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Sustainable Livestock Farming in the European Union: A Study on Beef Farms in NUTS 2 Regions

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Abstract: Despite the significant role of beef in the European agri-food industry, its intensification challenges environmental sustainability, a focus of the Common Agricultural Policy (CAP) 2023–2027. Balancing industry importance with sustainability is crucial. This study aims to address sustainability issues in livestock production by establishing a correlation between sustainability levels and regional specificities at the NUTS 2 level. The study aims to categorize more sustainable models, with a particular focus on cattle farming activities that exert minimal environmental pressure on renewable resources. The goal is to identify eco-friendly practices that align the best with environmental conservation efforts in agricultural settings within European Union countries. To achieve this, a survey was conducted, utilizing principal component analysis, followed by cluster and georeferenced analyses of structural and socio-economic data from the beef sector. This encompassed factors such as land use, physical farm dimensions, socio-economic and management characteristics, and environmental indicators. Sixteen indicators were extracted and analyzed from EUROSTAT datasets, referencing NUTS 2 regions, and the comprehensive analysis identified five clusters as distinct farm management models, distributed variably across the territory. The results demonstrate that the best-performing models exhibit significant differences in terms of farming intensiveness, geographical distribution, and economic profitability, underscoring a certain polarization between economic and environmental sustainability. This study innovatively guides EU sustainable agriculture initiatives by categorizing sustainability levels in diverse cattle farming contexts, considering regional specificity, and emphasizing environmental impact reduction. The results can inform policy decisions, guide financial incentives, and promote eco-friendly practices, shaping a more targeted and resilient European agricultural policy.

Keywords: cluster analysis; cattle farming; management models; environmental sustainability; livestock policies

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Citation: Di Vita, G.; Zanchini, R.; De Cianni, R.; Pippinato, L.; Mancuso, T.; Brun, F. Sustainable Livestock Farming in the European Union: A Study on Beef Farms in NUTS 2 Regions. *Sustainability* **2024**, *16*, 1098. https://doi.org/10.3390/su16031098

Academic Editor: Andrea Pezzuolo

Received: 18 December 2023
Revised: 24 January 2024
Accepted: 25 January 2024
Published: 27 January 2024

1. Introduction

Recognition of the European Union beef sector is crucial for defining farm strategies and new common agricultural policies from a sustainability perspective, especially in light of the current identification of the meat sector as one of the most potentially hazardous [1,2]. As a result of this, a large strand of research shows that livestock production is contributing significantly to climate change, both in time and space [3], thus highlighting the potential responsibility of the livestock sector for high greenhouse gas emissions (GHG) and gradual deforestation worldwide related to feed crops [4,5]. For this very reason, the cattle farming system in particular is recognized as the most significant contributor to global warming [2,6,7]. In this regard, it has been estimated that 10% of the total GHG emissions in the European Union, with 27 member countries (EU-27), stem from livestock activities [8].

The environmental impact of livestock farming can be both direct and indirect. The first is mainly due to factors such as enteric fermentation, manure management, methane production, or nitrate leaching, which releases nitrogen [9–11]. There are also indirect effects of livestock farming due to deforestation, the expansion of pastures and fodder crops, water consumption, and competition between food and feed [5,12].

The heterogeneity of the livestock farming system leads to significantly different outcomes, e.g., switching from an extensive to a more efficient production system contributes to reducing GHG emissions [2,5].

A Chinese study, showing the prominent role of the livestock industry in GHG emissions, highlighted the need to drastically reduce emissions by the livestock industry, even going as far as to suggest that a partial phase-out of livestock activities is almost required [10]. However, this solution, based on current market trends, does not seem feasible, at least in the short to medium term, since meat is a staple food in the diet and nutritional habits of millions of people, and experts predict a significant increase in worldwide demand for meat products [2,13]. On the contrary, it seems more realistic to reduce cattle farming as an unavoidable choice, seeking to identify those activities that can reduce environmental pressure.

As a result, the environmental impacts of farming vary in relation to environmental contexts, including animal species and farming methods and practices; so, the assessment of livestock pressure requires a thorough understanding of all of these factors [5,14].

Although these are important aspects of European agricultural activity as a whole, they are more important in specific contexts and limited areas where the environmental impact of production and processing is geographically concentrated [15]. In addition, assessing the sustainability of cattle breeding at the regional level requires a complex analytical approach due to the multifaceted combination of policy makers and stakeholders [16].

There are other challenges that the sector will have to face in the short term. The first concerns the prospect of increasing the organic Utilized Agricultural Area (UAA) to 25% of the EU UAA, studied under the Common Agricultural Policy (CAP) of the European Union for the period of 2021–2027 [17]. The development of meat labelling that attests to animal welfare and that will lead consumers to distinguish EU-origin meat from non-EU meat [18] is the second challenge. The other major challenge is to maintain European livestock farms using all the innovative solutions that technology and applied research make available to meet the ambition of decarbonizing this activity as part of the European Green Deal [19].

Moreover, in view of the serious challenges that affect the beef sector and given the scarcity of studies at the regional level, it is useful to conduct a more in-depth analysis from the perspective of NUTS 2 regions, considering the sustainability and socio-economic dimensions of European livestock farming. NUTS 2 in the context of the European Union refers to "Nomenclature of Territorial Units for Statistics—Level 2". It is a classification system used for statistical and administrative purposes, dividing countries into smaller regions for the collection and analysis of data. In EU agricultural policy, NUTS 2 regions are often used to provide a more detailed understanding of agricultural practices, production, and other relevant factors at the subnational level.

Thus, this study is the first systematic approach to the European livestock production system, identifying the best management models that are deserving of further study, especially with a view to sustainable intensification.

The remainder of the paper is organized as follows. The first section presents a brief contextual framework of the beef production sector in the EU, thus contextualizing the analytical approaches to sustainable cattle breeding farming at the NUTS 2 regional level and the objectives of the study. The second section presents the policy background, aims, and research questions, while the third section presents the methodological approach based on three different perspectives that aim to identify and group the main management models, livestock farms, and their geographical localization. The fourth and fifth sections present the main findings and discuss the results, while the final section concludes the document, presenting suggestions in terms of sustainable territorial development.

The EU Beef Sector

The specialized cattle-rearing and fattening sector is an important economic resource for the European Union. In fact, in 2018, the EU, with over 88 million head of cattle, was the third largest producer of beef and veal after the USA and Brazil [20]. In 2019, EU beef production amounted to 7.8 million tons and nearly half of all EU beef was produced in the following countries: France, Germany, the United Kingdom, and Italy [21].

Although the beef industry is fragmented and very heterogeneous, it contributes to the vitality of the territory, its role being crucial not only in terms of rural development, but also in characterizing social, cultural, and gastronomic aspects of many producing regions [22]. In mountain and other disadvantaged areas, it even contributes to maintaining the environmental balance by ensuring more sustainable agricultural management among marginal mountain or rural communities [23].

The EU beef sector is able to provide excellent products thanks to the high-quality protein content and the European labelling system linked to quality certifications [24]. Nevertheless, in the last decade, the cattle sector has faced several challenges related to declining profitability, international world trade agreements and policies, as well as challenges related to climate change [25], not neglecting changed consumer attitudes and preferences [26]. Despite these challenges, the importance of understanding European citizens' and consumers' attitudes towards beef has been highlighted, emphasizing the need for innovative meat product concepts to enhance trust and revitalize the European beef industry [26].

The EU cattle sector can be divided into two main groups: the EU dairy sector and the beef sector. The second sub-sector provides beef and veal and, in practice, refers to the meat industry. In this study, the EU bovine meat sector was analyzed using Eurostat statistics, referring to Specialist cattle—rearing and fattening [25].

Although the livestock sector in Europe is of considerable importance, few studies have addressed the characteristics of bovine meat [27–29]. A recent study on the technical efficiency of farms in Bulgaria [27] showed that, as the degree of specialization of farms increases, the technical efficiency rises too. Furthermore, pig, poultry, or cow farms seemed to be more efficient than activities not specialized in livestock but in other agricultural products [28].

Another study carried out in Romania highlighted the dependence of cattle farmers' incomes on fixed investments and subsidies [28]. In addition, differences in income among European beef producers were found [29].

Considering the economic outlook, it appears necessary to ensure the sustainability and profitability of the beef sector in the EU since major problems are related to heterogeneity between countries in terms of income, practices, and structural characteristics [22].

2. Policy Background, Aims of the Study, and Research Questions

This section provides a brief outlook on the regional approaches to assess the European farming systems at the NUTS 2 level, presenting the main objectives of the study and research questions.

The European Community manages a very large and diverse territory and needed to divide its regions into statistically homogeneous units within them. The NUTS classification has responded to this need by structuring different levels of territorial subdivision to meet specific homogeneity requirements. This classification has been officially in use since 2003, implemented with Regulation EC 1059/2003 [30], and has played the main role of functional units used for the collection, classification, and publication of EU statistics, from demography to policy implementation, land use, and urbanization.

The NUTS classification, based mainly on the criteria of administrative and demographic homogeneity, is hierarchical and consists of three levels: NUTS 1, 2, and 3. In addition, in order to provide a statistical unit, the NUTS levels also establish homogeneous areas for the implementation of regional and territorial policies (NUTS 2) or for diagnostic purposes (NUTS 3). These classifications are maintained for at least three years, after which a complete revision of the territorial classification is carried out according to the current needs and the political/economic situation of the EU. The version considered was adopted with European Commission Regulation 2016/2066 [21].

Several studies have been carried out considering the differences and similarities among European regions and sub-regions, since the analysis of the specific characteristics of agricultural systems is a useful tool for implementing or evaluating European policies [31].

In this context, several authors [32,33] have emphasized the importance of a regional approach based on the NUTS classification for factor analysis relevant to the economic assessments of EU farming systems. Similarly, recent studies have assessed, on the basis of the same classification, the main determinants of agricultural productivity [34] or the role of knowledge transfer and innovation in a more sustainable rural development [35].

Regarding the regional NUTS 2 approach, which was adopted in this study, it has been widely used, from a policy analysis perspective, to assess the impact of EU policy changes and to evaluate the effects on extension services and competitiveness [33,36]. Another study assessed the so-called regional convergence, analyzing it in terms of the deviation of the growth rate among regions, a factor of particular importance for the proper design of regional development, which is a fundamental pillar of CAP [37]. Along the same lines, other authors have investigated the economic impact of the CAP subsidies in representative regions [38,39], assessing the effects of rural development programs [40], or even estimating the effects of a credit crunch on agricultural investments [41].

Another strand of the literature based on the NUTS 2 level has focused on the social aspects of rural and agricultural phenomena, assessing labor productivity [42] or considering farm exiting [43], while other authors have evaluated the uptake of innovation adoption in regional sustainable development [44].

Other lines of research have focused on the sustainability analysis of agricultural activities at the regional level, suggesting articulated and composite indicators [45–47]. Similarly, the concept of the sustainability of the agricultural sector in its different social, economic, and environmental dimensions has been used to suggest models of regional classification of the EU territory, according to sustainability levels.

Despite the wide use of the NUTS 2 classification to explore the different economic, social, and sustainability aspects of the EU agricultural system, the literature review shows a certain scarcity of studies concerning the beef sector from a regional perspective. The exploration of the beef farm model in the NUTS 2 regions within the European Union agricultural policy is driven by several key reasons, such as regional specificity, and the relevance of EU agricultural contexts. In fact, the NUTS 2 classification allows for a more granular analysis, considering regional variations, paying specific attention to various agricultural contexts across EU countries, and acknowledging the diversity of farming landscapes and practices. In addition, this approach allows to categorize and identify more sustainable models within the beef farming sector, thus suggesting practices that minimize environmental impact and that are crucial for long-term ecological balance.

As global environmental concerns intensify, understanding the specific environmental impact of key sectors becomes crucial. In this context, delving into the intricacies of the EU beef sector not only contributes to the knowledge of livestock farming's broader environmental implications but also sheds light on sector-specific challenges and opportunities for sustainable practices.

Consequently, considering the importance of this sector in the European panorama and given the limited number of studies at the NUTS 2 level, this study aims to fill this knowledge gap by highlighting beef farm structural characterization and management models through both georeferenced and multivariate analyses.

This paper starts with the assumption that the marked regional specificities of production systems lead to different management models of agricultural activities. These, in turn, produce heterogeneous results for the respective farming systems and have repercussions on environmental sustainability levels. In particular, the objective of the research is to identify and analyze the main structural and economic features of cattle farming in EU regions classified as NUTS 2 in order to study their relationships to and repercussions on sustainability, with particular attention to their environmental components. More specifically, this paper tries to answer four research questions:

R1: What are the main characteristics of the EU bovine meat sector and how are they distributed across the EU?
R2: Is there a geographical diversification within EU regions?
R3: Are there more sustainable cattle farming models?
R4: Which group of regions are the most deserving in terms of environmental and economic sustainability?

3. Materials and Methods

3.1. Data Collection

The data were obtained from the EUROSTAT databases available for the agricultural sector and referred to 2016, the latest available update at the time when the analyses were conducted. EUROSTAT refers to the Statistical office of the European Union, tasked with disseminating high-quality, pan-European statistics and indicators that facilitate comparisons among countries and regions. As mentioned above, it was decided to work at the NUTS 2 geographical level to ensure a more focused analysis from a regional perspective. At this level, there are 281 sub-regions. Since not all of them are included in the EU territory, only the NUTS 2 areas that fall within the EU were selected. In this first step, starting from the variables present in the EUROSTAT datasets, a total of 16 indicators were extracted, as reported in Table 1.

Table 1. Indicators selected for the statistical analysis.

Class	Indicators	Definitions
Land use	Arable land	Ratio between arable land (ha) and the total cultivated surface
	Permanent grassland	Ratio between permanent grasslands (ha) and the total cultivated surface
	Cereals	Ratio between lands for cereals (ha) and the total cultivated surface
	Pastures and meadows	Ratio between lands for pasture and meadows (ha) and the total cultivated surface
	Cattle farms	Ratio between cattle farms (n) and the total livestock farms (n)
Physical farm size	LSU	Ratio between LSU and the total livestock farms (compared to 100)
	Farms of 0–4.9 ha	Ratio between the number of farms (size of 0–4.9 ha) and the total number of farms in the selected sector
	Farms of 5–49.9 ha	Ratio between the number of farms (size of 5–49.9 ha) and the total number of farms in the selected sector
	Farms > 50 ha	Ratio between the number of farms (size > 50 ha) and the total number of farms in the selected sector
Economic and management features	Non-family labor force	Ratio of non-family labor force to the total number of workers in the selected sector

Recalling that the fresh meat production sector depends on the interaction of several agronomic, environmental, managerial, and socio-economic factors, the necessary indicators were selected based on the current literature. These indicators were then divided into the following four classes: (a) land use [33]; (b) physical farm size [33]; (c) socio-economic and management features [33,34]; and (d) environmental indicators [34,46,48].

To avoid misunderstandings, the meaning of the acronyms of some indicators is provided as follows. LSU = Livestock Unit, where dairy cows represent the unit, while the value for other cows older than two years of age is 1;

SO = Standard Output, which represents the average monetary value of production at the farm-gate price;

UAA = Utilized Agricultural Area, which indicates the total area occupied by arable land, grassland, and permanent crops expressed in hectares.

3.2. Principal Component Analysis (PCA)

The considerable number of variables available would have made the spatial statistical analysis minimally effective in describing and characterizing the EU bovine meat sector; so, a factorial analysis was carried out using the PCA method. This analysis makes it possible to synthesize the information and, at the same time, to optimize the explained variance, reducing the number of original variables into new orthogonal factorial dimensions, defined as principal components (PCs) [49]. In order to simplify the interpretation of the PCA, the Varimax rotation was then applied. The Varimax rotation was selected over other rotation techniques not only for being the most widely employed rotation method in statistical analysis but also for its ability to maximize the variance for each factor load [50]. This is achieved by redistributing the total variance, thereby generating distinct factors with a relatively balanced variance, a characteristic that aligns well with the specific goals of the research. Indeed, the factor loadings and the explained variance for each component, shown in Table 2, refer to the rotated PCs.

Table 2. Rotated component matrix on the main patterns of EU bovine farms.

	Components			
	1	**2**	**3**	**4**
Non-family labor force	0.825			
Family labor force	−0.815			
Farms managed by a natural person	−0.792			
Farms managed by a legal person	0.734			
Farms > 50 ha	0.569		0.512	
Arable land		−0.940		
Permanent grassland		0.936		
Cereals		−0.871		
Pastures and meadows		0.703	0.439	
Farms of 0–4.9 ha			−0.890	
Irrigated area			−0.625	0.492
Farms of 5–49.9 ha	−0.506		0.602	
Cattle farms		0.437	0.578	
SO				0.860
LSU/UAA				0.716
LSU	0.478			0.715
Sample adequacy measurement (KMO)	0.636			
Bartlett's sphericity test	0.000			
Explained variance	23.114	20.400	15.902	13.657

With regard to the choice of the number of PCs, several methods are traditionally used in the literature, such as the scree plot, the percentage of variance explained by the PCs, and the value of the eigenvalues [51]. Similar to other studies on spatial analyses [34,52], the selection of the PCs was conducted using the eigenvalue method, whereby PCs with eigenvalues higher than 1 were selected.

With regard to the analysis of the loadings matrix, values of 0.35 are usually considered reliable [53]. However, in order to make the results of the study more trustworthy, only variables with values greater than 0.4 were considered.

The goodness of fit of the model was assessed using the KMO and Bartlett's tests. The former is used to check the adequacy of the sample; it admits values between 0 and 1, where values below 0.5 are considered unsatisfactory for conducting a factorial analysis [49,54,55]. Bartlett's test, on the other hand, is a statistical tool for assessing the level of similarity between a correlation matrix and an identity matrix [56], testing the null hypothesis that the two matrices correspond to each other.

3.3. Cluster Analysis and Georeferencing

A cluster analysis was carried out using the factorial scores obtained for each record and that referred to each NUTS 2 region. The clustering method chosen was K-means because it is considered the most suitable to be applied to a factorial analysis, given the large number of applications in the literature for territorial analyses [52,57]. K-means represents a non-hierarchical type of clustering, where the number of clusters is chosen a priori. It is derived from an iterative process that forms clusters by minimizing the Euclidean distance between the centroids of the groups [58].

Identifying the appropriate number of clusters is crucial, especially for non-hierarchical methods where cluster formation is chosen a priori and their validity cannot be verified by dendrograms as in hierarchical methods [59]. To solve this problem, the two-step cluster procedure was carried out in SPSS, using the silhouettes index to identify the most appropriate number of groups, which in this case was 5. The silhouette index is a composite index reflecting the degree of compactness within clusters and the separation between different clusters, providing the overall quality of the cluster solution [60].

Once the clusters were obtained, a one-way analysis of variance (ANOVA) was carried out to compare their characteristics and check for significant differences between them [61]. Subsequently, in order to more precisely analyze the spatial distribution of the cluster obtained, it was decided to carry out a georeferenced analysis, using a geographical information system (GIS). The software used was QGIS, in its long-term release version 3.10.9 Coruña [62]. The choice of QGIS over other georeferencing software is justified by its cost-effectiveness, strong community support, broad interoperability, versatile functionalities, and continuous development, making it a reliable and accessible option for geospatial projects.

Based on the above, the maps refer to the most recent NUTS 2 classification, updated in 2016, and were obtained from EUROSTAT. The reference system was EPSG:3857 pseudo-Mercator.

4. Results

This section presents the main outcomes of the study, which, as already mentioned, was organized in two steps: a principal component analysis and cluster analysis. The first analysis allowed for the identification and definition of homogenous models of livestock management within the EU territory. These were subsequently grouped during the cluster analysis to characterize distinct regions according to different models of farm typologies.

4.1. Principal Component Analysis

The PCA allowed the identification of four factorial dimensions, rotated with Varimax rotation, for a total explained variance of 73.1%. The four principal components (PCs) collect and synthesize information from the original correlated variables and represent new uncorrelated factorial dimensions. These new variables make it possible to identify and describe the traits and characteristics of EU beef farming patterns.

The first PC accounts for about 23% of the variance and describes a "Professional large livestock production" whose farming management patterns are highly externally labor-intensive. This component includes farms based on a non-family labor force (0.825) and managed by legal persons (0.734). A legal person pertains to a legally recognized entity, such as a corporation or organization, created by law, while a natural person refers to an individual human being that can own property, enter into contracts, be subject to laws, and assume personal responsibilities. This legal person management system is further confirmed by the presence of a negative correlation with a family labor force (−0.815) and with management by physicalnatural persons (−0.792). On the other hand, this pattern shows a positive correlation with a large farm surface, of more than 50 ha (0.569), and with a high density of livestock units per farm (0.478). Furthermore, considering the negative coefficient of small to medium farm size (−0.506), large farms strongly characterize this factorial dimension.

The second component explains about 20% of the total variance and is characterized by a high presence of permanent grasslands (0.936), which refers to grass-covered land intended for continuous agricultural use without periodic conversion, meadows, and pastures (0.703), which instead have no implication for permanent land use, and a fair presence of livestock farms (0.437). On the contrary, the strongly negative correlation with arable (−0.940) and cereal-crop lands (−0.871) suggests that it is non-specialized extensive livestock farming with some marginal characteristics. Considering that the variables expressed in this PC refer to extensive and marginal agriculture with a good presence of zootechnical activity, this component was named "Marginal livestock farming".

The third PC, which accounts for about 16% of the total variance, includes medium- (0.602) and large-sized farms (0.512), with a significant presence of pastures and meadows (0.439) and a certain prevalence of cattle farms in the territory (0.578). The negatively correlated variables of irrigated agricultural area (−0.625) and small-sized farms (−0.890) improve the characterization of this component. The variables included in this component suggest an extensive management profile with sustainable features, considering, for instance, a reduced water consumption. In fact, the variables expressed in this case suggest areas with large-sized farms associated with pastures and low irrigation use. These are therefore elements of environmental sustainability, as the high presence of pastures (typically polyphytic, rich in plant species) and the reduced use of irrigation can preserve biodiversity and prevent soil erosion, respectively; for these reasons, this PC was defined as "Extensive and sustainable livestock farming".

The fourth and last component, describing about 13% of the variability, depicts the most market-oriented model with the highest economic performance, which is why this PC was named "Business-based cattle farming". Indeed, it is positively correlated with an economic indicator such as the high standard output (0.860). The business orientation is evidenced by rational management, as shown by the high percentage of irrigated areas (0.492) and to the high livestock density coefficient. The significance of the variables Livestock units per unit of utilized agricultural area (LSU/UAA) (0.716) and livestock units per livestock farm (LSU = 0.715) describes highly specialized beef farming. The latter component can also be considered intensive cattle farm management because it uses a low percentage of agricultural land.

4.2. Cluster Analysis

A cluster analysis was carried out on the obtained factorial dimensions and, in order to assess the optimal number of clusters, a two-step cluster analysis was employed using the silhouette index.

Table 3 shows the results of the cluster analysis and the outcome of the ANOVA, used, as mentioned before, to check the effective difference among the obtained clusters. Since the p-value is less than 0.01, highly significant differences exist, and it can be argued that the clusters are well differentiated. This method allows for the combination of the PCs to define different models of farm typologies, based on the interpretation of the cluster centers.

Cluster 1 strongly expresses the fourth component, "Business-based cattle farming", while the other components are all negatively expressed, in particular the PC related to "Extensive and sustainable livestock farming". This cattle farming pattern, which is widespread in a small number of NUTS 2 regions, is therefore characterized by farms with a high degree of specialization, livestock intensity, and economic performance, which can be referred to as "High-yield specialist livestock farms".

Table 3. Final cluster centers.

PCs	Cluster					p-Value
	1 (n = 9)	2 (n = 45)	3 (n = 56)	4 (n = 44)	5 (n = 114)	
Professional large livestock production	−0.163	−0.379	−0.304	1.795	−0.381	0.000
Marginal livestock farming	−0.298	0.301	1.249	−0.082	−0.677	0.000
Extensive and sustainable livestock farming	−0.823	−1.673	0.635	0.021	0.405	0.000
Business-based cattle farming	3.805	−0.425	0.081	−0.161	−0.110	0.000

Cluster 2 expresses positively the PC called "Marginal livestock farming", where the component "Extensive and sustainable livestock farming" is strongly negative. These characteristics help to outline a territorial model where the presence of cattle farms is scarce and, if present, has marginal characteristics. In view of the fact that the remaining PCs are negatively related to the cluster, this group can be identified as "Non-specialized extensive cattle-farms", thus falling into areas with low beef-producing activity.

Cluster 3 is strongly characterized by marginal livestock farming, with a high presence of meadows, pastures, and permanent grasslands. These conditions lead to a certain propensity for sustainability, given that the second and third PCs are strongly expressed. It is therefore possible to consider this cluster as "Marginal and sustainable cattle farms".

Cluster 4 is distinguished from the others by the significant presence of intensive livestock farming, organized in corporate form, as observed in the first PC. The other components have coefficients close to 0; so, they are barely, or not at all, relevant in its characterization. Considering this profile, it is possible to name the cluster "Highly intensive cattle farms".

The last cluster (Cluster 5), which includes the third PC, contains elements of extensiveness and sustainability, unlike the third cluster, where NUTS 2 regions are more characterized by attributes of marginality. Furthermore, considering that the expression of the second PC is negative, it is possible to suppose that these territories are mainly represented by extensive and sustainable farms. For these reasons, Cluster 5 was named "Low environmental impact and large-sized farms".

It should be noted that not all macro-areas identified by the NUTS 2 classification could be used for PC analysis and subsequent clustering, mainly due to the lack of data about the variables used in the multivariate analysis. For this reason, about 16% of the areas were not analyzed and, together with other EU areas, are represented in crossed-out white.

Furthermore, the spatial distribution of the five identified clusters can be observed in Figure 1. It can be noticed that Cluster 1 includes a limited number of regions, mainly in Italy, Netherlands, Belgium, and in a single NUTS of Spain (Murcia). This localization is highly concentrated in northern Italy and in the Netherlands, where livestock farming reaches very high levels of specialization, with consequent economic returns that are higher than those of other livestock management models.

Cluster 2 is the second smallest cluster by diffusion and is mainly concentrated in the Balkan, Aegean, and Eastern European areas. In addition, some Italian regions (Trentino-Alto Adige and some others in southern Italy) and about two-thirds of Portugal are included. Cattle farming in this group is not very widespread and is characterized by a low level of organization, probably due to other livestock farming of more profitable species or to a different land use.

Cluster 3 is mainly present in the central-northern area of Great Britain, the whole of Ireland, and most of the Alpine region of central-southern Europe, plus some areas of northern Spain and central-eastern France. The breeding most represented here is consistent with a large presence of meadows and pastures, aiming at the maintenance of a marginal, but more widespread, type of livestock farming and with more marked aspects of environmental sustainability.

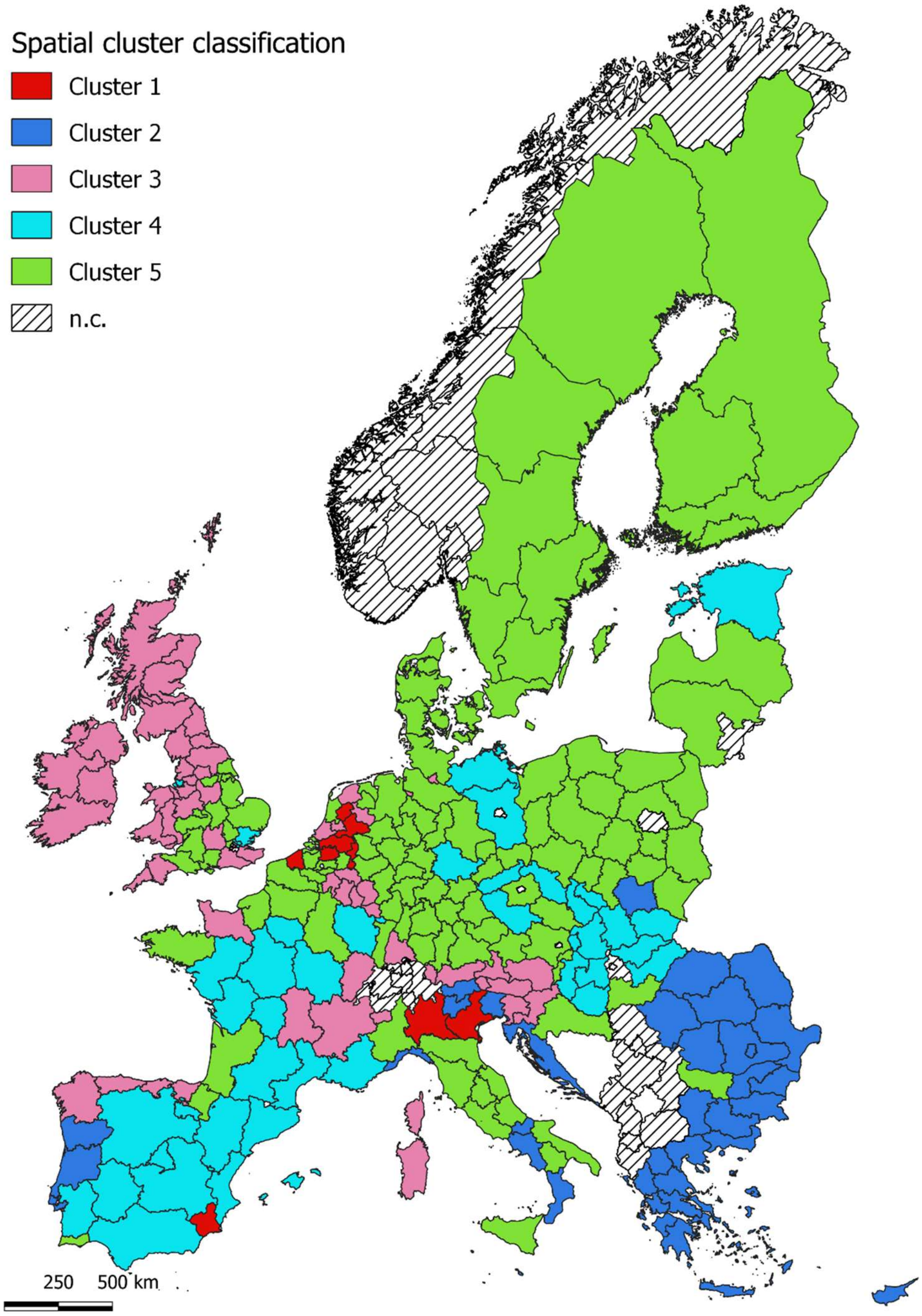

Figure 1. Georeferenced cluster analysis.

Cluster 4 includes most of the Spanish and French territories, as well as Central and Eastern Europe, with parts of Germany and Poland, the Czech Republic, and Slovakia. Again, the nature of the cluster is in line with the spatial location of the NUTS 2, which includes part of areas with strong livestock farming intensity. This is particularly the case of the French and Eastern European territories, which are already large-scale exporters of cattle for breeding and slaughter.

Cluster 5 is by far the group with the widest distribution, as it is present in most of the Italian peninsula, almost all of Germany, Poland, the Baltic States, Finland, and Sweden, as well as in southern Great Britain and parts of northern France. These areas are characterized by large-scale farms. The widespread incidence of this cluster throughout the EU territory, and in particular in Eastern European territories, suggests that this kind of beef production, extensive and with a low environmental impact because of pastures and low irrigation use, could represent a substantial share of production within the EU. However, extensive farming does not always translate into broad production and economic capacity, which is why these farms could be mainly oriented toward satisfying the local or national demand.

5. Discussion

The outcomes of this study fully support the assumption that the regional specificities of production systems lead to different management models of farming activities. In particular, the study supports the initial hypothesis that each farming system and each management model have different effects on the sustainability of livestock farming.

It is important to point out the relationship between farm management models and sustainability. It was derived as a consequence of directly or indirectly sustainable-related variables with a low environmental impact, such as extensiveness, the large presence of pastures (typically polyphytic, rich in plant species), and the reduced use of irrigation identified by cluster analysis. Consequently, the characteristics of sustainability in all factors or clusters were identified, including partially or fully.

Concerning the first research question (R1), it was observed the coexistence of different farming systems all over the EU—more or less oriented toward sustainability—which only partially reflects a geographical distribution among the Member States. There is, indeed, a marked regionalization that extends beyond the boundaries of each state and combines NUTS 2 regions from different countries. This first piece of evidence is confirmed by several studies on livestock production in the EU-27, where the authors observed large regional differences in intensive animal production [63,64].

At the same time, the second question (R2) was also answered affirmatively, i.e., that there is a geographical diversification within EU livestock farms, which can be traced to four management models and to five geographical and farm groups. These results are partially consistent with those of a previous study that identified two main livestock systems in Europe [33]. This study thus contributed to increasing the level of knowledge by identifying two additional systems through the overall characterization of four different types of farming models, reaffirming the traditional multifaceted nature of European livestock systems [22,65].

Based on an overall analysis of the results, it was also possible to respond positively to the third research question (R3), affirming the existence of more sustainable cattle-breeding models. In this direction, several, sometimes conflicting, concerns coexist simultaneously in the meat industry. Indeed, human nutritional needs conflict with the reduction in GHG emissions. Furthermore, improving animal welfare and preserving the rural landscape are compelling considerations in an integrated sustainable approach to livestock farming [65,66].

With regard to the final question (R4), regarding which is the most deserving region in terms of environmental and economic sustainability, different leadership styles can be observed depending on the indicator considered. Consequently, from a sustainability perspective, it is possible to bring the discussion of the results back to two points: (a) management and organizational models and (b) farm types and territorial areas.

Based on the four management patterns identified by the PCA, the third component, "Extensive and sustainable livestock farming", is the model that shows significant environmental sustainability characteristics, leading us to consider it as the most environmentally sustainable. It is interesting to note that this organizational model includes medium-sized farms that are located in areas with a high presence of pastures and meadows, factors that seem to be significant in reducing the impact on the environment. According to the previous literature, it has been observed that the intensification of pasture-raised beef is a factor in sustainability, as it can reduce the carbon emissions per kilogram of meat produced [7]. In fact, it is now widely recognized that carbon capture and storage are significantly influenced by plant cover, and their ability to absorb excess carbon emissions varies depending on specific plant ecosystems [67]. In this regard, the high prevalence of cattle farming in the area and the availability of wide, non-irrigated areas dedicated to fodder cultivation certainly allow for some rotation between fodder species, thus leading to crop diversification and increasing the biodiversity of insects, soil microorganisms, and (autochthonous) indigenous plants. Moreover, with regard to farm dimensions, it appears that medium-sized enterprises are more capable of addressing sustainable issues and practices than larger enterprises, given their greater responsiveness to change with respect to environmental and business modifications [68]. Shifting the focus to the most economically sustainable organizational model, a clear preponderance of business-based cattle farming can be observed. In fact, encouraging signs in this direction come from the top-performing farms, since these models, although intensive, can be equally or more sustainable when compared to less intensive livestock farming, at least in terms of GHG emissions, while they are less sustainable in terms of excess nitrogen surplus per hectare. For this reason, it might represent a limitation in the diffusion of this model from an environmental sustainability perspective [69].

Regarding the second point of discussion, the clusters showed the distribution of some representative types of livestock farms within the EU territory. It is important to underline that, even within the clusters, there is a certain variability in farm types; however, considering that the clustering was carried out using factorial dimensions, the output can be considered the most widespread farm typology within a specific area.

Starting from Cluster 1 (High-yield specialist livestock farms), it can be seen that the high production and the considerable number of livestock units per hectare make these farms less vulnerable from an economic point of view but represent a challenge from an environmental perspective [22]. Moreover, considering that these farms are located in areas with a heavy irrigation use, probably for fodder production, it is a further indication of their considerable specialization, with positive implications with respect to technical efficiency [28].

Cluster 2 (Non-specialized extensive cattle farms) includes farms that, despite operating at the territorial level, are probably not numerically significant and may be associated with other extensive activities. In fact, when the production system is less specialized, it is likely that the level of diversification increases [29]. It can therefore be assumed that cattle farming is a secondary activity, and given its low specialization, is vulnerable economically [22], but very useful for the active management and protection of less developed areas [23].

Moving on to Cluster 3 (Marginal and sustainable cattle farms), the observation reveals that one type of cattle farm is widespread on the territory with connotations of sustainability and extensiveness. These farms play an important role in the development of the territory and are associated with meadows and pastures, making scarce use of irrigation systems. Given the high territorial extension, it is likely that they produce fodder themselves, suggesting a diversification of activities [23], which can be a tool in reducing the economic vulnerability of marginal enterprises [22].

Cluster 4 (Highly intensive cattle farms) shows another type of intensive enterprise, which, unlike Cluster 1, is characterized by large areas and high labor demand. The high level of an external labor force and the legal form of the companies suggest that it is specialized and more technically efficient than family-owned enterprises [27].

The last cluster (Low environmental impact and large-sized farms) shows that the large size of the enterprise can be associated with a lower environmental impact, thanks to the presence of pastures and meadows and to the low use of irrigation, even for intensive crops. In addition, the large number of hectares that these farms use suggests that the low ratio of LSU to UAA is linked to environmental benefits. As for the third cluster, the presence of a diversification of activities can reduce economic risks [22].

The georeferenced analysis also showed a strong heterogeneity across EU regions and sub-regions. Cluster 3 emerged as the most environmentally friendly due to the prevalence of permanent grasslands, shaped by the unique landscape features of the territories where they are located. These land-use types are indeed among the most important in terms of sustainability and ecosystem services production [70], especially when compared to ploughed land and high-intensity arable land, as partially confirmed by Kempen and colleagues [71]. These authors highlighted how the beef sector with pasture landscape is widespread in Ireland, northern Spain, and central-eastern France. Moreover, the same study showed that northern Great Britain is more specialized in sheep and goats than in cattle, partly explaining the characterization of these areas with an environmentally friendly pattern of cattle farming [71].

Focusing on the economic sustainability of beef farms, this is strongly expressed by Cluster 1, which is widespread in the northern Italian regions (mainly Lombardy and Veneto) and in the Netherlands region. The results are partially confirmed by Hocquette et al. [22], who point to the north-eastern Italian regions as the territories with the highest economic performance in the beef sector, as well as their productivity, which is also higher in the Benelux than in the rest of Europe [1,22]. Despite the high degree of specialization and the labor force employed, these farms could face environmental sustainability issues related to animal feeding, land use, and consumer perspectives [72].

6. Conclusions

6.1. Major Insights

This paper addressed sustainability issues from the point of view of livestock production, thus establishing a link between sustainability levels and regional specificities. In particular, the study aimed to better understand and categorize which models could be more sustainable, paying particular attention to those cattle farming activities that ensure a lower environmental pressure on renewable resources and are more environmentally friendly and more consistent with the environmental conservation of the different agricultures in the European Union countries.

The analyses conducted permitted to respond to all the research questions. Indeed, as highlighted in the discussion, there is a distribution of cattle farms in Europe that is not always aligned with the borders of the Member States. There is also geographical diversification among the farms, with some breeding models that can be considered more sustainable than others. The effort was to shed light on management and agricultural models that are more sustainable, or at least more compatible with fragile environmental equilibria, and that can be reasonably replicated across the EU.

The overall results show that there is no single, fully replicable model that can be taken as an example. However, there are certainly some drivers that make livestock management more efficient and, as such, can be proposed as better able to guarantee a greater environmental sustainability. In this context, implementing backgrounding strategies aimed at enhancing productivity and profitability has the potential to create more sustainable management models. The current research pointed to the role of several factors in reducing environmental pressure, such as the presence of medium-sized farms in areas with a high proportion of pastures, low livestock densities, and the enhancement in crops and forage productivity through optimized water use and soil management.

Finally, a kind of polarization between environmental and economic sustainability was observed. As it might reasonably be expected, these two terms appear to be antithetical, although they could be combined through a more efficient production system. As in all processes of technical improvement, the current dichotomy mentioned above could be overcome by increasing knowledge of the processes involved and setting income thresholds compatible with the desired degree of sustainability. With the aim of increasing farmers' profitability, strategies could be directed toward breeding more profitable animal species or those that are more in touch with the environment. In addition, a more efficient land-use destination or diversification of farm activities seems to be the most useful tool for improving economic performance, primarily for the economies of marginal and rural districts.

6.2. Implications

In addition to private solutions, policies adopted to encourage environmentally sustainable production choices and ensure an adequate level of profitability for businesses obviously play a key role.

In this context, the present study provided some interesting insights in terms of both policies and business strategies. With regard to policies, the results can be a useful tool to support sustainable decision-making while adhering to well-established EU policies. To achieve this, the development of a more sustainable beef sector could be pursued through a more circular vision of agricultural and livestock farming practices, with adequate support from the EU and a greater recognition of these peculiarities by better-informed consumers. This research sought to offer an understanding of the practices promoting environmental sustainability, considering the distinct features of individual regions. More specifically, focusing on cattle farming methods with minimal environmental impact on renewable resources is aligned with the broader goal of advancing sustainable agriculture. The outcomes can influence policy decisions, direct financial incentives toward sustainable practices, establish sustainability objectives, and encourage environmentally friendly agricultural approaches, thereby contributing to the development of a more focused and resilient European agricultural policy.

On the other hand, from a business perspective, increased investment in research would facilitate the introduction of more sustainable technologies, which could help to alleviate the critical environmental threats emphasized by scientists. A reduction in animal density, the extensification of pastures, limited water use, or more efficient water management could be the way forward. Nevertheless, it is well known that reducing the factors used results in lower outputs for the same techniques adopted. Therefore, the key issue is again to improve the techniques or to find appropriate compensation in the form of public aid or higher prices through increased consumer appreciation.

6.3. Limitations and Future Research

The present work constitutes the first systematic approach to the European cattle production system, identifying some of the best management models that are worthy of further study, especially with a view to sustainable intensification.

Certainly, there are some limitations in the approach used, mainly due to the content of the database, which did not allow for an in-depth investigation of some aspects related to important economic and environmental indicators and EU subsidies. These factors require further and more specific research, which is beyond the systematic approach intended for the present work. Another limitation is of an econometric nature and is linked to the intrinsic characteristics of the model used. Factorial analyses, such as PCA, are very useful to compress information when using multivariate databases. However, this synthesis of information leads to a loss of explained variance; so, the results have to be interpreted carefully.

For these reasons, there is also a need to develop similar analyses, not only to confirm the results obtained in the analyzed sector, but also for other agri-food sectors, including a wider number of variables related to economic and environmental aspects.

Furthermore, it would be desirable to analyze in greater depth the role of subsidies in improving environmental sustainability.

The potential conversion to organic farming of about a quarter of the EU's UAA could be a future scenario: the possible effects on the availability of fodder crops will have to be carefully assessed. The same is true for animal welfare labelling; in this case, too, an expected impact could be a decrease in the number of animals reared overall. In addition, increased attention to aspects of crop management for animal feed could lead to improving the sustainability aspects of livestock farms, as well as increasing attention to animal welfare.

Finally, from a medium-term perspective of enhancement of the livestock system, further studies on precision breeding, precision feeding techniques, precision farming technologies, and changing manure management techniques could lead to an improvement in European farming systems.

There is a need to develop similar analyses for other agro-food sectors, by including a wider number of variables related to economic and environmental aspects. It would also be desirable to analyze the role of subsidies in enhancing environmental sustainability. Finally, from a medium-term perspective of increased intensification of the livestock system, further studies on precision livestock farming are required.

Author Contributions: Conceptualization, G.D.V.; methodology, R.Z., R.D.C. and L.P.; software, R.Z. and L.P.; validation, G.D.V.; formal analysis, R.Z. and L.P.; investigation, R.D.C., R.Z. and L.P.; resources, G.D.V., T.M. and F.B.; data curation, R.Z. and L.P.; writing—original draft preparation, G.D.V., R.Z. and L.P.; writing—review and editing, G.D.V., R.Z., R.D.C., L.P., T.M. and F.B.; visualization, L.P.; supervision, G.D.V., T.M. and F.B.; project administration, G.D.V.; funding acquisition, T.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding. The APC was funded by MIUR—University of Turin, through the project entitled: "Sustainability of agro-food productions in a circular economy perspective: business models and consumers' preferences".

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Publicly available datasets were analyzed in this study. These data can be found at: https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/nuts (accessed on 8 January 2020); http://www.fao.org/faostat/en/#data/QL (accessed on 8 January 2020).

Conflicts of Interest: The authors declare no conflicts of interest.

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