	112.86	114.01
Finland	530.54	516.69	523.97	532.51	537.73
France	6,809	6,817	6,950	7,470	7,548
Germany	5,629.29	5,576	5,573	5,618	:
Greece	1,279.52	1,251.19	1,309.9	1,331	:
Hungary	625.78	619.33	617.12	618.38	618
Ireland	1,230.47	1,210.41	1,286.49	1,375.95	1,429.42
Italy	1,970.7	1,935.9	1,943	1,966.5	:
Latvia	190.71	193.35	189.13	190.9	:
Lithuania	102.17	100.61	100.66	106.98	101.54
Netherlands	51.3	50.4	50.5	53	:
Poland	5,693	5,681.1	5,811.6	5,836.6	:
Portugal	:	:	1,392	1,424.06	:
Romania	3,661.61	3,548.06	3,582.19	3,588.6	3,539
Slovakia	1,084.8	1,065.77	1,058.46	1,082.26	1,078.64
Slovenia	544.8	539.58	544.55	558.28	564.06
Spain	504.6	484.2	497.8	512	:
Sweden	335	334.8	335.2	346.2	357.4

Source: own processing [7].

A common feature is the increase in disparities between countries: although all have recorded an upward trend in the medium term, growth rates have consolidated the initial differences, which suggests a persistent fragmentation of economic convergence within the Union.

This dynamic reveals that GDP/capita, although sensitive to external shocks, remains closely associated with the degree of innovation and modernization of rural economies, being supported in particular by investments in human capital, infrastructure and diversification of the productive structure (Table 1).

Countries with high shares of the population employed in industry and agriculture reflect rural economies where traditional activities continue to absorb a significant part of the workforce. In these countries, agriculture and related industries remain the main pillars of employment, which can mean both an anchoring in productive structures with low added value and an opportunity for modernization through mechanization and technology. In Poland and Romania, for example, a high share of the population employed in agriculture is associated with fragmented holdings and traditional practices, which limits the diffusion of innovations (Table 2). However, this human potential can become an advantage when public policies stimulate the transition to smart agriculture and green industrial processes. In countries where the share of employment in industry and agriculture is low, such as the Netherlands, Belgium or the Baltic countries, the economic structure indicates a stronger orientation towards services and innovative sectors with high added value.

Table 3. Employment rate in the European Union Member States (2018–2023) (%)

Country	2020	2021	2022	2023	2024
Austria	75.3	74.8	76.6	76.6	76.4
Belgium	64	63	64.2	65.9	68
Bulgaria	64.4	64.1	66.8	63.8	63.4
Croatia	58.2	62.6	64.5	63.7	67.3
Czechia	75	75.2	76.3	75.6	76.2
Denmark	73.2	74.9	75.7	75	76.2
Estonia	71.3	72.1	75.2	75.7	73.8
Finland	70.5	71.2	72.5	73.4	73.7
Germany	:	77.8	:	79.2	79.3
Greece	56.8	57.1	59.8	62.1	63.8
Hungary	66.3	68.5	70	70.6	69.6
Ireland	66.6	68.7	72.2	73	73.1
Italy	57.6	58.7	60.7	61.4	62.6
Latvia	70.5	67.5	69.6	71.2	70.6
Lithuania	64.6	64.9	69.4	67.5	67.2
Netherlands	77.7	80.9	82.3	83.1	84.4
Poland	66.7	67.7	68.4	69.2	69.6
Portugal	68.9	69.6	71.5	72.1	72.1
Romania	70.1	60.5	61.5	60.7	60.7
Slovakia	66	66.9	68.8	70.6	70.9
Slovenia	70	70.1	71.6	71.3	71.7
Spain	63.6	65.2	65.9	66.6	67.5
Sweden	74.6	75	77	77	77.7

Source: own processing [8].

This reduces dependence on traditional agriculture and allows for a faster integration of digital and sustainable technologies in rural areas. In these economies, agriculture often becomes a niche activity, highly technological and competitive in international markets.

The impact on innovation in agriculture is clear: where the share of employment in agriculture remains high, the pressure to modernize is strong, but financial and educational constraints delay change. In economies where this share is low, agriculture plays a smaller role in labor absorption, but benefits from more consistent investment and an institutional and logistical infrastructure that favors rapid innovation.

Countries with high employment rates, such as the Netherlands, Germany, Sweden, Austria or the Czech Republic, demonstrate a functioning labour market and a constant capacity to integrate available human resources into economic activities. This has direct consequences for innovation in rural areas: the active population is involved not only in traditional sectors, but also in industrial activities and services related to agriculture, which stimulates diversification and the adoption of modern technologies. For example, a high employment rate facilitates the formation of agricultural and agro-industrial clusters, supports farmer associations and favours the rapid transfer of innovations to agricultural holdings. At the same time, the involvement of the workforce in sectors with higher added value contributes to the stability of rural incomes and to reducing vulnerability to external shocks. (Table 3).

In countries such as Belgium, Romania, Croatia, Italy and Greece, where the employment rate remains low, the consequences are multiple. The fragmented labour market generates high pressure on the agricultural sector, which becomes an occupational refuge for the rural population. Traditional methods with little technological advancement continue to dominate agriculture in the lack of varied economic options. The result is low productivity and limited innovation potential. In addition, low labour market participation leads to the migration of young and skilled workers, which amplifies the shortage of innovative human capital in rural areas.

The employment rate thus has a direct impact on agricultural modernisation processes. A strong and inclusive labour market favours investments in mechanisation, digitalisation and green solutions, as there are both financial resources and skills to use these technologies. Conversely, a low employment rate perpetuates dependence on manual labour, reduces the attractiveness of investments in agriculture and delays the transition to sustainable and innovative production models (Table 3).

Tertiary education represents the strongest source of differentiation between European Union countries in terms of innovation potential in rural areas. Countries with high levels of qualified population, such as Ireland, Finland, Belgium or Sweden, benefit from human capital capable of generating and disseminating innovative knowledge and technologies. These economies have managed to build efficient networks between academia, research centers and productive sectors, including agriculture (Table 4).

The direct consequence is the acceleration of the transition to smart, digitalized and sustainability-oriented agricultural models, in which the use of data, biotechnology and green energy is becoming increasingly common. In countries such as Romania, Italy, Hungary, Bulgaria or Croatia, where the share of the population with tertiary education is low, rural areas face major difficulties in attracting and retaining qualified human capital. These regions risk remaining trapped in a vicious circle of underdevelopment: the lack of specialists limits the modernization of agriculture, which reduces economic attractiveness and leads to the migration of young people to urban areas or to other Member States. The impact on agriculture is visible through the persistence of traditional practices, a low level of use of digital technologies and a slow pace of adaptation to the demands of global markets.

Table 4. Share of population with tertiary education (ISCED 5–8) in the European Union Member States in the period 2018–2023 (% of population 25–64 years old)

Country	2020	2021	2022	2023	2024
Austria	:	27.3	27.8	29.9	30.9
Belgium	38	40.2	41.9	40.6	41.9
Bulgaria	17.1	19.4	20.9	21.6	25.3
Croatia	:	19.2	20.5	20.5	21.7
Czechia	20.3	21.9	22.2	23	23.5
Denmark	29.8	31.4	31.2	29.6	32.4
Estonia	32.2	33.6	34.2	30	28
Finland	42.7	37.7	38.3	:	35.5
Germany	:	25.6	:	26.1	27.2
Greece	:	24.8	25.1	23.9	24
Hungary	17.2	18.3	19.3	19.9	20.8
Ireland	45.3	48.6	49.8	50.4	52.5
Italy	16.4	16.3	16.4	17.4	17.9
Latvia	28	28	30.3	32.4	31.3
Lithuania	26.9	25.1	26.4	28.2	26.6
Netherlands	24.3	29.8	27.9	26.8	30
Poland	23.7	23.9	24.7	27.9	28.7
Portugal	24.3	25.3	25.9	25.7	26.7
Romania	13.5	14.1	14.4	13	13.3
Slovakia	23.5	25.1	25.7	24.7	24.5
Slovenia	30.9	35.9	36	29.8	31
Spain	33.7	34.5	35.6	36.4	35.8
Sweden	35.3	37.6	41.6	40.4	40.5

Source: own processing [9].

The presence of skilled human capital in rural areas not only has a direct effect on agricultural productivity, but also generates indirect results by stimulating entrepreneurship, creating modern cooperatives and strengthening rural innovation ecosystems. Thus, differences between countries in terms of tertiary education translate into significant structural gaps in agricultural innovation capacity and in the pace of European convergence.

The countries with the highest volumes of road freight transport – Germany, France, Poland, Austria and Romania – are characterised by economies with a strong industrial and agricultural component, integrated into extensive logistics networks. These trade flows reflect both the infrastructural capacity and the intensity of rural economic activities. In rural areas, a high volume of road transport indicates not only the mobility of agricultural products, but also the existence of diversified value chains, which include processing, distribution and export. This connectivity facilitates the rapid diffusion of innovations, from agricultural production technologies to digital solutions for logistics management, strengthening the resilience and competitiveness of rural regions.

States with low volumes, such as Lithuania, the Netherlands, Estonia, Belgium and Latvia, illustrate two types of situations: either an economy more oriented towards services and high value-added sectors (the case of the Netherlands and Belgium), or limited infrastructural and economic capacity (the case of the Baltic countries) (Table 5).

Table 5. Volume of road freight transport in the European Union Member States in the period 2018–2023 (million tons)

Country	2020	2021	2022	2023	2024
Austria	173,436	186,991	181,321	167,090	152,413
Belgium	17,814	14,424	13,692	14,628	16,491
Bulgaria	19,013	23,550	30,793	24,382	11,577
Croatia	35,283	36,730	37,079	38,781	42,381
Cyprus	:	:	:	:	:
Czechia	106,087	118,490	103,578	95,249	91,308
Denmark	64,856	60,690	62,977	61,647	42,386
Estonia	10,152	14,134	13,834	12,349	9,374
Finland	117,699	131,408	:	:	67,176
France	541,998	582,553	555,224	547,002	524,755
Germany	666,831	676,910	665,232	627,874	539,351
Greece	164,449	106,195	148,600	120,159	98,399
Hungary	24,910	30,565	26,170	25,849	27,500
Ireland	79,691	85,268	88,357	90,081	89,149
Italy	113,495	128,829	125,028	128,160	101,005
Latvia	22,327	21,949	25,366	24,234	24,031
Lithuania	4,110	4,390	3,292	4,744	4,938
Netherlands	5,768	4,481	5,041	3,511	4,130
Poland	454,482	497,186	515,730	490,474	521,855
Portugal	54,769	59,086	57,915	50,094	46,841
Romania	120,237	137,623	144,806	147,130	126,507
Slovakia	51,520	43,178	45,531	44,370	54,475
Slovenia	28,693	32,958	34,428	35,692	37,819
Spain	81,324	88,203	89,627	83,887	68,849
Sweden	68,355	55,980	62,311	51,258	36,932

Source: own processing [10].

In these cases, although the dependence on road transport is lower, there is a risk that rural areas remain poorly connected to major trade flows, which reduces innovation opportunities and limits farmers' access to international markets.

The impact on agriculture is significant. In countries with high transport flows, farmers can more easily integrate modern technologies and benefit from economies of scale through rapid access to competitive markets and logistics networks. Conversely, in regions where road transport is reduced, the adoption of innovations is slowed down by isolation, high distribution costs and dependence on local markets. Thus, transport infrastructure appears as an essential element of rural innovation capacity, conditioning both the modernization of agriculture and the sustainable development of communities.

The integrated analysis of the five indicators reveals the existence of clear structural differences between European Union countries in terms of the conditions favourable to innovation in rural areas.

Western and Nordic countries, such as Germany, France, the Netherlands, Sweden, Finland and Ireland, have a profile that is conducive to innovation. They are distinguished by high GDP/capita, high employment rates, high levels of tertiary education and a low share of employment in traditional agriculture. At the same time, the logistics infrastructure and the volume of road freight transport are consistent, reflecting the connectivity of rural areas to European and

international value chains. In these countries, agriculture is rather intensive and technologically advanced, characterised by investments in mechanisation, digitalisation and ecological solutions. The impact on innovation is visible in the rapid adoption of precision farming practices, digital technologies and green transition processes.

A second group is represented by the southern and central European economies – Italy, Spain, Portugal, Croatia or Greece – which present an intermediate position. They have moderate GDP/capita, lower employment rates and a relatively low level of tertiary education, which limits the potential for innovation. Agriculture remains an important sector for rural employment, but the lack of highly qualified human capital and migration pressure affect the capacity for modernization. However, transport infrastructure and proximity to external markets contribute to maintaining favorable connectivity, which provides a basis for a gradual transition to innovative practices.

Central and Eastern European nations, such as Poland, Romania, Bulgaria, and Hungary, have a dual character: on the one hand, a sizable percentage of the labor force is employed in traditional industries and agriculture; on the other hand, there is accelerated economic growth and a sizable amount of road transportation. These characteristics show a significant innovation potential, but constrained by low levels of tertiary education and a still rigid occupational structure. In agriculture, this translates into the persistence of small and fragmented holdings, where the adoption of innovations is slow and dependent on the support of public policies and European funds. However, the pressure from global markets compels these nations to quicken their modernization process, which accounts for the latest efforts in the areas of modern cooperatives and agricultural digitalization.

The Baltic countries, Estonia, Latvia, Lithuania, occupy a particular position. Although they are distinguished by limited logistical connectivity and a low share of highly qualified human capital, they are gradually developing digital infrastructures and support networks for innovation, which could become a competitive advantage in the long term.

An emerging dimension of rural innovation is the adoption of precision agriculture technologies, but for which there is still not enough data reported at the country level. Recent estimates indicate that, for example, the European agricultural drone market is experiencing rapid expansion, set to grow from approximately USD 5.8 billion in 2024 to over USD 7.4 billion in 2025, with a compound annual growth rate of 28.6% until 2033 [11]. In line with the goals of the Green Deal and the shift to a knowledge-based economy, this dynamic validates the European Union's propensity to encourage the adoption of smart technology and assist the digital transformation of agriculture. Agricultural drones facilitate real-time monitoring of crops, differentiated application of inputs and optimization of production processes through the integration of artificial intelligence, which can increase the accuracy of agronomic diagnostics by up to 40%. In addition, their use contributes to reducing the consumption of pesticides and fertilizers, supporting sustainability and environmental protection objectives. However, the pace of adoption remains uneven across the Union, affected by fragmentation of flight and licensing regulations (implemented by EASA) and data protection concerns, which are causing reluctance among farmers – almost 40% of them expressing concerns about the unauthorized use of the information collected (Figure 1).

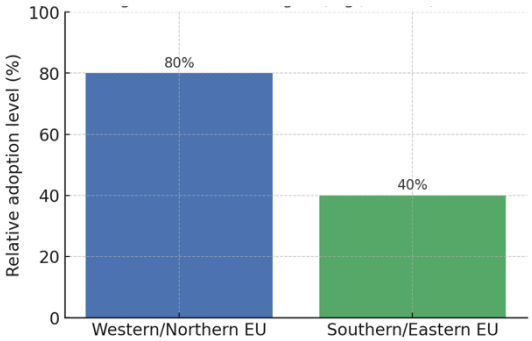

Fig. 1. Comparative Adoption of Agricultural Technologies in Rural Areas of the European Union
Source: own processing [11].

The comparative analysis shows that the degree of innovation in rural Europe is

conditioned by the combination of economic performance, labor market dynamics, education level, occupational structure and logistics infrastructure. Western and northern countries, characterized by high GDP, qualified human capital and high-performance digital infrastructure, adopt new technologies faster, which strengthens competitive advantages and the pace of innovative transformation. In contrast, southern and eastern countries, where employment in agriculture remains high, the level of tertiary education is low, and the logistics infrastructure is deficient, encounter significant barriers to the diffusion of innovations and risk perpetuating development gaps. Thus, the example of emerging technologies, such as agricultural drones, demonstrates that rural innovation reflects not only the general trends of the European market, but also territorial differences in innovative capacity, which underlines the need for differentiated policies to reduce disparities. After the comparative analysis of the five selected indicators, it became necessary to statistically test the relationships between them, in order to capture the structural links that define the degree of innovation. If the descriptive analysis highlighted the differences between the states and the general trajectories, the correlational analysis provides confirmation of the hypotheses regarding the association between economic performance, human capital, occupational structure and logistics infrastructure.

For this purpose, the Pearson and Spearman correlation coefficients were applied, based on the multiannual averages 2018–2023, for the 27 Member States of the European Union. This approach aimed not only to quantify the intensity of the relationships, but also to test the statistical significance ($p < 0.05$), which allows the differentiation between conjunctural associations and consistent links, with relevance for the innovation process.

The results are summarized in Table 6 which constitutes a matrix of correlations between the five indicators considered proxies for rural innovation: GDP/capita, employment rate, share of the population with tertiary education, employment structure in agriculture and industry, and volume of road freight transport. This table provides an integrated picture of how economic performance, human resources and infrastructure interrelate in supporting rural innovation (Table 6).

Table 6. Analysis of correlations between innovation indicators in rural areas in the European Union member states in the period 2018-2023 (multiannual averages)

Var_X	Var_Y	Pearson_r	Pearson_p	Spearman_r	Spearman_p
GDP_pc	Emp_ind_agri	0.802	0	0.867	0
GDP_pc	Emp_rate	0.217	0.32	0.09	0.683
GDP_pc	Tertiary_edu	0.012	0.958	-0.045	0.837
GDP_pc	Freight_vol	0.872	0	0.885	0
Emp_ind_agri	Emp_rate	-0.001	0.998	-0.152	0.488
Emp_ind_agri	Tertiary_edu	-0.326	0.129	-0.421	0.045
Emp_ind_agri	Freight_vol	0.919	0	0.858	0
Emp_rate	Tertiary_edu	0.325	0.131	0.423	0.044
Emp_rate	Freight_vol	0.19	0.385	0.015	0.946
Tertiary_edu	Freight_vol	-0.141	0.52	-0.163	0.457

Source: own processing.

The correlation analysis highlights several strong statistical relationships, with direct significance for understanding innovation in rural Europe. First, there is a very close association between GDP/capita and the volume of road freight transport ($r > 0.85$, $p < 0.001$), which shows that economic performance is inextricably linked to the degree of logistics connectivity, and rural regions well integrated into trade networks benefit from an increased capacity to diffuse innovations. A significant correlation is also

observed between the share of employment in agriculture and industry and the volume of road transport ($r > 0.90$, $p < 0.001$). This result shows that economies with a strong traditional structure generate intense, but not necessarily innovative, logistics flows, which may reflect both the potential for modernization and vulnerability to market fluctuations.

In social terms, the relationship between tertiary education and employment structure is negative and significant ($r = -0.42$, $p < 0.05$), which confirms the hypothesis that regions where agriculture and traditional industries absorb a high proportion of the workforce tend to be characterized by a low level of skilled human capital, which limits the capacity for innovation. Simultaneously, the positive correlation between employment rate and tertiary education ($r = 0.42$, $p < 0.05$) indicates that a more dynamic labor market is linked to a greater level of human capital, with a preference for digital and green technologies as well as agricultural modernization.

Other correlations, such as that between GDP and employment rate or GDP and tertiary education, were not significant, indicating that general economic performance does not automatically translate into rural innovation if it is not supported by adequate infrastructure and human capital. The results obtained confirm that rural innovation in the European Union depends on a complex combination of factors: logistical infrastructure and economic connectivity, occupational structure and education level. Public policies aimed at stimulating innovation in agriculture must therefore simultaneously target investments in human capital and infrastructure, alongside the structural transformation of rural economies.

CONCLUSIONS

The comparative analysis of the five indicators reveals that innovation in the rural areas of the European Union is not evenly distributed, but depends on the interaction between economic performance, human resources and logistical infrastructure. Western and northern countries have managed to build innovative rural ecosystems by integrating skilled human capital and by orienting agriculture towards modern technologies and sustainable processes. This development confirms that innovation is not an isolated process, but the result of a combination of economic, social and institutional factors.

Southern and eastern countries, especially those in Central and Eastern Europe, face persistent challenges: low levels of tertiary education, a high share of the population engaged in traditional agriculture and insufficiently developed logistical infrastructure. These characteristics limit the potential for diffusion of innovations and reduce the attractiveness of investments in agriculture. At the same time, the competitive pressure of European and international markets forces these countries to accelerate modernization, which can transform current vulnerabilities into opportunities in the medium term if supported by appropriate public policies.

From the perspective of European rural development policies, the results suggest the need for a differentiated approach. High-performing regions can be supported to become centers of excellence and diffusion of agricultural innovation, while regions with structural deficits require priority investments in education, vocational training, logistics infrastructure and digitalization. Only by reducing these gaps can real convergence between countries be ensured and European agriculture transformed into a competitive, sustainable and innovative sector on a continental scale.

The results of the comparative analysis highlight the need for differentiated policies, adapted to the structural specificities of the Member States. In the Western and Northern countries, where the rural environment is already highly technological and connected to complex value chains, policies should support the strengthening of innovative ecosystems by stimulating applied research, developing digital agriculture and accelerating the transition to climate neutrality. In these regions, the main objective is to create models of good practice and extend networks for the diffusion of innovations to other areas of the Union.

For the Southern and Central-Eastern countries, where agriculture continues to be a major employment sector, but qualified human capital and logistical infrastructure are insufficient, public policies should focus on vocational training and tertiary education adapted to rural needs. Expanding training programmes in smart farming, biotechnology and digital management can help to increase local innovation capacity. Simultaneously, investments in digital infrastructure and logistics are necessary to promote the adoption of contemporary technology and link rural regions into European economic processes.

The nations with the biggest gaps, particularly those in Eastern Europe and the Balkans, require focused assistance from the European Structural Funds and the Common Agricultural Policy to modernize small and medium-sized farms, encourage agricultural cooperatives, and establish collaborations between farmers, research facilities, and the private sector. These interventions could transform traditional productive structures into innovation actors and accelerate rural convergence at European level.

Therefore, rural innovation policies must combine financial, educational and institutional instruments to create a framework conducive to the modernisation of agriculture and the strengthening of economic sustainability. The structural differences identified between Member States show that a uniform approach is not effective; success depends on the application of flexible strategies adapted to the specificities of each rural economy.

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