

THE ROLE OF SMALL FARMS WITHIN THEIR NATIONAL CONTEXTS IN CENTRAL AND EASTERN EUROPE

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Abstract

Small farms play a crucial role in shaping the agricultural landscapes and economies of many nations, serving as both cultural staples and significant contributors to food security and rural livelihoods. This study applies K-Means clustering to examine the dynamics of small agricultural holdings across European regions, using key indicators such as the number of holdings, utilized agricultural area (UAA), economic output (Euro), and agricultural labor input (AWU). The analysis identified four distinct clusters that reveal the diverse roles small farms play in national agricultures. The findings illustrate the multifaceted roles small farms perform—from sustaining rural economies and preserving traditions to confronting productivity challenges and resource constraints. The study underscores the necessity for region-specific policies that enhance the sustainability and competitiveness of small farms. By framing the role of small farms within their national contexts, this research provides a strategic foundation for strengthening their contributions to agricultural sustainability and resilience.

Key words: small farms, region, Central and Eastern Europe. Cluster analysis

INTRODUCTION

Small farms are integral to global agriculture, contributing significantly to food security, biodiversity preservation, and rural economies. Despite the trend towards large-scale industrial farming, smallholder farms—those typically smaller than 2 hectares—remain common, making up more than 80% of all farms globally and providing a significant amount of the global food supply [23]. Small-scale farms are central to promoting regional development and sustainable agricultural practices, as they challenge the industrial agrifood complex by fostering local food systems and agroecological alternatives [1]. The importance of small farms extends beyond mere food production. They play a vital role in maintaining agrobiodiversity, as diverse cropping systems are more prevalent in smallholder settings, enhancing resilience against pests, diseases, and climate variability [2]. Moreover, small farms often employ sustainable practices that contribute to environmental conservation, such as reduced chemical use and integrated crop-livestock

systems [27]. Small farms have a crucial role in maintaining rural life on an economic level. They are vital to the socioeconomic fabric of rural communities and offer job possibilities. In many developing countries, smallholder agriculture is a primary source of income and plays a crucial role in poverty alleviation [17]. Furthermore, small farms contribute to local economies by supporting local markets and preserving traditional food systems [19]. However, small farms face numerous challenges, including limited access to markets, credit, and technology, which can impede their productivity and sustainability. This study aims to analyze the role of small farms in national agricultures by examining their contributions to sector. Through a comprehensive review of existing literature and empirical data, the research seeks to highlight the multifaceted importance of smallholder farms and observe their current state to inform policy decisions that support their integration into broader agricultural development strategies.

MATERIALS AND METHODS

The K-means clustering algorithm was chosen for this study due to its efficiency in handling large datasets and its ability to identify underlying patterns within multidimensional agricultural data. K-means is a widely used unsupervised learning technique that partitions data into distinct groups based on feature similarity [24]. The method has been extensively applied in agricultural research, particularly for farm typology classification, land-use pattern analysis, and productivity assessment [5, 30]. K-means clustering operates by minimizing intra-cluster variance through an iterative reassignment process [16]. Unlike hierarchical clustering methods, which can become computationally expensive as dataset size increases, K-means efficiently handles large-scale agricultural datasets, making it particularly suitable for studies involving spatial and economic data [32]. Prior to applying the K-means algorithm, data preprocessing was conducted to ensure consistency and comparability across different variables. Given the multidimensional nature of the dataset—including economic indicators (e.g., farm income, subsidies), structural characteristics (e.g., land size, labor input), and productivity measures—normalization was applied using min-max scaling to bring all variables into a comparable range between 0 and 1 [15]. This step is crucial, as K-means clustering relies on Euclidean distance, which can be disproportionately influenced by variables with larger magnitudes [20]. Outliers were identified and addressed using the interquartile range (IQR) method to prevent their undue influence on clustering results [21]. Missing values were handled through multiple imputation, ensuring that incomplete records did not introduce bias into the clustering process [35].

Choosing the optimal number of clusters (K) is one of the main challenges in K-means clustering. To address this, two main methods are used: Silhouette Score Analysis [29] and the Elbow Method [34]. In the Elbow Method, a graph is created showing how the within-cluster sum of squares (WCSS) changes with respect to the number of clusters, K. The best number of clusters is the one where the graph shows the so-called "elbow" — the point where

the reduction in WCSS begins to slow down, and the improvements become less significant. The Silhouette Score, on the other hand, evaluates the cohesion and separation of clusters by measuring how similar an observation is to its assigned cluster compared to others. Both methods were computed, and results were cross-validated to ensure the robustness of cluster selection. The final K-value was determined based on the convergence of both techniques and domain-specific knowledge of agricultural classifications.

Once the optimal number of clusters was established, the K-means algorithm was applied as follows:

- Random Initialization – K initial centroids were randomly selected from the dataset to serve as the starting points.
- Assignment Step – Each data point was assigned to the nearest centroid based on Euclidean distance.
- Centroid Update – New centroids were computed as the mean of all data points in each cluster.
- Convergence Check – Steps 2 and 3 were repeated iteratively until centroid positions stabilized or the maximum number of iterations was reached [22].
- To mitigate the sensitivity of K-means to centroid initialization, the K-means++ initialization technique was implemented, ensuring that initial centroids were spread out to improve clustering performance [3].

To assess the quality of the clustering results, multiple validation techniques were applied:

- Dunn Index [12] to evaluate the compactness and separation of clusters.
- Calinski-Harabasz Index [6] for measuring cluster dispersion.
- Silhouette Analysis for internal validation of clustering quality. Following validation, clusters were interpreted based on agricultural characteristics, economic performance, and structural factors. Statistical comparisons (e.g., ANOVA, post-hoc Tukey tests) were conducted to identify significant differences between clusters [18].

RESULTS AND DISCUSSIONS

The analysis of small agricultural holdings (0–2 ha) in selected EU countries between 2010 and 2020 reveals a pronounced decline in their numbers, particularly in Romania, Poland, and Hungary. Over the period from 2010 to 2020, significant structural changes have occurred in the agricultural sector of this EU countries, particularly in the segment of small farms (0-2 ha). The comparative analysis of the data from Figures 1 and 2 highlights a general decline in the number of small holdings, accompanied by an increase in economic output (measured in Euro), a reduction in the agricultural workforce (AWU), and relatively stable levels of utilized agricultural area (UAA). The observed transformations suggest that the remaining small farms have either intensified production, diversified their activities, or become more commercially integrated. This shift away from small agricultural holdings can be further analyzed through the lens of labor input and economic performance. The limited investment in fixed assets indicates a low level of capital allocation, which considerably restricts the growth potential and financial viability of small farms. These trends are particularly pronounced in Romania and Poland, where the most substantial declines in small farm numbers have been recorded. At the same time, the economic productivity of small farms has increased, suggesting improved efficiency and farm consolidation. In contrast, countries such as Czechia, Slovenia, and Slovakia have exhibited minimal structural changes, maintaining relatively stable farm numbers and economic performance. The observed trends can be attributed to multiple factors, with the most influential being agricultural policy reforms under the European Union's Common Agricultural Policy (CAP), population and economic changes. The CAP is one of the main forces behind this trend and has been widely criticized for disproportionately favoring large agricultural enterprises. In Romania, the sharp decline in small farm numbers can be linked to ongoing land consolidation processes, the outmigration of rural labor, and a shift towards commercialized agriculture. Despite the reduction in farm numbers, the economic output of the remaining farms has increased, suggesting efficiency

gains and improved access to CAP subsidies. Poland exhibits a similar trajectory, where small farms are disappearing due to consolidation and integration into larger agricultural structures. Increased mechanization and access to EU markets have facilitated higher productivity, reflected in the rise in economic output. Greece stands out as an exception, where economic productivity has surged, possibly due to diversification into high-value crops and agritourism rather than extensive farm consolidation. In Hungary and Bulgaria, the decline in small farm numbers is also apparent but at a more moderate scale.

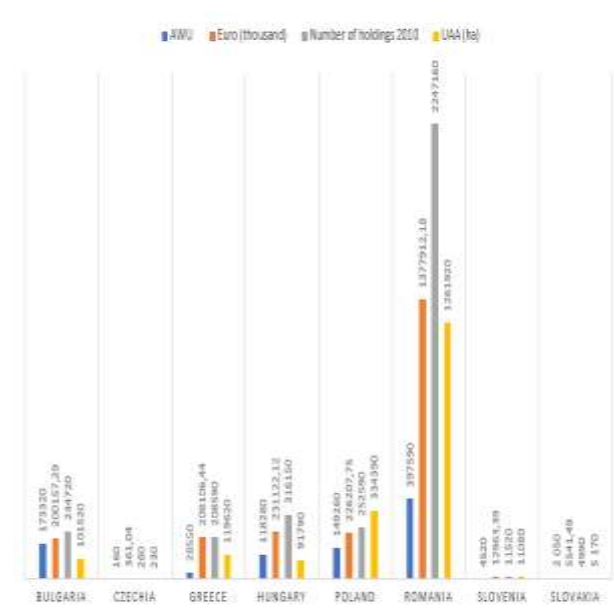


Fig. 1. Small farms/holdings 0-2 ha 2010

Source: Eurostat - Statistics | Eurostat [13].

These countries have experienced a gradual transition towards commercial farming, supported by CAP payments and foreign investments. However, the workforce reduction suggests a declining interest in small-scale farming as younger generations migrate to urban areas. Meanwhile, in Czechia, Slovenia, and Slovakia, the structure of small farms has remained largely unchanged, which can be attributed to the historically lower prevalence of fragmented land holdings and a focus on larger, corporate-style farming. Overall, the transformation of small farms in the EU is driven by economic pressures, policy incentives favoring larger commercial farms, and demographic changes that reduce labor availability in rural areas. The trend suggests a

continuing transition towards a more capital-intensive and technologically advanced agricultural sector, where fewer but more efficient farms dominate production. This shift has implications for rural development, food security, and land ownership patterns, requiring adaptive policy measures to balance economic viability with social sustainability in the agricultural sector.

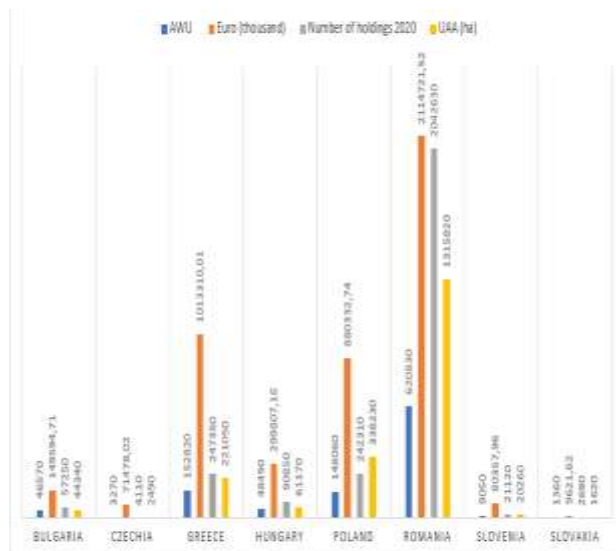


Fig. 2. Small farms/holdings 0-2 ha 2020
Source: Eurostat - Statistics | Eurostat [13].

Clusters

Identifying (k) the effective number of clusters is to provide meaningful dataset segmentation. The within-cluster sum of squares (WCSS) was plotted against various values of k to use the Elbow Method. The results reveal a distinct inflection point at $k = 4$, indicating that beyond this point, adding more clusters results in marginal improvements in intra-cluster compactness while increasing complexity. This suggests that a four-cluster solution provides a balanced trade-off between cluster cohesion and separation (Figure 3). To further validate the clustering structure, Silhouette Analysis was conducted. The silhouette score measures how well each data point fits within its assigned cluster while maintaining distinct separation from others. The analysis demonstrates a peak silhouette score at $k = 3$, followed by a gradual decline as k increases. The drop in silhouette scores beyond $k = 4$ suggests that higher cluster numbers lead to overlapping and less-defined groupings. Given

these results, $k = 4$ was selected as the optimal clustering solution, ensuring both meaningful segmentation and distinct cluster differentiation (Figure 4).

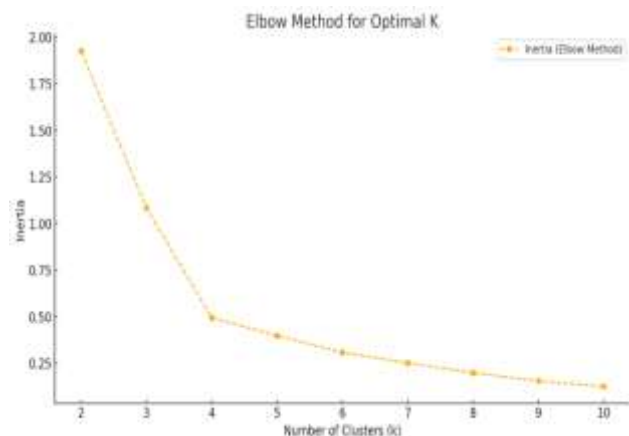


Fig. 3. Elbow Method optimal K
Source: Eurostat and calculation by the authors [13].

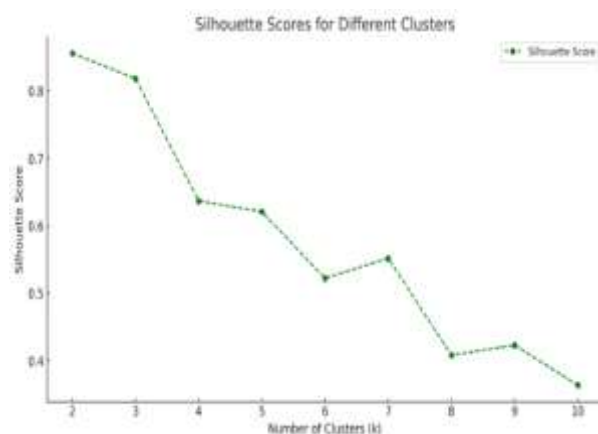


Fig. 4. Silhouette scores
Source: Eurostat [13] and calculation by the authors.

This distribution suggests a clear differentiation between high-performance agricultural regions and those struggling with structural inefficiencies. The findings reinforce the argument that small farm efficiency is not solely dependent on land area or number of holdings but also on infrastructural investments, technological adoption, and market accessibility (Figure 5).

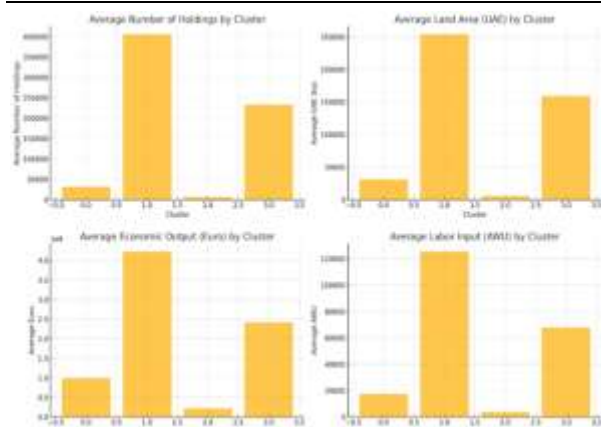


Fig. 5. Farm specifics for the clusters
Source: Eurostat [13] and calculation by the authors.

Structural Patterns in Cluster Frequency and Land Utilization

Further insights were derived from analyzing cluster frequency distributions and utilized agricultural area (UAA). The results show that certain clusters are overrepresented in particular regions, indicating strong spatial patterns in agricultural organization. For instance, regions with a predominance of smallholder farms demonstrate high cluster frequencies but exhibit disparities in productivity, emphasizing the need for policy interventions targeted at increasing efficiency.

Clusters on NUTS2 level

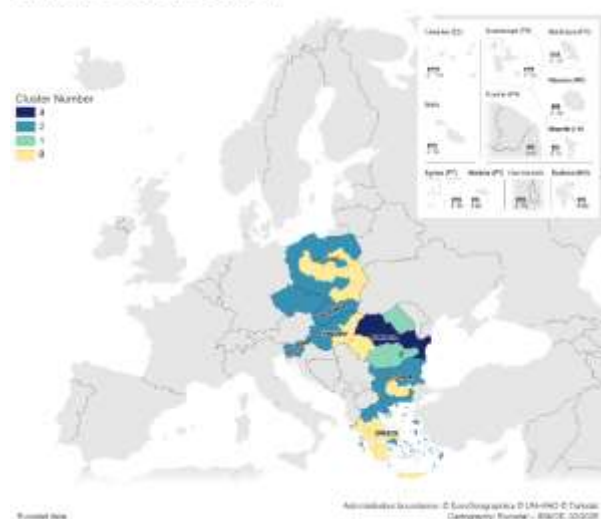


Fig. 6. Clusters on NUTS2 level
Source: Eurostat [13].

Clusters with lower economic output yet high land utilization (as seen in Cluster 3) underscore the presence of inefficient extensive farming, reinforcing the need for modernization efforts. On the other hand, high-

output clusters align with regions that have successfully integrated modern farming techniques, value chain participation, and targeted governmental support (Figure 6).

•Cluster 0: High Economic Activity and Productivity

Characterized by high economic output per holding and per hectare.

Includes regions such as Kriti (Greece), Thessalia (Greece), Mazowiecki Regionalny (Poland), and Sud-Vest Oltenia (Romania).

These regions likely benefit from mechanized farming, efficient input use, and market-oriented production.

Policy Implications: Investment in modern agricultural technologies, irrigation, and sustainability-oriented subsidies.

•Cluster 1: Extensive Agriculture with Low Productivity

Includes regions such as Nord-Est and Sud-Muntenia in Romania, with high farm counts but low output per unit of land.

Agriculture is dominated by subsistence farming, labor-intensive practices, and fragmented land ownership.

Policy Implications: Urgent need for mechanization, cooperative farming models, and infrastructure investments.

•Cluster 2: Medium-Scale Agricultural Activity

Comprising regions from Bulgaria, Hungary, Czechia, and Poland, exhibiting a balanced mix of traditional and modern agriculture.

These regions benefit from CAP funding but require further modernization to remain competitive.

Policy Implications: Targeted subsidies for mechanization, training programs for farmers, and expansion of value-added agricultural production.

•Cluster 3: Low Activity and Small Holdings

Predominantly urbanized or industrialized regions where agriculture plays a marginal role.

Includes regions such as Prague, Bratislava, Budapest, and Bucuresti-Ilfov.

Policy Implications: Diversification strategies such as agro-tourism, organic farming, and non-agricultural rural employment.

Comparative Analysis of Agricultural Structures Across Countries

A comparative assessment of the clustered countries highlights key differences and similarities in agricultural structures, economic output, and trade performance.

•Bulgaria vs. Greece:

Greece, particularly in regions like Kriti and Thessalia, has successfully developed high-value export crops such as olives and citrus fruits, leveraging CAP funding for modernization. In contrast, Bulgaria remains highly dependent on cereal and sunflower production, with lower value-added exports.

•Bulgaria vs. Poland:

Poland's agricultural sector benefits from larger average farm sizes, better mechanization, and stronger integration into European markets. While Bulgaria struggles with land fragmentation, Poland has successfully consolidated small farms into cooperatives, enhancing trade competitiveness.

•Bulgaria vs. Romania:

Romania, similar to Bulgaria, has a high number of fragmented farms, particularly in regions like Nord-Est and Sud-Muntenia. However, Romania's total agricultural land is significantly larger, and its domestic market absorption capacity is higher, providing it with slightly better resilience in times of trade disruptions.

•Bulgaria vs. Hungary:

Hungary has a more diversified agricultural portfolio, with a significant emphasis on horticulture and specialty crops, while Bulgaria relies more on extensive farming of staple grains. Hungary's investment in agri-tech and climate resilience strategies provides a useful model for Bulgaria's adaptation to climate change.

Trade Implications and Policy Considerations

Bulgaria should leverage its climate conditions and agricultural potential to develop export-oriented sectors, such as organic farming, wine production, and processed agricultural goods. The dominance of small and fragmented farms hinders scalability and productivity, limiting Bulgaria's competitiveness in international markets. Greece, Poland, and Hungary exhibit

successful agricultural trade models, emphasizing farm consolidation, mechanization, and integration into high-value markets.

Discussion

The dynamics of the EU's CAP, which often favours larger farms over smaller ones, are the main factor influencing the loss of small agricultural holdings in a few EU countries. The small farms have significantly decreased due to this policy-driven imbalance, with recorded decreases of 45,000 in Slovakia, 50,000 in Latvia, 88,000 in Lithuania, and 79,000 in Germany. Conversely, Czechia and Slovakia, which already had low numbers of small farms in 2010, appear to have undergone early consolidation following economic transitions in the 1990s. The most pronounced decline is observed in Poland, where more than 1 million small farms disappeared over the study period. Overall, this shift has resulted in a 41% reduction in the total number of farms across the region.

Another key factor influencing this trend is the liberalization of land markets in post-socialist EU member states. Research by Swinnen and Mathijs [33] highlights that, following accession to the EU, Eastern European countries experienced a surge in land acquisitions by agribusinesses and foreign investors. This has particularly affected small farmers in Poland and Romania and Bulgaria where land consolidation has been more pronounced. The shift toward commercial agriculture has also contributed to these developments, as small farms face difficulties in integrating into modern supply chains dominated by larger agribusinesses [26].

Demographic factors also play a crucial role in the decline of small farms. Studies by Davidova & Thomson (2014) [11] indicate that a significant proportion of smallholders in Eastern European countries are of advanced age, with limited generational succession in farming. This demographic trend is further exacerbated by rural depopulation, as younger generations increasingly migrate to urban centers or Western European countries in search of better economic opportunities. Research by Davidova and collective [10] highlights that youth outmigration reduces

labor availability and intergenerational land transfer. Romania and Poland report the highest Agricultural Work Unit (AWU) values, reflecting the labor-intensive nature of small holdings. However, this is juxtaposed with low economic returns per AWU, indicating inefficiency. Studies [28] suggest that mechanization remains limited in these holdings due to high upfront costs and fragmented land ownership. Despite the overall decline in small agricultural holdings, some countries exhibit distinct trends. Greece, for instance, shows an increase in economic output despite a reduction in the number of small farms, suggesting that the remaining farms have adapted through diversification or specialization in high-value agricultural products. This aligns with findings by Mattas and collective [25], who emphasize the role of product differentiation in enhancing smallholder profitability. The data reveals a marked decline in the number of small holdings across all countries studied, with Romania showing the steepest drop. For instance, Romania's small holdings decreased by nearly 20% between 2010 and 2020. Similar trends are observed in Bulgaria and Hungary, where rural depopulation, particularly in Eastern Europe, has led to the abandonment of small farms. Romania dominates in UAE for small holdings, followed by Poland. This suggests that while the number of holdings declines, the total land area cultivated remains significant. However, studies [9] argue that land fragmentation continues to impede efficiency and sustainability.

CAP's Pillar II measures, aimed at rural development, provide crucial support to smallholders. For example, subsidies for organic farming and agri-tourism encourage diversification. While Pillar I subsidies (area-based payments) disproportionately benefit larger farms, marginalizing smallholders. This is corroborated by studies [31] that critique CAP for exacerbating inequality in subsidy allocation. Previous research [7, 8] has demonstrated that CAP direct payments contribute to increased land prices, making it more challenging for small farms to remain viable. Consequently, many smallholders have been forced out of the sector, either due to

economic pressures or through land acquisitions by larger agricultural entities. The decline in small holdings signals the erosion of a critical economic safety net for rural households. Without targeted interventions, rural poverty and inequality may rise, particularly in countries like Romania and Bulgaria. Small holdings often employ traditional, low-intensity farming practices, which are more environmentally sustainable than industrial agriculture. Their disappearance could lead to increased land degradation and biodiversity loss, as highlighted by Baldock and collective [4]. Small holdings provide cultural and social value, sustaining rural traditions and communities. Their decline undermines social cohesion in rural areas, as noted in studies by Halfacree [14]. If these trends persist, the EU's small-scale farming faces an increasingly uncertain future, underscoring the need for legislative initiatives and measures that support their resilience and sustainability.

CONCLUSIONS

The ever-reduction in small-scale farming in the EU is a multifaceted process driven by CAP policies, demographic shifts, technological advancements, and land market dynamics. The observed trends indicate a structural transformation toward larger, capital-intensive farming enterprises, posing significant challenges for the sustainability of smallholder agriculture. If these developments persist, targeted policy interventions may be necessary to support small farms, given their important role in rural livelihoods, biodiversity conservation, and local food security. Bulgaria's agricultural trade competitiveness is significantly influenced by structural disparities, climate risks, and land ownership patterns. The clustering analysis highlights key policy directions that can enhance regional resilience, productivity, and external market integration. By implementing targeted interventions in climate adaptation, land consolidation, and high-value export diversification, Bulgaria can strengthen its agricultural sector and improve its positioning in global trade networks. Small agricultural

holdings in Eastern Europe are at a crossroads, caught between traditional practices and modern pressures. While their decline is driven by economic and demographic forces, policy adjustments and innovative practices can revitalize their role in sustainable agriculture and rural development. A balanced approach, integrating economic viability with environmental and social goals, is essential to ensure their continued relevance.

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