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Sustainable Agriculture and Its Impact on the Rural Development in EU Countries: A Multivariate Analysis

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Abstract: The aim of this study was to highlight the interrelationship between the environmental, social, and economic pillars of agricultural sustainability and their impact on rural development in EU countries. By considering the cumulative influence of 15 social, economic, and environmental indicators, the study clustered the EU countries into five homogeneous groups using principal component analysis and cluster analysis. The research findings confirm that there is a significant trade-off between the three dimensions of sustainability, particularly between the environmental dimension, on the one hand, and the socio–economic dimension, on the other. Thus, the main real challenges identified for the countries included in cluster 5 (Bulgaria, Greece, Croatia, Lithuania, Latvia, Poland, Romania, and Hungary) are related to the socio–economic pillar of sustainability. Moreover, for four EU countries (Netherlands, Belgium, Denmark, and Ireland), included in two different clusters, achieving environmental goals such as reducing agricultural emissions (SDG 2.60) and increasing area under organic farming (SDG 2.40) represents a significant issue in sustainable agriculture. The results highlighted specific challenges to sustainability in agriculture for EU countries that can hinder its effects on rural development. Therefore, tailored measures should be designed to efficiently address these specific issues.

Keywords: sustainable agriculture; rural development; area under organic farming; agricultural emissions; land and labor productivity; agricultural income; SDG 2; European Union; principal component analysis; cluster analysis

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1. Introduction

Almost half of the European Union's territory is covered by predominantly rural regions (44.7% of the total area), where 20.8% of the EU population lives [1]. For a long time, those rural areas have coped with a myriad of socioeconomic and demographic challenges, including poverty, social exclusion, high unemployment rates, low income levels, aging and decline of population, and heavy dependence on the agricultural sector [2–4]. At the same time, a huge economic gap between urban and rural areas has also widened in EU countries (rural GDP/capita is only 58.63% of urban GDP/capita) [5]. Moreover, concurrently, the main global and national issues at the rural and urban levels are food security, poverty eradication, and environmental pressures [6]. Therefore, achieving sustainable rural development has become one of the most important priorities of EU strategies, including the Common Agricultural Policy (CAP) Strategic Plans [7], the European Green Deal [8], and the Farm to Fork Strategy [9], as well as a core objective integrated into the 2030 Agenda for Sustainable Development Goals (SDGs) [10]. Furthermore, according to nine in ten Europeans [11], agriculture and rural areas are considered important priorities for the EU's future.

The issues of sustainable rural development and agriculture are inseparable because agriculture "fulfils its basic role by producing food, but at the same time affects rural development, food safety and soil quality" [12] (p. 2). It creates jobs, but there is a very high risk of in-work poverty in rural areas [13]. Although the EU agricultural sector contributes to a small percentage of Gross Value Added (GVA) and employment (1.8% of total GVA, 3.7% of total employment in 2021) [14], due to its specificity and multi-functionality, it plays a crucial role in sustainable development [15]. Furthermore, agriculture is directly linked to the natural environment and can generate both a positive and negative environmental impact [16]. Moreover, sustainable rural development is closely linked to "the multi-functionality of agricultural activities, economic diversification, innovation and knowledge transfer, and the resilience of cultural and environmental heritage" [2] (p. 1). Therefore, it is widely recognized that one of the most important paths to achieving sustainable rural development is to perform a high level of sustainable agriculture [17–19].

Despite a broad consensus on the importance of sustainable agriculture for sustainable development, there is significant variability in its definition [20,21] and in the practical approaches to its implementation within the policy-making process [22–25]. Some authors [26] underline that although "sustainable agriculture means different things to different people" (p. 1), the fundamental goals of sustainable agriculture are economic profitability, social and economic equity, and environmental health [27]. Various studies [20,28] emphasized that the definition of sustainable agriculture should align with the definition of sustainable development, which is described as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [29] (p. 43). Sustainable agriculture, as a multidimensional concept, should encompass all three dimensions of sustainability: economic, social, and environmental. According to these three central pillars of sustainable development, the Food and Agriculture Organization (FAO) Council defines sustainable agriculture and rural development as "the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable" [30]. In the current study, in accordance with the FAO definition as well as those of other authors [12,20,31], sustainable agriculture is seen as an integrated agricultural production system designed to meet long-term food needs, improve the quality of life on earth, preserve environmental quality, conserve natural resources, and also support sustainable socio–economic development. Moreover, at the EU level, sustainable agriculture is defined within the framework of the Common Agricultural Policy (CAP), which integrates the three main pillars of sustainability. Thus, the ten specific objectives for the EU CAP for the period 2023–2027 are divided among these pillars: environmental objectives (environmental care; climate change action; preserving landscapes and biodiversity), economic objectives (increasing competitiveness; ensuring a fair income for farmers; improving the position of farmers in the food chain), and social objectives (supporting generational renewal; vibrant rural areas; protecting food and health quality; fostering knowledge and innovation) [7].

Due to the complexity and multidimensionality of sustainability in agriculture, measuring sustainable agriculture is challenging [32–34]. The conditions for each country and region, the high functional and organizational complexity of agricultural activities, as well as the complexity of social, demographic, and economic processes [35], generate a broad range of indicators that are used to evaluate the level of sustainable agriculture. The review of these indicators carried out by Latruffe et al. [36] highlights that the environmental pillar has experienced an "indicator explosion" due to the wide range of themes covered and the heightened societal focus on this pillar of sustainability. By contrast, social and economic indicators of the sustainability of agriculture are less developed. It is worth mentioning here that sustainable agriculture implies not only the environmental concerns frequently prioritized in research papers but also the productivity of production factors used in agricultural productions and social issues related to the income and living conditions of farmers [16]. To achieve sustainability in agriculture, there is a need to create a balance between economic, social, and environmental areas [22,37].

Therefore, for agriculture to positively contribute to sustainable development, especially in rural areas, a holistic approach is needed that considers the interrelationship between the environmental, economic, and social pillars of sustainability. It is equally important to maintain a balance between these three pillars. In light of these considerations, the aim of this study is to highlight the interrelationship between the environmental, social, and economic pillars of the sustainability of agriculture and its impact on rural development in EU countries. Additionally, this research paper emphasizes the specific measures that should be taken to boost all pillars of sustainability in agriculture to increase its effect on rural development. The two main research questions (RQ) answered by the current article are: (RQ1). Is there a trade-off between the environmental, social, and economic pillars of sustainability in agriculture in the EU countries? (RQ2). To what extent does the level of sustainable agriculture influence EU rural development?

The originality of this research lies in the multivariate analysis of the interrelationship between environmental, economic, and social pillars of sustainability in agriculture and rural development in EU countries, based on correlation analysis, principal component analysis (PCA), cluster analysis (CA), and regression analysis. Moreover, the originality of this study derives also from the indicators (4 for the environmental pillar, 5 for the social pillar, and 6 for the economic pillar) selected to assess the level of sustainable agriculture. Taking into consideration that sustainable agriculture is a critical challenge for national economies, understanding its main key factors and characteristics can be an important step in tailoring national and global policies so that sustainable agriculture becomes a driving force for rural development.

2. Theoretical Background and Research Hypotheses

Although the role of the agricultural sector at the macroeconomic level has decreased with the socio–economic progress of the countries, it still remains a strategic sector with multiple economic, social, and environmental functions [15,38,39]. Agriculture contributes to job creation, generates wages and incomes [40,41], supplies food to people and raw materials for industry, shapes foreign trade, and fulfills critical environmental functions [18,42]. Also, agriculture and the food value chain play a crucial role in ensuring global food security and driving economic progress [43].

The agricultural sector generates "multiplier effects far beyond agriculture itself" [3] (p. 764) and maintains the positive spill-over effects on the upstream and downstream sectors. Thus, the socio–economic development of rural areas is closely tied to competitive agriculture, which provides jobs and incomes for a significant number of rural residents as well as generates positive spill-over effects on various other rural activities, such as manufacturing, local services, industries, and tourism [44]. Also, studies [13,45] identified negative correlations between shares of agriculture in GDP and employment, on the one hand, and economic development and labor productivity, on the other hand, a fact that can be explained by the relative higher contribution of agriculture to employment than to GVA, especially in countries with low economic development. Moreover, other empirical research [46] showed that the incomes obtained by agricultural households are below the average household income in all EU countries. Significant gaps in income differentiation in EU countries can be mainly explained by the size of the farm, production orientation, and the economic status of agricultural workers (employees versus self-employed people). Furthermore, employment in agriculture is positively associated with a high incidence of working poverty, particularly in EU economies where own-account workers and unpaid family workers dominate the agricultural sector [47]. To cope with these social and economic issues of agriculture and consequently to boost rural development, authors [48,49] pointed out the necessity of agricultural transformation as "the process by which an agri-food system transforms over time from being subsistence-oriented and farm-centred into one that is more commercialised, productive, and off-farm centred" [48] (p. 779). Growing economies of scale in the agricultural sector increases land and labor productivity, generates more incomes for investment in agriculture, and in turn, farmers can become more productive and resilient [50]. Guth et al. [51], focusing on the economic sustainability of EU farms, showed that CAP subsidies helped narrow the gaps between agricultural income and average non-agricultural income in EU countries during the 2005–2015 period. The authors also identified significant disparities in the agricultural incomes of EU farms, which were attributed to farm size. Thus, they highlighted the inefficiency of CAP in reducing these gaps due to the fact that this support was predominantly directed towards the largest farms.

Studies [46,52] emphasize that the level of EU agricultural development is highly diverse, being influenced by differences in natural conditions, various types of agricultural production, agrarian fragmentation, and levels of economic development. Empirical research [53] has shown that there are two main factor categories that can differentiate the level of agricultural competitiveness: competitiveness sources (human resources, farming conditions, and capital outlays) and competitiveness effects (land, labor, and capital productivity, farm income). At the EU level, in the 2010–2019 period, authors [53] highlighted that agricultural human resources have the utmost importance among sources of agricultural competitiveness. Also, studies [54,55] highlighted the important role of innovation and digitalization in agricultural transformation to enhance land and labor productivity, strengthen the resilience of farmers, and respond to climate change. Bocean [54] showed that the EU countries with a high degree of digitalization exhibit higher agricultural productivity, underscoring the importance of investment in digital technology to bolster the performance of the agricultural sector.

Maintaining high agricultural productivity in the long term not only enhances agricultural competitiveness but also drives the transition from industrial to sustainable agriculture [42]. Traditional agriculture often depends intensely on fossil fuels for machinery, transportation, and fertilizers. Enhancing agricultural productivity through the adoption of more efficient technologies and practices can reduce the energy consumption related to farming, contributing to lower greenhouse gas emissions and aligning with the goals of a just energy transition [56].

At the same time, various studies have highlighted that the significant increases in agricultural productivity achieved through industrialized agriculture have not been without major costs [24,34,57–59], which have generated negative effects on social and environmental development. Also, Trigo et al. [34] pointed out that intensive conventional agriculture both contributes to and is directly affected by climate change, water pollution, biodiversity loss, and the depletion of natural resources. According to Zhang and Drury [24], "the dichotomous goals of environmental protection and economic development have contributed to the failure of environmental policies" (p. 1–2) in the context of EU agriculture. This highlights the need for more efficient environmental policies to mitigate the environmental impact of agriculture. Nevertheless, due to a rapidly increasing global population and the impacts of globalization, the agricultural sector faces numerous environmental issues, such as water scarcity, soil degradation, and greenhouse emissions.

These challenges significantly threaten the long-term sustainability of agriculture and, in turn, the whole economy and society [19,43]. Thus, when agricultural sustainability is evaluated, it is important to take into account that agriculture has two externalities. On the one hand, agriculture provides public goods such as food security, and on the other hand, it simultaneously generates negative effects on the natural environment, like water, air, and soil pollution, thus being detrimental to environmental sustainability [12,16]. At the EU level, the EU Report [50] highlights that due to growing pressures from climate change and competition for essential natural resources such as water and soil, EU agriculture must cope with unprecedented environmental issues, as it is "both driving climate change and being highly impacted by it" [50] (p. 9). Therefore, adopting practices and techniques that conserve soil, water, air, and biodiversity, such as crop rotation, organic farming, integrated farming, and precision agriculture, is a crucial way to enhance the environmental dimension of sustainability in agriculture [19,50,60].

To achieve the Sustainable Development Goals (SDGs) in each EU country as well as in the whole EU economy, it is essential to enhance sustainable agriculture as an "integrated system of plant and animal production practices having a site-specific application that will, over the long term: (a) satisfy human food and fiber needs; (b) enhance environmental quality; (c) make efficient use of non-renewable resources and on-farm resources and integrate appropriate natural biological cycles and controls; (d) sustain the economic viability of farm operations; and (e) enhance the quality of life for farmers and society as a whole." [61]. Sustainable agriculture can ensure the framework in which natural resources are used efficiently to achieve satisfactory agricultural income while respecting environmental laws and improving the life 'quality of both farmers and society as a whole [42]. The backbone of sustainable agriculture can be ensured through the harmonious combination of efficient production of goods and services (economic function), improvement of socio–economic rural conditions (social function), and management of natural resources (ecological function) [33,36]. Furthermore, according to Guttenstein et al. [62], sustainable agriculture and rural development aim to achieve a balanced approach between food self-sufficiency and food self-reliance, employment and income generation in rural areas to eradicate poverty, and the conservation of natural resources and environmental protection.

Marković et al. [12], in assessing the level and dynamics of agricultural sustainability in EU countries, using a composite index based on ten indicators, identified significant differences between Northern EU countries (Sweden, Finland, and Denmark) and Southern countries (Italy, Spain, and France). The study revealed that southern countries exhibited higher agricultural economic performance (measured by the net entrepreneurial income of agriculture) but showed significantly poorer results in terms of environmental sustainability. Specifically, eight out of the ten indicators used for the agricultural sustainability composite index were related to the environmental dimension (greenhouse gas emissions from agriculture, ammonia emissions from agriculture, organic crop area, etc.). This reflects, according to Marković et al. [12], the need to prioritize the environmental pillar in achieving agricultural sustainability. Magrini [33], using twelve indicators related to the economic, social, and environmental dimensions of sustainability, categorized EU countries based on strong and weak sustainable objectives. Thus, in the 2004–2018 period, common strong objectives included income increases in rural areas, reduction of rural poverty, productivity improvements, and the expansion of renewable energy production and organic farming. On the contrary, the reduction of greenhouse gas emissions was one of the weak objectives of the EU countries. Nowak et al. [35] evaluated the level of sustainable agriculture in EU countries using 20 indicators related to two dimensions of sustainability: socio–economic indicators (for example, labor productivity, agricultural income, area under organic farming, investments in agriculture, employed persons) and environmental indicators (such as agricultural area, soil erosion by water, soil organic matter, production of renewable energy from agriculture, emissions from agriculture). Building a composite index based on these dimensions, the authors found a lower degree of sustainable agriculture in six old EU countries (Ireland, Portugal, Greece, Italy, Denmark, and the United Kingdom) compared with some Central and Eastern Europe (Slovakia, the Czech Republic, Bulgaria) and the Baltic states. This disparity can be attributed to weaker environmental performance compared with socio–economic performance in the agricultural sectors of the older EU countries.

The current study examines sustainable agriculture within the context of systems theory to explore the interactions between different components of the agricultural system, including environmental and socio–economic factors. Understanding sustainability in agriculture requires a systems perspective [27]. This approach views the agricultural system in its broadest sense, encompassing individual farms, local ecosystems, and the communities impacted by the farming system, both locally, nationally, and globally [27,63,64].

The literature review reveals the interconnectedness between the social and economic dimensions of agriculture and the multiple effects of the agricultural sector and/or agricultural holdings at both micro and macro levels. These effects include employment and self-employment, poverty, productivity, income, and GDP/capita, all of which can influence rural development. Moreover, empirical studies have shown that achieving a high level of economic and social sustainability in agriculture often incurs an environmental cost. This study explores the level and characteristics of sustainable agriculture in the EU countries and investigates the extent to which the level of sustainable agriculture can influence rural development in the EU.

Based on the theoretical background and evidence from the literature, we developed the following hypotheses:

Hypothesis 1. *There is a strong association between the determinants of social and economic sustainability in the agricultural sector in EU countries.*

Hypothesis 2. *There is a trade-off between the environmental, social, and economic pillars of the sustainability of agriculture in EU countries.*

Hypothesis 3. *The level of sustainable agriculture in EU countries positively influences rural development.*

As empirical research [12,16,32,33,35] has shown, the level of sustainable agriculture at the farm, regional, and national level depends on how it is defined and measured. According to Marković et al. [12], a key prerequisite "for achieving a satisfactory level of agricultural sustainability is the establishment of an adequate measurement and monitoring system in order to facilitate the transition to sustainable agricultural practices" (p. 3). Moreover, valuable information for tailoring specific policies can be obtained based on efficient monitoring and evaluation indicators [16]. There are different approaches to evaluating the level of sustainable agriculture [16,33]. Theoretical and empirical studies focused on the assessment of the sustainability of agricultural holdings [51,65–67] or on the whole agriculture sector [16,33,35]. Furthermore, some authors analyzed only the economic and social dimensions of agricultural sustainability [15,53,65,68], while others focused only on the environmental dimension [31,51,69]. A few empirical studies take into consideration all three pillars of sustainability to evaluate sustainable agriculture in the EU [12,16,33,35]. Therefore, in this paper, as opposed to the existing empirical studies, we investigate the level of sustainable agriculture and its impact on rural development, considering the interrelationship between the environmental, economic, and social pillars of sustainability as well as maintaining a balance between these three pillars. Thus, this research contributes to filling the gap in empirical studies that evaluate the level of sustainable agriculture through a holistic and integrative approach.

3. Materials and Methods

3.1. Measurement of the Level of Sustainable Agriculture and Rural Development

There is considerable debate regarding the indicators and methods used to measure and evaluate sustainable agriculture [21,34,36]. The plethora of definitions and indicators reflects the interdisciplinary and multi-dimensional nature of sustainable agriculture, highlighting the need for a more holistic approach to monitoring agricultural sustainability [25]. To evaluate sustainable agriculture, we used a systems perspective that integrates all three dimensions of sustainability from the agricultural holding level to the agricultural sector level.

The level of sustainable agriculture in the EU countries was measured, taking into account 15 indicators (Tabel 1) that reflect economic, social, and environmental dimensions of sustainability in agriculture. These indicators were selected based on some theoretical and empirical studies [16,19,21,33,35,36] as well as the guidelines available in international and European reports on the assessment of sustainable agriculture [70,71]. Additionally, many of the selected indicators were designed according to the Common Agricultural Policy (CAP) indicators—Context Indicators (CMEF) [72].

The environmental pillar of agricultural sustainability was assessed based on four indicators (Table 1), which emphasize both positive ($Ienv_1$, $Ienv_4$) and negative ($Ienv_2$, $Ienv_3$) effects on the natural environment and climate change.

Table 1. Indicators for sustainable agriculture and rural development.

Variables *	Description
	Environmental indicators for agriculture
$Ienv_1$ (+)	Area under organic farming [sdg_02_40] (% of total utilized agricultural area—UAA)
$Ienv_2$ (−)	Ammonia emissions from agriculture [sdg_02_60] (Kilograms per hectare)
$Ienv_3$ (−)	Share of agriculture in emissions of greenhouse gases [1] (% of total emissions of greenhouse gases)
$Ienv_4$ (+)	Share of agriculture in production of renewable energy [2] (% of total production of renewable energy)
	Social indicators for agriculture
Is_1 (+)	Agricultural factor income (real) per annual work unit ** (thousand EUR/AWU)
Is_2 (+)	Agricultural entrepreneurial income per family work unit (thousand EUR/AWU)
Is_3 (+)	Salaried work in agriculture [calculated as share of salaried labor input in total labor force input (annual work units)] (%)
Is_4 (−)	Employment in agriculture [3] (% din total employment)
Is_5 (−)	In-work at-risk-of-poverty rate among employed persons except employees (%)
	Economic indicators for agriculture
$Ieco_1$ (+)	Labor productivity (thousand EUR/AWU)
$Ieco_2$ (+)	Land productivity [Total standard output (SO)/UAA—thousand EUR/1 ha]
$Ieco_3$ (−)	Share of agriculture [3] Gross Value added (GVA) (% of total GVA)
$Ieco_4$ (−)	Small economic size of farms (% of farms with standard output (SO)/farm < EUR 4000 in total farms)
$Ieco_5$ (+)	Gross fixed capital formation (GFCF) in agriculture (% of total GVA in agriculture)
$Ieco_6$ (+)	Government budget allocations for R&D (GBARD) for agriculture (Euro per inhabitant)
	Rural development (RD) indicators
Rural GDP/capita	GDP at current market prices in predominantly rural regions (Euro per inhabitant)
HDI	HDI score (0–1 values)
Rural Poverty	At-risk-of-poverty rate in rural areas (%)

Note: * Signs (+) or (−) reflect the potential impact of the variable on sustainable agriculture according to literature review; [1] Greenhouse gases (CO_2, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF6 in CO_2 equivalent, NF3 in CO_2 equivalent) [72]; [2] The total production of renewable energy from agriculture is the sum of biodiesel, bioethanol, and biogas production, all expressed in ktoe (kilotons of oil equivalent) [53]. [3] Including forestry and fishing; ** "Annual work units (AWUs) are defined as full-time equivalent employment (corresponding to the number of full-time equivalent jobs), i.e., as total hours worked divided by the average annual number of hours worked in full-time jobs within the economic territory" [53]. Source: Own calculations based on references [72–75].

Thus, Area under organic farming (as % of total UAA—utilized agricultural area)—$Ienv_1$ and Share of agriculture in production of renewable energy (as % of total production of renewable energy)—$Ienv_4$ were used in order to illustrate the sustainable agricultural management system, which "seeks to limit environmental impacts by using agricultural practices that encourage responsible use of energy and natural resources, maintain or enhance biodiversity" [70], increasing its capacity to adapt to climate change. Moreover, the "Area under organic farming" indicator (SDG 2.40) is used to monitor the EU's performance in achieving SDG 2 ("End hunger, achieve food security and improved nutrition and promote sustainable agriculture"), as well as a target set in the Farm to Fork Strategy for a fair, healthy, and environmentally friendly food system (achieving 25% of the EU's total farmland under organic farming by 2030) [9]. Organic production is considered the most evident example of sustainable agriculture [12]. Its advantages include enhanced environmental protection, the promotion of sustainable land use, improved animal welfare, and higher product quality. Increasing the production of renewable energy in any sector, including the agricultural sector, represents a key component of environmentally sustainable development. Therefore, producing a minimum of 42.5% of EU energy from renewable sources is an important renewable energy target at the EU level for 2030 [76].

To assess the negative impact on the natural environment, two indicators were used: ammonia emissions from agriculture (SDG 2.60)—$Ienv_2$ and share of agriculture in emissions of greenhouse gases—$Ienv_3$. Ammonia emissions from agriculture and the share of agriculture in emissions of greenhouse gases are considered non-sustainability indicators for agriculture (deterrents to sustainable agriculture). According to Hayati [21], when assessing agricultural systems, non-sustainability indicators can be used instead of sustainability indicators, as "it is easier and quicker to identify constraints to progress rather than all the factors that contribute to progress" (p. 52). Unfortunately, statistical data show that agriculture generates about a quarter of global greenhouse gas emissions and over 90% of total ammonia emissions in the EU. A high level of these indicators reflects a significant level of pollution, which can contribute to global warming and pose a substantial threat to achieving long-term sustainability goals [19]. Therefore, transforming agriculture towards a climate-friendly agriculture by reducing the levels of $Ienv_2$ and $Ienv_3$ could significantly contribute to achieving the objectives of the European Green Deal [8].

Six indicators were used in order to assess the economic pillar of agricultural sustainability (Table 1). Five indicators cover aspects related to productivity (labor productivity—$Ieco_1$ and land productivity—$Ieco_2$), the contribution of the agricultural sector to gross value added ($Ieco_3$), investments in the agricultural sector (gross fixed capital formation in agriculture—$Ieco_5$), and government budget allocations for R&D in agriculture ($Ieco_6$). The positive impact of these variables on the sustainable development of the agriculture system was supported by several empirical studies [51,69]. One of the six economic indicators refers to the small economic size of farms, measured as the share of farms with standard output (SO)/farm <EUR 4000 in total farms ($Ieco_4$). A wide range of studies [13,36] showed that small farms perform worse than large farms in terms of productivity, generating a negative effect on economic sustainability in agriculture. Also, there were studies that pointed out a potential positive impact on the environmental sustainability of small farms [19,69]. According to Hurduzeu et al. [19], the role of small producers in the agricultural sector is multidimensional and encompasses several specific objectives, such as eliminating hunger, improving nutrition, achieving food security, and promoting sustainable agriculture.

According to empirical studies [13,16,36,77], the share of agriculture in total GVA ($Ieco_3$) and the share of farms with standard output (SO)/farm < EUR 4 000 in total farms ($Ieco_4$) negatively contribute to the economic sustainability of agriculture, as they are considered non-sustainability indicators (deterrents to sustainable agriculture).

The social pillar of agricultural sustainability was assessed based on five indicators, which refer to the agricultural income level (Is_1, Is_2), contribution of agriculture to employment (Is_3, Is_4), and in-work poverty risk (Is_5). Agricultural factor income (real) per annual work unit (Is_1) and agricultural entrepreneurial income per family work unit (Is_2) are indicators used to assess the agricultural income level in EU countries. Is_1 measures the incomes generated by a unit engaged in an agricultural production activity, which is used to remunerate all factors of production (land, capital, labor) regardless of whether they are borrowed/rented or owned [74]. In contrast to Is_1, agricultural entrepreneurial income per family work unit (Is_2) measures only "the income derived from agricultural activities that can be used for the remuneration of own production factors" [74]. Due to the fact that an important share of agricultural factor income comprises EU subsidies and direct payments, agricultural factor income is "best suited for evaluating the impact of changes in the level of public support", especially Common Agricultural Policy (CAP) [74]. It is worth mentioning that the agricultural factor income indicator (SDG 2.20) is used to monitor progress towards SDG 2, taking into account that boosting agricultural productivity and the incomes of farmers are the key drivers that ensure access to sufficient food (SDG 2) [19].

The contribution of agriculture to the creation of jobs is assessed based on two indicators: the "Salaried work in agriculture" indicator (Is_3), measured as the share of salaried labor input in total labor force input, and the employment in agriculture indicator (Is_4), measured as a percentage of total employment. As for Is_3, studies [13,44,45,78] highlighted that a high proportion of wage and salaried workers in an economy or activity sector indicates a high level of economic development and social security. Instead, a high share of own-account workers and contributing family workers who are vulnerable segments of self-employment reflects a low level of productivity and income, challenging working conditions, informal activities, poverty risk, and a large agricultural production sector. Concerning the employment in agriculture indicator (Is_4), some studies underlined its negative impact on sustainable development [16,35], with a high share of agricultural workers being associated with a low level of economic development (GDP/capita), labor productivity, and incomes, but also with a high risk of poverty.

Taking into account that the workers in agriculture, especially self-employed persons, are significantly exposed to the risk of poverty, we use the in-work at-risk-of-poverty rate among self-employed persons (Is_5) as an indicator for the social non-sustainability of agriculture. A high level of this indicator represents a significant challenge for the achievement of SDG 1, "No poverty". Thus, Is_4 and Is_5 negatively impact the social sustainability of agriculture, and they are considered indicators of non-sustainability (deterrent to sustainable agriculture).

Moreover, a high level of the majority of the selected socio–economic indicators should be reached for the achievement of the SDGs, especially SDG 2 and SDG 8 (promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all).

In order to analyze the degree of rural development at the EU level, we used GDP per inhabitant in predominantly rural regions (Euro per inhabitant), the at-risk-of-poverty rate in rural areas, and the Human Development Index (HDI). HDI is a composite index that measures "average achievement in three basic dimensions of human development—a long and healthy life, knowledge and a decent standard of living" [75].

3.2. Statistical Methods

In order to test the research hypotheses, we used descriptive statistics (minimum-maximum values, mean, and standard deviation), correlation analysis, principal component analysis (PCA), cluster analysis (CA), and regression analysis.

The Pearson correlation coefficient (r) was used to investigate the strength of association between the analyzed variables. The values of this coefficient are between −1 and 1. If r is closer to −1 or 1, it means a stronger negative or positive correlation between variables [79].

PCA and CA were used to test hypotheses H1 and H2. Firstly, PCA with Varimax rotation and Kaiser normalization was used considering that the principal advantage of the PCA is to reduce the dimensionality of a dataset, which includes a large number of interrelated variables (15 variables in our case; see Table 1). Multiple criteria were applied to determine the number of principal components, such as the Kaiser criterion, Catell's scree plot criterion, and the percentage of cumulative variance, which retains only those principal components that involve a large percentage (between 70 and 90%) of the total variation of the initial variables [45,80,81]. Secondly, the principal components obtained by PCA served as the basis for our cluster analysis, enabling the identification of homogeneous groups of countries. Initially, we employed hierarchical cluster analysis using Ward's method and the Euclidian distance to find out the number of clusters. Following this, we conducted k-means cluster analysis [82].

The choice of using principal component analysis in this study was primarily based on its main objective: to reduce the dimensionality of a dataset with many variables while preserving as much statistical information as possible. Additionally, PCA creates an uncorrelated "new" dataset (a linear combination of variables) suitable for the subsequent multivariate analyses, such as cluster analysis [83]. Compared with other data reduction techniques (e.g., factor analysis), PCA is more efficient as it allows us to identify the components that maximize variance, which are then used in cluster analysis. Secondly, it was considered that this multivariate statistical method can help address the issues caused by using different measurement units for the initial variables and the high variations in covariance coefficients [80–82]. Finally, PCA and cluster analysis are often used by different authors [2,3,15,41,42,49,67,84] to investigate multiple aspects of the agricultural sector, including its sustainability.

To explore the impact of sustainable agriculture (measured by the Sustainable Agriculture Index) on rural development, we used simple linear regression analysis according to Equation (1):

$$Y = \alpha + \beta \times X + \varepsilon \tag{1}$$

where Y is the dependent variable, such as rural GDP/capita, HDI, or at-risk-of-poverty rate in rural areas, X is the explanatory variable (Sustainable Agriculture Index), α and β are regression coefficients, and ε is the residual or error.

The Sustainable Agriculture Index (explanatory variable in regression analysis), as a composite index that assesses the level of sustainable agriculture in each analyzed EU country, was constructed using the weights of each principal component in the total variance based on the methodology used by other authors [85,86]. This composite index of agricultural sustainability provides a unique assessment of the level of agricultural sustainability achieved by EU countries [12,53].

The regression coefficients (α and β) were estimated based on the least-squares method. The validity of the regression model was evaluated using the Fisher Snedecor (F) statistic. The coefficient of determination (R^2) was used to assess the quality of the prediction, indicating the extent to which the independent variables explain the variance in the dependent variable [80].

3.3. Data and Sample

Our sample consisted of 24 EU countries without Luxembourg, Malta, or Cyprus. These three EU countries were excluded from our analysis for several reasons: some statistical data were unavailable, they are outliers in several variables due to their very high intensity of agricultural production and their small significance to EU agriculture [16], and they lack predominant rural regions [72–74]. All variables are analyzed for the most recent year for which data are available, 2021, respectively. The statistical data used in this study were collected from the Eurostat database [72–74] and the UNDP database [75]. For data processing, IBM SPSS Statistics 26.0 (IBM, Armonk, NY, USA) was used.

4. Results and Discussion

Descriptive statistics (minimum–maximum values, mean, and standard deviation) for all 15 indicators used to assess the level of agricultural sustainability in the EU-24 countries, as well as for three rural development indicators, are presented in Table 2. Despite the convergence trend within the EU, there remains a high level of heterogeneity, with significant disparities identified among the analyzed countries in terms of all three categories of sustainable agriculture variables and rural development indicators.

Table 2. Descriptive Statistics (N = 24).

Variables	Minimum	Maximum	Mean	Std. Deviation
$Ienv_1$	1.71 (BG)	25.69 (AT)	11.376	6.479
$Ienv_2$	6.8 (LV)	57.8 (NL)	19.896	12.119
$Ienv_3$	5.7 (SK)	35.8(IE)	13.133	6.914
$Ienv_4$	0.5(EE)	30.1(NL)	9.200	6.792
Is_1	5.20(SL)	49.69 (DK)	22.31	12.48
Is_2	4.23 (SL)	46.84(ES)	20.58	12.52
Is_3	5.96 (SL)	73.09 (SK)	35.547	19.756
Is_4	0.91 (BE)	11.72 (RO)	4.415	2.869
Is_5	6.5 (SL)	62.2 (RO)	19.329	11.736
$Ieco_1$	5.748 (SL)	69.532 (NL)	26.372	17.814
$Ieco_2$	6.89 (LV)	136.83 (NL)	25.593	26.993
$Ieco_3$	0.7 (BE)	5.3 (RO)	2.604	1.358
$Ieco_4$	2.01 (NL)	86.19 (RO)	34.345	22.650
$Ieco_5$	11.06 (PL)	111.85 (EE)	42.297	25.164
$Ieco_6$	0.1 (PL)	23.8 (DK)	7.346	5.634
HDI	0.795 (BG)	0.948 (DK)	0.894	0.042
Rural GDP/capita	7100 (BG)	71,000 (IE)	24,729.167	15,661.542
Rural Poverty	7.8 (CZ)	38 (RO)	18.875	7.781

Source: Own calculations based on References [72–75].

An initial overview of the relationship between the 15 variables of sustainable agriculture in the EU countries is presented in the correlation matrix (Table 3). $Ienv_2$ was found to be significantly negatively correlated with $Ieco_3$ ($r = -0.599$), $Ieco_4$ ($r = -0.602$), and Is_4 ($r = -0.415$), and significantly positively correlated with $Ieco_2$ ($r = 0.861$), $Ieco_1$ ($r = 0.608$), Is_1 ($r = 0.482$), and $Ienv_4$ ($r = 0.591$). These results indicate that in EU countries with high levels of ammonia emissions from agriculture ($Ienv_2$), there is a low level of contribution from agriculture to total GVA and employment and a low share of small economic farms in total farms. Conversely, in these countries, there are high levels of land productivity, labor productivity, and agricultural factor income.

Furthermore, significant correlations were identified between the social and economic indicators. Specifically, $Ieco_1$ is positively correlated with Is_1 ($r = 0.958$), Is_2 ($r = 0.818$), $Ieco_2$ ($r = 0.717$), $Ieco_6$ ($r = 0.634$), and negatively correlated with Is_4 ($r = -0.596$), $Ieco_3$ ($r = -0.627$), and $Ieco_4$ ($r = -0.781$). This means that a high level of labor productivity is associated with a high level of agricultural incomes, land productivity, and investments in agriculture. Additionally, this high level of labor productivity is linked to a low level of contribution from agriculture to employment and GVA in the total economy, as well as a low level of small-scale agriculture. These correlation results confirm that high agricultural employment and low agricultural productivity are significant factors that contribute to the disparities in agricultural performance [53] and living standards between countries and thus hinder efficient structural change [87]. This strong association between the determinants of social and economic sustainability in the agricultural sector in EU countries validates Hypothesis 1.

The correlation matrix also shows that there are no high correlations between the analyzed variables. Thus, multicollinearity issues were avoided, and consequently, the full set of variables was used in the PCA.

To assess the level of sustainable agriculture in the EU countries, we took into consideration the cumulative influence of all 15 variables using principal component analysis (Rotation Method: Varimax with Kaiser Normalization; the rotation converged in 6 iterations). The results of the KMO (Kaiser-Meyer-Olkin Measure of Sampling Adequacy) and Bartlett's Test indicated the suitability of the 15 variables set for the PCA. Four principal components were identified based on cumulative criteria, including Catell's scree plot, percentage of cumulative variance, and the eigenvalue greater than one rule. The four components explain 81.55% of the total variance in the environmental, social, and economic variables that characterize the sustainability of agriculture in the EU (Table 4).

Table 3. Correlation matrix.

	$Ienv_1$	$Ienv_2$	$Ienv_3$	$Ienv_4$	Is_1	Is_2	Is_3	Is_4	Is_5	$Ieco_1$	$Ieco_2$	$Ieco_3$	$Ieco_4$	$Ieco_5$	$Ieco_6$
$Ienv_1$	1	−0.252	−0.226	−0.361	0.039	0.118	0.307	−0.344	0.000	0.001	−0.188	−0.283	−0.137	0.655 **	−0.054
$Ienv_2$		1	−0.055	0.591 **	0.482 *	0.243	−0.144	−0.415 *	−0.284	0.608 **	0.861 **	−0.599 **	−0.602 **	0.108	0.348
$Ienv_3$			1	−0.233	0.156	0.134	−0.150	0.066	0.051	0.091	−0.147	0.005	0.036	−0.040	0.542 **
$Ienv_4$				1	0.523 **	0.358	0.379	−0.391	−0.370	0.645 **	0.712 **	−0.322	−0.460 *	−0.218	0.306
Is_1					1	0.893 **	0.466 *	−0.613 **	−0.335	0.958 **	0.570 **	−0.652 **	−0.813 **	0.109	0.700 **
Is_2						1	0.528 **	−0.498 *	−0.204	0.818 **	0.343	−0.484 *	−0.654 **	−0.012	0.583 **
Is_3							1	−0.541 **	−0.160	0.400	0.060	−0.226	−0.223	0.122	0.322
Is_4								1	0.554 **	−0.596 **	−0.303	0.789 **	0.719 **	−0.441 *	−0.467 *
Is_5									1	−0.287	−0.203	0.421 *	0.582 **	−0.122	−0.309
$Ieco_1$										1	0.717 **	−0.627 **	−0.781 **	0.110	0.634 **
$Ieco_2$											1	−0.388	−0.514 *	0.022	0.285
$Ieco_3$												1	0.847 **	−0.418 *	−0.535 **
$Ieco_4$													1	−0.371	−0.607 **
$Ieco_5$														1	0.231
$Ieco_6$															1

Note: ** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed). Source: Own calculations based on References [72–74].

Table 4. Total variance and eigenvalues explained.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.721	44.805	44.805	6.721	44.805	44.805	4.609	30.727	30.727
2	2.375	15.835	60.639	2.375	15.835	60.639	3.214	21.425	52.152
3	1.702	11.345	71.984	1.702	11.345	71.984	2.541	16.942	69.094
4	1.436	9.570	81.554	1.436	9.570	81.554	1.869	12.461	81.554
	…	…	…						
15	0.008	0.052	100.000						

Extraction Method: Principal Component Analysis.

The first principal component (PC1) explains 44.805% of the total variance and includes seven variables (Table 4). The correlation coefficients from the rotated component matrix (Table 5) show that PC1 is strongly positively correlated with Ienv2—ammonia emissions from agriculture (0.949) and $Ieco_2$—land productivity (0.870), and moderately positively correlated with $Ienv_4$—share of agriculture in the production of renewable energy (0.718) and $Ieco_1$—labor productivity (0.678). These results suggest that increases in these variables, such as $Ienv_2$ and $Ieco_2$, are associated with higher values of PC1. Conversely, negative correlations with economic variables such as Ieco4 (small economic size of farms) and $Ieco_3$ (share of agriculture GVA in total GVA), as well as with one of the social indicators (Is_5—in-work at-risk-of-poverty rate), indicate that higher values of these variables are associated with lower values of PC1. It is worth mentioning that all three variables ($Ieco_4$, $Ieco_3$, and Is_5) are considered deterrents to sustainable agriculture. Thus, a high level of land and labor productivity, along with a low share of small farms with a standard output of less than EUR 4000 and a low share of agriculture GVA in total GVA, reflects the high economic performance of agriculture. Conversely, a high level of ammonia emissions from agriculture reflects a low level of environmental sustainability in agriculture. Taking these aspects into consideration, PC1 was named the "Economic and environmental sustainability trade-off component."

Table 5. Principal components for EU-24 countries (rotated component matrix).

	Rotated Component Matrix *			
Initial Variables	**PC 1**	**PC 2**	**PC 3**	**PC 4**
$Ienv_2$	0.949	−0.100	−0.003	0.082
$Ieco_2$	0.870	0.129	0.152	−0.068
$Ieco_4$	−0.719	−0.370	0.419	−0.224
$Ienv_4$	0.718	0.425	0.326	−0.216
$Ieco_1$	0.678	0.616	−0.045	0.255
$Ieco_3$	−0.626	−0.263	0.563	−0.202
Is_5	−0.464	−0.159	0.271	−0.009
Is_3	−0.080	0.890	−0.157	−0.182
Is_2	0.293	0.805	−0.049	0.309
Is_1	0.561	0.696	−0.103	0.348
$Ieco_5$	0.079	−0.074	−0.878	0.063
$Ienv_1$	−0.266	0.199	−0.818	−0.199
Is_4	−0.472	−0.492	0.573	−0.026
$Ienv_3$	−0.153	−0.044	0.114	0.924
$Ieco_6$	0.350	0.425	−0.154	0.712

Note: * Rotation converged in 6 iterations. The extraction method was PCA, and the rotation method was Varimax with Kaiser normalization.

The second principal component (PC2) accounts for 15.835% of the total variance and includes three variables related to the social dimension of agricultural sustainability (Is_1—agricultural factor income, Is_2—agricultural entrepreneurial income, and Is_3—share of salaried labor input in total labor force input). Given that these social indicators have a significant positive contribution to the creation of PC2 (Table 5), this component was named the "Social agricultural performance Component."

The third principal component (PC3) accounted for 11.345% of the total variance in the observed variables. It was strongly negatively correlated with two of the original variables: $Ieco_5$—GFCF in agriculture (−0.878) and $Ienv_1$—area under organic farming (−0.818), and moderately positively correlated with Is_4—employment in agriculture (0.573).

The higher level of PC3 is associated with smaller investment (GFCF) in agriculture, a smaller area under organic farming, on the one hand, and higher employment in agriculture. The negative correlations of PC3 with investment and organic farming suggest that countries with higher PC3 values tend to have lower investments in agriculture and smaller areas dedicated to organic farming. The positive correlation with employment in agriculture may indicate that countries with higher agricultural employment rely more on traditional and labor-intensive farming practices, which might result in reduced investment and organic farming. Therefore, PC3 was named the "Organic agriculture & investment in agriculture component."

The fourth principal component (PC4) explains 9.570% of the total variance and is strongly positively correlated with $Ienv_3$—share of agriculture in emissions of greenhouse gases (0.924) and $Ieco_6$— government budget allocations for R&D (GBARD) for agriculture (0.712). Therefore, a high share of agriculture's emissions of greenhouse gases require a high level of government budget allocations for R&D in agriculture. Consequently, PC4 was named the "Agricultural greenhouse gasses emissions & Public R&D investment in agriculture component."

In the next step, the four principal components (PC1–PC4) were used in the cluster analysis to classify the EU-24 member states. The number of clusters and their composition were determined using hierarchical cluster analysis (Ward's method and Euclidean distance) and K-means analysis [82]. Results from Figures 1 and 2 and Table 6 reveal that the EU countries were classified into five clusters. The formed clusters were statistically significant according to the results of the ANOVA analysis (for PC1, $F(4, 19) = 11.362$, $p < 0.001$; for PC2, $F(4, 19) = 11.362$, $p < 0.05$; for PC3, $F(4, 19) = 10.955$, $p < 0.001$; for PC4, $F(4, 19) = 15.718$, $p < 0.001$; Table 6).

Cluster 1 comprises four countries (Austria, Slovenia, Estonia, and Finland) and is strongly negatively correlated with PC3 (−1.559) and moderately negatively correlated with PC 2 (−0.729) (Table 6, Figures 2 and 3). Therefore, this cluster is mainly determined by the variables that define PC 3 ("Organic agriculture & investment in agriculture component"), such as GFCF in agriculture ($Ieco_5$), area under organic farming ($Ienv_1$), and employment in agriculture (Is_4). Thus, cluster 1 is characterized by a higher level of investment and organic farming and a lower level of variables related to social sustainability (Is_1, Is_2, and Is_4) (see Figures 4 and 5). On average, this cluster ranks first in terms of the level of area under organic farming (18.48% of total area) and the share of GFCF in GVA in agriculture (86.85% of GVA in agriculture), but third in terms of agricultural income (Is_1, Is_2) and salaried work in agriculture (Figure 5), variables that define PC 2 ("Social agricultural performance component"). A particular position in this cluster is occupied by Slovenia, which has the lowest levels of agricultural income (Is_1, Is_2), salaried work in agriculture, and labor productivity, both among countries included in cluster 1 and among all analyzed EU countries. Slovenian agriculture is characterized by a high number of small farms and significant agricultural subsidies [68].

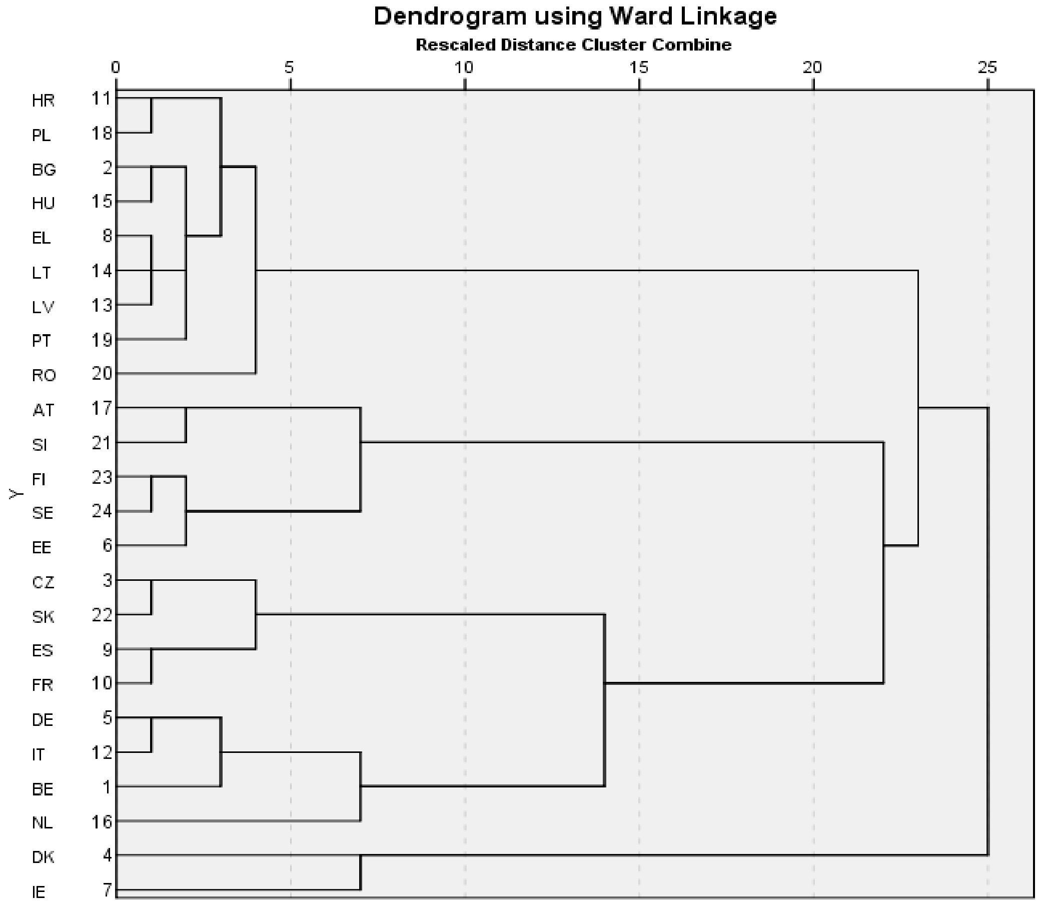

Figure 1. Dendrogram using Ward Linkage method for EU-24 countries. Source: authors' own calculations.

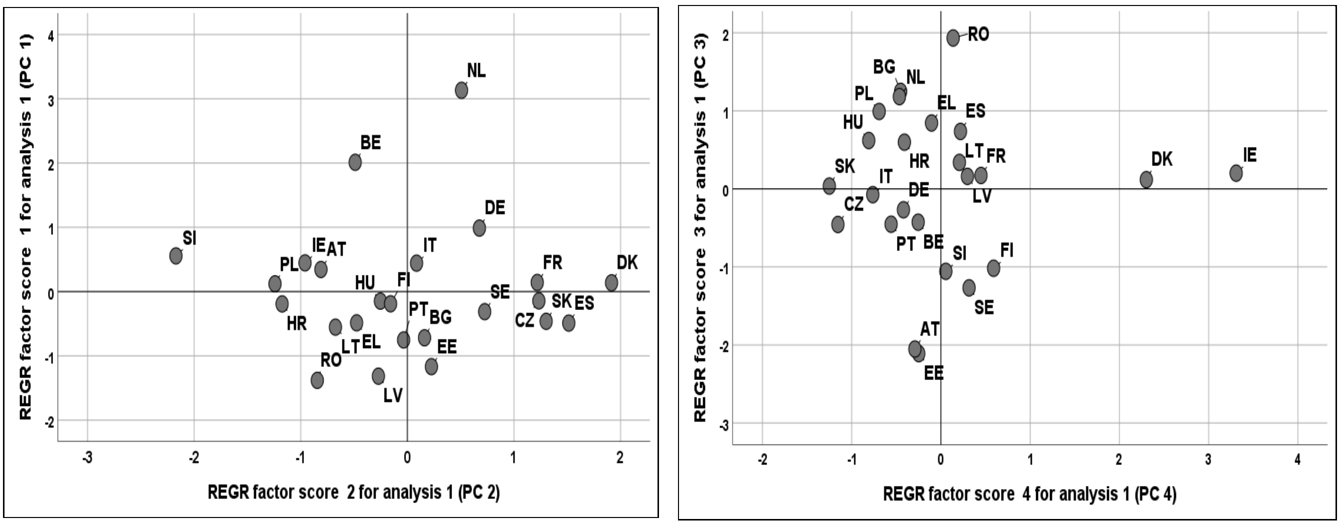

Figure 2. EU clusters based on PCA and CA.

Table 6. The results of the cluster analysis: final cluster centers and ANOVA.

	Final Cluster Centers					ANOVA					
						Cluster		Error		F	Sig.
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Mean Square	df	Mean Square	df		
PC1	−0.114	2.571	−0.074	0.292	−0.584	4.055	4	0.357	19	11.362	0.000
PC2	−0.729	0.009	0.840	0.478	−0.597	2.769	4	0.628	19	11.362	0.011
PC3	−1.559	0.378	−0.197	0.159	0.842	4.011	4	0.366	19	10.955	0.000
PC4	0.026	−0.360	−0.396	2.805	−0.228	4.416	4	0.281	19	15.718	0.000

Figure 3. The distribution of EU-24 countries across four clusters using MapChart https://www.mapchart.net (accessed on 8 April 2024).

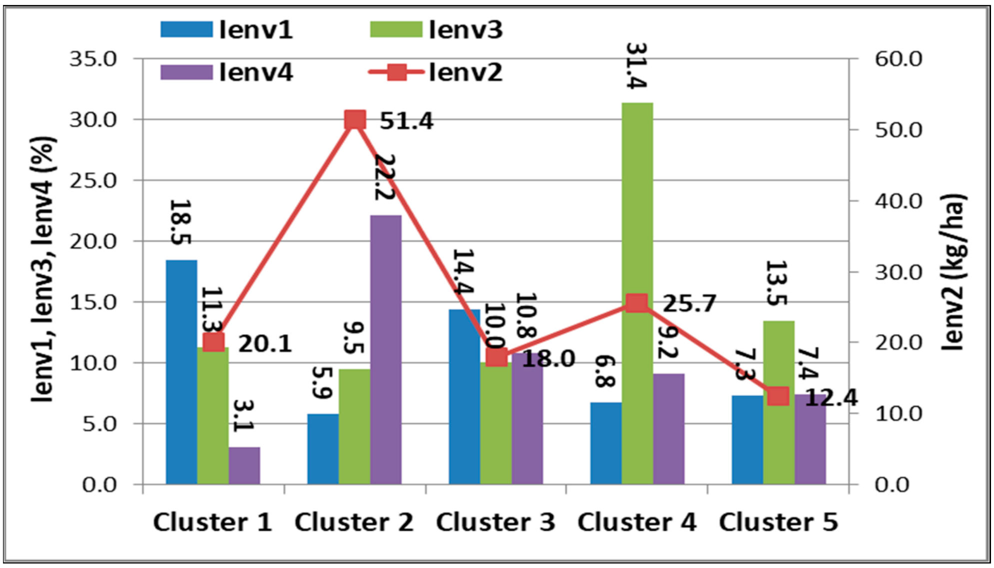

Figure 4. Environmental indicators (mean values per cluster). Source: own calculations based on [72].

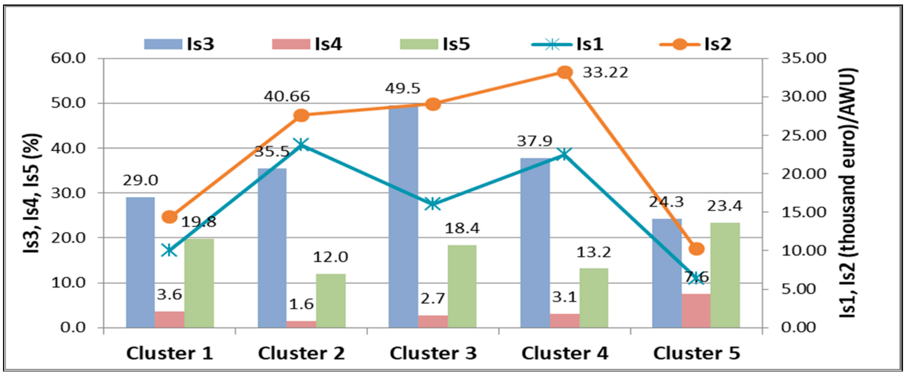

Figure 5. Social indicators (mean values per cluster). Source: own calculations based on [72–74].

The Netherlands and Belgium were grouped in cluster 2, which is strongly positively correlated with PC1 (2.571), being mainly characterized by the level of variables that define PC1 (Table 6). Despite achieving the best socio–economic performance, with the highest values for labor productivity (58.4 thousand EUR/AWU), land productivity (99.1 thousand EUR/1 ha), and agricultural factor income (40.66 thousand EUR/AWU) and the lowest in-work poverty rate (12% of self-employed persons) (see Figures 5 and 6), this cluster recorded the worst performance in terms of two environmental sustainable goals (SDG 2.40 and SDG 2.60) linked with the achievement of SDG 2 ("Zero hunger"). On average, this cluster recorded the highest level of pollution from agriculture (51.4 Kilograms per hectare of ammonia emissions from agriculture) and the lowest share of area under organic farming (only 5.9% of the total UUA) (see Figure 4). Due to the performance achieved by the Netherlands, which leads among EU countries in the production of renewable energy by agriculture (agriculture generates 30.1% of the total production of renewable energy), this cluster ranks first in terms of this environmental indicator. Furthermore, in Belgium and The Netherlands, only 2% of farms have small economic sizes (SO/farm <EUR 4000), which emphasizes large-scale agriculture with potential positive effects on the socio–economic dimension of agricultural sustainability but negative impacts on the achievement of environmental goals.

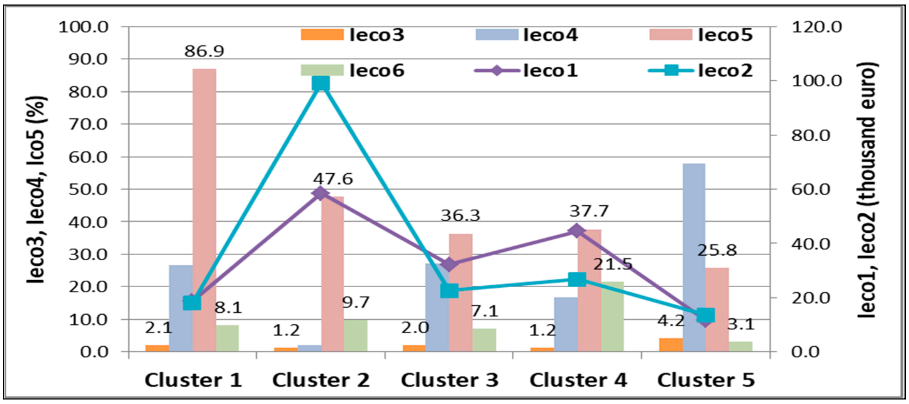

Figure 6. Economic indicators (mean values per cluster). Source: own calculations based on [72–74].

Two other EU countries (Denmark and Ireland) were grouped in cluster 4, being mainly characterized by the highest levels of variables ($Ienv_3$ and $Ieco_6$) that define PC4, the "Agricultural greenhouse gasses emissions and public R&D investment in agriculture component". Consequently, this cluster performs the poorest in terms of agriculture's contribution to greenhouse gas emissions, recording the highest value (31.4%). Notably, Ireland is the EU leader in this regard (33.83%). Moreover, this cluster performs poorly in terms of SDG 2.40, with the second highest values for ammonia emissions from agriculture (25.7 kg per hectare). The highest values of government budget allocations for R&D for agriculture attained by these countries [Denmark (the EU leader) with 23.8 Euro per inhabitant, followed by Ireland with 19.2 Euro per inhabitant] demonstrate these countries' commitment to reducing pollution by investing in R&D to find new and less polluting technologies to sustain agriculture. As for the share of area under organic farming, countries included in cluster 4 have a low propensity for organic farming, accounting for 6.8% of the total UUA, which is below the average value obtained by cluster 1 (6.8% against 18.5%). Our results are in line with those of [19], who demonstrated that countries receiving substantial funding for agricultural research and development experience increasing ammonia emissions from agriculture. Therefore, it is crucial for all EU countries to implement effective measures to reduce ammonia emission levels.

As for most economic indicators (labor productivity, land productivity, farm economic size) and social indicators (agricultural factor income, in-work poverty rate, salaried work), cluster 4 ranks second among the five identified clusters. Furthermore, agricultural entrepreneurial income per family work unit in this cluster recorded the highest value (33.22 thousand EUR/AWU) compared with other clusters (with Denmark ranking second among EU countries). Therefore, we can state that in the case of cluster 2 and cluster 4, there is a significant trade-off between the environmental pillar and the socio–economic pillar of sustainability in EU agriculture.

Cluster 3 consists of eight countries (Czech Republic, Slovakia, Germany, Spain, France, Italy, Portugal, and Sweden) and is mainly characterized by the variables that define PC2 (Is_1, Is_2, and Is_3). Consequently, this cluster achieved the highest level of agricultural entrepreneurial income (Spain leading among EU-24 countries with 46.84 thousand euros/AWU) and the share of salaried work in agriculture (with Slovakia as the EU leader at 73.09%), making it the top-performing cluster. Additionally, it attained a very high level of real agricultural factor income (France being the leader in this cluster and ranking third among EU-24 with 41 thousand euros/AWU), ranking as the second-best performer in this regard. From the perspective of the environmental dimension of sustainable agriculture, this cluster ranks second in terms of all environmental indicators ($Ienv_1$, $Ienv_2$, $Ienv_3$, and $Ienv_4$) (Figure 4). In terms of three of the six economic indicators, cluster 3 holds the third position among the five clusters ($Ieco_1$, $Ieco_2$, and $Ieco_3$) and the fourth position with regard to the other three economic indicators ($Ieco_4$, $Ieco_5$, and $Ieco_6$) (see Figures 5 and 6).

The inclusion of Slovakia and the Czech Republic in this cluster, which predominantly contains older EU countries, is mainly due to the employment status of agricultural workers (the main variable that defines PC3). The highest share of salaried work in agriculture in these countries, which experienced collective agriculture, is linked to the significant share of land managed by large farms [46].

Cluster 5 comprises eight countries (Bulgaria, Greece, Croatia, Lithuania, Latvia, Poland, Romania, and Hungary). This cluster mainly consists of new EU member states (except for Greece) and former centrally planned economies, which still predominantly lag behind the mature economies of the EU. The values of all six economic indicators reflect the lowest level of economic sustainability in agriculture. For instance, the average labor productivity in this cluster was 11.75 thousand EUR/AWU, which represents only 20% of the average labor productivity achieved by the countries included in cluster 2. The situation is even worse in terms of land productivity, which accounted for only 13.8% of the average land productivity in cluster 2 (13.7 compared with 99.1 thousand EUR/1 ha). The lowest level of productivity can be explained by the existence of an agriculture characterized by the highest share of farms with small economic size in total farms (57.8% compared with 2.1%—cluster 2) and the lowest level of investments in agriculture, expressed by GFCF in agriculture (25.8% of GVA in agriculture) and GBARD in agriculture (3.1 Euro per inhabitant).

As for the social indicators, this cluster has the lowest level of agricultural incomes (Figure 5). For example, agricultural factor income (Is_1) in this cluster accounted for only 27% of the average income in cluster 2 (11.02 compared with 40.66 thousand EUR/AWU). Additionally, agricultural entrepreneurial income (Is_2) (10.26 compared with 33.22 thousand

EUR/AWU) is more than three times lower than income achieved by countries in cluster 4 (the best performer as regards Is_2). The lowest level of income is correlated with the lowest share of salaried labor input in total labor force input (24.3%) as well as with the highest level of in-work at-risk-of-poverty rate among self-employed persons (23.4%).

In this cluster, on average, the contribution of agriculture to employment was 1.8 times higher than the contribution of agriculture to gross value added. Even though cluster 5 is the largest contributor to employment (7.6% of total employment compared with 1.6% in cluster 2), it is worthwhile to mention that agricultural workers in this cluster perform work characterized by the lowest level of productivity and the highest level of poverty compared with the other four clusters.

Lower agricultural productivity in new member states of the EU (seven countries in cluster 5) compared with the older ones (see clusters 2 and 4) has also been confirmed in other studies [51,53,65,88]. Furthermore, studies have shown that agricultural productivity between the old and new EU countries has converged due to significant changes in the agricultural sector in the new EU countries [19,31]. Our results are consistent with those of Hurduzeu et al. [19], confirming that agricultural income per family work unit tends to be higher in countries with highly technologized, input-intensive production systems (see clusters 2 and 4) than in countries "using more traditional, labour-intensive methods" like those included in cluster 5.

The average level of environmental indicators achieved by cluster 5 reflects a relatively higher level of the environmental dimension of agricultural sustainability (compared with clusters 2 and 4) in terms of SDG 2.60 (12.4 kg per hectare of ammonia emissions from agriculture, making it the best performer cluster), SDG 2.40 (7.3% of the total UUA is area under organic farming, ranking third among clusters), and $Ienv_3$ and $Ienv_4$ (fourth performer cluster) (Figure 4). This moderate environmental performance of agriculture can be explained by the lower intensity and smaller concentration of agricultural production, which imposes a lesser burden on the natural environment compared with countries with more intensive and developed agricultural systems [35].

There is high heterogeneity in cluster 5. For instance, in the case of Romania, results confirm a particular agricultural system characterized by a very large number of agricultural holdings but with a small economic size (subsistence farms), due to the excessive fragmentation of agriculture land [15,84], the "inadequate structures of agricultural production and high shares of crop production," and a very low level of investments, especially in irrigation systems [89]. Thus, in 2021, Romania was the EU's leader in terms of small economic size farms (86.19% of total farms have a SO/farm < EUR 4000), employment in agriculture (11.72% of total employment), in-work poverty rate (62.2% of self-employed people), and agriculture GVA (5.3% of total GVA). Taking into account that these socio–economic indicators are considered barriers to achieving sustainable agriculture [16], these results show that Romania faces critical challenges in increasing the sustainability of its agricultural sector.

The findings demonstrate that within the EU, there are significant differences and commonalities between member states based on the interaction between the environmental, social, and economic pillars of sustainable agriculture. Therefore, special attention needs to be paid to supporting convergence across EU countries and promoting a high level of sustainable agriculture.

Taking into consideration these results, the ranking of the EU clusters based on all three dimensions of the level of agricultural sustainability is presented in Table 7.

We can conclude that there is a real challenge for EU countries to achieve, at the same time, the economic, social, and environmental development pillars of sustainable agriculture. Therefore, our results confirm the existence of a trade-off between the three sustainability dimensions, especially the environmental dimension, on the one hand, and the socio–economic dimension, on the other. Thus, Hypothesis 2 was confirmed.

Table 7. The ranking of EU clusters.

Rank	Environmental Sustainability	Social Sustainability	Economic Sustainability
1st	Cluster 3 *	Cluster 3	Cluster 2
2nd	Cluster 1 **	Cluster 4	Cluster 4
3rd	Cluster 5 ***	Cluster 2	Cluster 3
4th	Cluster 4	Cluster 1	Cluster 1
5th	Cluster 2	Cluster 5	Cluster 5

Note: * Cluster 3 was ranked first due to its second-best performance in terms of all environmental indicators; ** Cluster 1 was ranked second due to its best performance in terms of $Ienv_1$, but third in terms of $Ienv_4$ and $Ienv_5$, and fifth for $Ienv_4$; *** Cluster 5 was ranked third due to the best performance in terms of $Ienv_2$, third for $Ienv_1$, and fourth for $Ienv_3$ and $Ienv_4$.

These results are, to some extent, aligned with the FAO Report [90], which highlights that advancements in agricultural productivity often entail social and environmental costs. These costs include water scarcity, soil degradation, ecosystem stress, biodiversity loss, decreasing forest cover, and high levels of greenhouse gas emissions. According to Czyżewski et al. [69], investment subsidies can stimulate the eco-efficiency of farmers at the EU level, allowing for a more efficient allocation of resources while integrating both economic and environmental objectives. Therefore, taking into account the identified trade-offs in the present research, we consider that more investment subsidies should be allocated through the new CAP to achieve a better equilibrium between the environmental, social, and economic pillars of sustainable agriculture.

It can be difficult to find a direct reference between these results and the results obtained by other authors due to the specific indicators and statistical methods used to assess the level of sustainable agriculture in the EU countries [16]. In spite of this, our results can be partially linked with other studies [12,33] as regards the differences and similarities among EU countries identified based on the three pillars of sustainability in agriculture. For instance, Nowak and Różańska-Boczula [16] assessed the level of sustainable agriculture based on a synthetic index using 26 indicators of sustainability in agriculture (11 for the environmental, 8 for the social, and 7 for the economic dimension) and classified EU countries in four groups based on performance in all three pillars of sustainability. As expected, due to the difference in some indicators and methods used, our results do not confirm EU countries' ranking achieved in that study [16].

The current study evaluates sustainable agriculture at the EU level, taking into account the interrelationship between the environmental, economic, and social pillars of sustainability and maintaining a balance between these three pillars. Therefore, this study differs from existing studies that investigate only the economic and social dimensions [15,53,65,68] or focus solely on the environmental dimension [31,65,69] of agricultural sustainability.

In the last step of our analysis, in order to test Hypothesis 3, we performed a regression analysis to investigate the influence of sustainable agriculture on rural development in the EU countries (models 1–3). Hence, the Human Development Index (HDI), rural GDP per capita, and rural poverty rate, which assess the level of rural development, were employed as dependent variables.

The Sustainable Agriculture Index (SAI) was used as an explanatory variable. This composite index was constructed using the weights of each principal component (PC1–PC4, see Table 4) in the total variance. Hence, SAI was determined as follows:

$$\text{SAI} = \frac{44.804}{81.554} \times \text{PC1} + \frac{15.835}{81.554} \times \text{PC2} + \frac{11.348}{81.554} \times \text{PC3} + \frac{9.570}{81.554} \times \text{PC4}$$

Model 1 (see Table 8) estimates the positive effect of SAI on HDI (β = 0.577). The regression model was statistically significant ($F(1, 22) = 10.952$, $p = 0.003$) and accounted for 30% of the variance of HDI ($R^2 = 0.332$, adjusted $R^2 = 0.302$). A positive β value (0.577) indicates that higher SAI scores are associated with higher HDI values, suggesting that sustainable agriculture practices contribute positively to human development.

Table 8. The results of regression analysis: the impact of sustainable agriculture (SAI) on rural development.

Models	Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta (β)		
Model 1 [1] (SAI→HDI)	(Constant)	0.894	0.007		123.485	0.000
	SAI	0.040	0.012	0.577	3.309	0.003
Model 2 [2] (SAI → Rural GDP/capita)	(Constant)	24729.167	2690.714		9.191	0.000
	SAI	14567.583	4502.601	0.568	3.235	0.004
Model 3 [3] (SAI → Rural Poverty rate)	(Constant)	18.875	1.377		13.706	0.000
	SAI	−6.756	2.304	−0.530	−2.932	0.008

Note: [1] Dependent variable: HDI; R^2 = 0.332, adjusted R^2 = 0.302; Std. error of the estimate = 0.035; F (1, 22) = 10.952, p = 0.003; [2] Dependent variable: Rural GDP/capita; R^2 = 0.322, adjusted R^2 = 0.292; Std. error of the estimate = 13181.754; F (1, 22) = 10.468, p = 0.004. [3] Dependent variable: Rural poverty rate; R^2 = 0.281, Adjusted R^2 = 0.248; Std. error of the estimate = 6.74631; F (1, 23) = 8.594, p = 0.008. Source: Own calculations based on references [72–75].

As for the SAI—Rural GDP/capita link, the regression model (model 2, Table 8) highlights that SAI positively influenced rural GDP/capita (β = 0.568). This model was statistically significant (F (1, 22) = 10.468, p = 0.004) and accounted for 29.2% of the variance of rural GDP/capita (R^2 = 0.322, adjusted R^2 = 0.292). These results reflect that improvements in sustainable agriculture practices are associated with increases in rural GDP per capita.

Moreover, model 3 (Table 8) points out that the rural poverty rate is negatively and significantly influenced by SAI (β = −0.530, p = 0.008). The negative β value indicates that higher SAI scores are associated with lower rural poverty rates, suggesting that sustainable agriculture practices help reduce rural poverty. The regression model was statistically significant (F (1, 23) = 8.594, p = 0.008, Std. Error of the Estimate = 6.74631, R^2 = 0.281, Adjusted R^2 = 0.248).

In summary, the results of the regression analysis demonstrate that sustainable agriculture practices have significant and beneficial effects on human development, rural economic prosperity, and the reduction of rural poverty, thereby contributing to the enhancement of rural development levels in EU countries.

Furthermore, all regression models estimated relatively small values for R^2, implying that, although the level of sustainable agriculture contributes to rural development, its magnitude cannot be solely relied upon as an integrated explanation for the existence of a certain level of rural development. Therefore, policymakers should consider increasing support for sustainable agriculture to achieve broader social, economic, and environmental benefits. In order to enhance rural development in EU countries, especially those included in cluster 5, it is crucial to boost smaller farms "to fulfill their functions in society—not only as food providers but also as guardians of the land and natural resources" [50]. This approach is crucial for preventing land abandonment and providing employment and green amenities in rural areas [68].

5. Conclusions and Main Implications

The main research questions of this study were as follows: Is there a trade-off between the environmental, social, and economic pillars of agricultural sustainability in EU countries? To what extent does the level of sustainable agriculture influence EU rural development? Therefore, this paper has shed light on the interrelationship between the environmental, social, and economic pillars of agricultural sustainability and its impact on rural development in EU countries. Furthermore, we consider that it is essential to evaluate and monitor the level of sustainable agriculture in EU countries as well as to identify both key opportunities and barriers in order to achieve a higher level of sustainable agriculture as a key driver for rural development.

Based on the findings of the PCA and cluster analysis, the EU-24 countries were classified into five clusters, which confirmed the differences and common features among

EU countries in terms of the interrelationship between the environmental, social, and economic pillars of agricultural sustainability. Additionally, our results confirm that there is a trade-off between the three sustainability dimensions in the EU countries, particularly between the environmental dimension, on the one hand, and the socio–economic dimension, on the other.

The results highlighted specific challenges to sustainability in agriculture for the analyzed EU countries that can hinder its effects on rural development. Therefore, tailored measures should be designed to efficiently address these specific issues.

Thus, the main real challenges identified for the countries included in cluster 5 (Bulgaria, Greece, Croatia, Lithuania, Latvia, Poland, Romania, and Hungary) are related to the socio–economic pillar of sustainability. Therefore, improving agricultural productivity is essential for increasing farmers' incomes, ensuring food security, and promoting socio–economic stability in rural communities [54]. To enhance the economic competitiveness of the agricultural sector in the EU countries, especially those from cluster 5 (countries like Romania and Bulgaria), which have the lowest labor and land productivity, it is necessary to reduce agricultural employment, integrate technological advancements, and accelerate the intensification of production processes. This will facilitate the benefits of production scale and increased efficiency [42]. Moreover, as human resources are a key driver of agricultural competitiveness [53], increasing the level of education and training of agricultural workers, particularly farm managers, would enhance agricultural economic performance [19]. Also, another main issue that countries in cluster 5 have to face is the smallest economic size of farms, which has negative consequences for socio–economic sustainability. Therefore, at the EU level, it is recognized that CAP remains vital in financially supporting farmers to transition to more sustainable agricultural practices, becoming more resilient and competitive while fulfilling their role as "food producers and stewards of natural resources and the land" [50] (p. 4). To reduce the significant income disparities between large and smaller farms, different actions should be taken under the new CAP to redistribute income support payments from large to smaller farms [51,91]. Additionally, with access to domestic and European funding, small farmers can be encouraged to focus on producing bio- and organic food, which is experiencing growing demand in an expanding market [84].

Our results showed that in four EU countries (Netherlands, Belgium, Denmark, and Ireland), included in two clusters (2 and 4), there is a significant trade-off between the environmental pillar and the socio–economic pillar of sustainability in agriculture. Thus, large-scale agriculture and capital-intensive production systems, which generate high levels of economic performance and positive effects on the socio–economic dimension of agricultural sustainability, come with a trade-off in the form of environmental degradation. Therefore, these countries should pay more attention to enhancing environmentally friendly farming systems. Given that these countries report high levels of government budget allocations for R&D in agriculture but perform poorly in terms of environmental sustainability, more actions are required to reduce pollution from the agricultural sector and promote friendly agricultural practices, such as supporting organic farming practices through incentives and subsidies, promoting biodiversity on farmland and crop rotation to enhance soil health, and encouraging the production of renewable energy by agricultural producers.

Although certain EU countries perform better than others in sustainability pillars, we consider that there is much room for improvement towards achieving more sustainable agriculture across all EU countries.

The findings of this research can be useful for policymakers in formulating policies that support improvements in sustainable agriculture and its impact on rural development.

Limitations and Future Research

Firstly, our empirical analysis consists of 15 variables related to the economic, social, and environmental pillars of sustainability in agriculture and 3 variables related to rural development. Consequently, some features of sustainable agriculture or rural development, such as the level of incentives and subsidies in the agriculture sector, more environmentally friendly practices, and other characteristics of the farmers (educational and aging level), may not be covered. Therefore, further research should take into consideration more variables to investigate the level of sustainable agriculture not only in the case of EU countries but also in other countries. Secondly, due to the unavailability of statistical data for all 15 variables used in the principal component analysis and cluster analysis to assess the level of sustainable agriculture, our cross-country analysis was limited to the last year for which data were available (2021). Therefore, as long as the statistical data are available and the time series do not have structural breaks or contain missing values, further research should extend the analyzed period to investigate trends in sustainable agriculture.

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