

# The effect of grasslands and pastures on dairy farming and cattle farming efficiency: The case of Türkiye and European Union countries

Duran Güler<sup>1\*</sup> 

<sup>1</sup> Ege University, Faculty of Agriculture, Department of Agricultural Economics, İzmir, Türkiye.

\*Corresponding author:  
[duran.guler@ege.edu.tr](mailto:duran.guler@ege.edu.tr)

Received: December 17, 2024

Accepted: November 25, 2025

**How to cite:** Güler, D. 2026. The effect of grasslands and pastures on dairy farming and cattle farming efficiency: The case of Türkiye and European Union countries. *Revista Brasileira de Zootecnia* 55:e20240216. <https://doi.org/10.37496/rbz5520240216>

## Editors:

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**ABSTRACT** - This study aimed to analyze the effect of grasslands, meadows, and pastures on the efficiency of dairy farming and cattle farming in Türkiye and European Union countries. The primary data for this study included information on the production of raw milk and cattle meat, nitrogen content in treated manure, dairy cow populations, livestock standard units (LSUs), and the extent of grasslands, meadows, and pastures in both European Union countries and Türkiye. In the study, two distinct models were developed: one to assess dairy farming efficiency and the other to evaluate cattle farming efficiency. Dairy farming refers specifically to the production system that focuses on milk production from dairy cows. In contrast, cattle farming is a broader term that encompasses both dairy cattle and beef cattle. Data envelopment analysis was used to calculate the efficiency scores. The difference between dairy farming and cattle farming efficiency values was tested using the Mann-Whitney U test, and the results indicated a statistically significant difference in total efficiency ( $z = -2.462$ ,  $P = 0.014$ ) and technical efficiency ( $z = -3.416$ ,  $P = 0.001$ ) values. The significant difference in total efficiency values suggests that cattle farming is more efficient than dairy farming. Regarding grasslands, meadows, and pastures, countries with below-average grassland areas showed higher total efficiency values for cattle farming. Additionally, in countries where meadow and pasture areas are below average, total efficiency values for both dairy farming and cattle farming were higher. These findings suggest that the higher efficiency values observed in countries with below-average meadow and pasture areas may be explained by the structural characteristics of their production systems. In the absence of abundant natural forage resources, farmers are likely to adopt more intensive and resource-efficient management strategies, which enhance both total and scale efficiency. In other words, the scarcity of grassland acts as a driving force toward optimizing input utilization, resulting in improved efficiency outcomes in both dairy and overall cattle farming.

**Keywords:** data envelopment analysis, efficiency analysis, livestock efficiency, sustainability

## 1. Introduction

Türkiye and the EU accounted for 23.04% of the global cow milk production, which totalled 753.32 million tons. In terms of value, Türkiye's cow milk production was worth 6.68 billion dollars in 2021, compared with 67.23 billion dollars in the EU countries. Combined, the meat production quantity in Türkiye and the EU countries accounted for 11.96% of the world's total meat production, which totalled 69.35 million tons (FAO, 2021).

The increasing production of milk and meat to meet the growing demand for these products leads to environmental problems due to significant resource consumption (Mu et al., 2018). Agriculture, especially dairy production, has significant environmental impacts (Grassauer et al., 2022). Milk and dairy products form the largest segment within the agricultural sector and represent as one of the most crucial industries in the EU (Bórawski et al., 2020). The findings of Koutouzidou et al. (2022) indicate that there is potential for enhancement in intensive dairy farming in European Union countries. It is expected that the annual production of milk in the EU will increase by 0.5% per year, reaching 162 million tons by 2031 (EC, 2021). To combat climate change and biodiversity loss, the European Union (EU) supports the encouragement of extensive farming practices (Latruffe et al., 2023). Nevertheless, evidence suggests that more intensive systems can achieve higher resource-use efficiency and lower emissions per unit of output (Oenema and Oenema, 2021). Therefore, overcoming nutritional challenges in the coming years depends on the development of more efficient and sustainable dairy farms (Britt et al., 2018). In this context, there is an urgent need to identify practical solutions to achieve the expected efficiency levels and ensure long-term sustainability (Bhat et al., 2022), given the emphasis on efficiency and sustainability in dairy farming management strategies (Brizga et al., 2021). Countries must effectively utilize their resources and implement measures to increase efficiency in dairy farming activities to reduce environmental problems and ensure sustainability. Pasture-based dairy farming has a significant advantage in terms of efficient use of resources, as it relies on sourcing half of the metabolizable energy requirement from pastures or locally grown forages (Garcia and Fulkerson, 2005; Islam et al., 2015). Türkiye and EU countries collectively hold 2.81% of the world's grassland area (3,062,602 thousand hectares) and 2.08% of the world's meadow and pasture area (3,207,673 thousand hectares) (FAO, 2021). Given their substantial share in both cow milk and meat production, Türkiye and EU countries must demonstrate the impact of grasslands, meadows, and pastures on dairy farming and cattle farming efficiency. Dairy farming refers specifically to the production system that focuses on milk production from dairy cows. In contrast, cattle farming is a broader term encompassing both dairy and beef cattle production systems.

This study aimed to analyze the effect of grasslands, meadows, and pastures on dairy and cattle farming efficiency in Türkiye and European Union countries. To achieve this, the following hypotheses were tested: (i) there is a difference between the efficiency values of dairy farming and cattle farming; (ii) efficiency values for dairy farming vary based on the number of dairy cows; (iii) efficiency values for dairy farming differ according to milk yield; (iv) efficiency values for dairy or cattle farming are influenced by grassland areas; (v) efficiency values for dairy or cattle farming are affected by meadow and pasture areas.

## 2. Material and methods

### 2.1. Material

The primary data for this study were obtained from the FAO for the year 2021 and include cattle raw milk production, cattle meat production, treated manure (nitrogen content), dairy cow numbers, livestock standard units (LSUs), and the extent of grasslands, meadows, and pastures in both EU countries and Türkiye. Accordingly, this dataset represents the complete data available for the year, rather than a limited or restricted sample. While the analysis covers the EU as a whole, Türkiye is emphasized in this study because it ranks first in several critical variables, such as dairy cow numbers, the extent of grasslands, meadows, and pastures, and cattle meat production, making it particularly noteworthy in the comparative efficiency assessment. These data were downloaded from the FAO in Excel format and organized by the author into a format suitable for analysis.

The selection of these variables was based on their critical role in assessing the efficiency of dairy farming and cattle farming, as well as their direct impact on economic performance. Raw milk and cattle meat production are fundamental outputs of cattle farming. These data are critical for evaluating

the agricultural productivity and economic performance of countries. Treated manure contributes to cost savings and improved crop yields, enhances waste management, supports nutrient management practices, and opens up market opportunities, all of which can lead to better economic outcomes for farmers. In some cases, it may also generate additional income when used as an organic fertilizer. Therefore, rather than being treated as a cost, treated manure was modeled as a beneficial output that positively contributes to the overall efficiency of cattle farming. The number of dairy cows and livestock standard unit (LSU) provide insights into the intensity and scale of cattle farming. LSU is a measure of herd size and composition, expressed in terms of the energy requirements of each animal relative to a standard adult female breeder (Lalonde and Sukigara, 1997). These metrics are essential for comparing production capacities between countries. The extent of grasslands, meadows, and pastures is crucial for understanding the sustainability of cattle farming activities and ecosystem balance. These data provide information about feed production potential and nutritional sources for livestock.

To clarify these terms, grassland predominantly refers to managed and often sown areas for forage production, frequently harvested mechanically. In contrast, meadows and pastures are primarily used for grazing and are usually characterized by their natural or semi-natural vegetation (Suttie et al., 2005; Squires et al., 2018). Evaluating them individually allows for a more precise analysis of how different land types influence efficiency in dairy and cattle farming, whereas merging these categories would mask these differences and reduce the analytical value of the study. This distinction, therefore, provides a more nuanced basis for analyzing land use intensity and its role in agricultural production models.

In the study, two distinct models were developed: one assessing dairy farming efficiency, with raw milk as the sole output, and the other evaluating overall cattle farming efficiency, which encompasses both dedicated beef cattle raised for meat and dairy cattle, whose meat is primarily obtained through culling at the end of their productive life.

In the first model, the sole output is the production of raw milk from cattle (tons). The inputs for this model include dairy cows (heads), grasslands (hectares), and meadows and pastures (hectares). The goal of this model is to evaluate the efficiency of dairy farming. In the second model, the outputs are raw milk production, cattle meat production (tons), and treated manure (nitrogen content, tons). This model incorporates LSU, grasslands (hectares), and meadows and pastures (hectares) as inputs. Its purpose is to assess the efficiency of cattle farming, considering both dairy and meat cattle together (Table 1). Although factors such as diet, labor, and production costs may influence efficiency, comparable and harmonized data across all EU countries are not available. Therefore, these factors were not included in the analysis.

**Table 1 - Inputs and outputs for models**

Model	Outputs/Inputs	Variables
The first model (Dairy farming efficiency)	Output	Production of raw milk of cattle
	Inputs	Dairy cows
		Grassland Meadows and pastures
The second model (Cattle farming efficiency)	Outputs	Production of raw milk of cattle Production of meat of cattle Manure treated (N content)
	Inputs	LSU Grassland Meadows and pastures

LSU - Livestock standard unit.

The study data are provided in Table 2. According to the data for the year 2021, Türkiye ranked as the country with the highest number of dairy cattle, as well as the country with the largest grassland, meadow, and pasture area. Additionally, it was the top producer of cattle meat among all countries. The country that produced the most raw milk from cattle was Germany. France ranked first among the countries in terms of LSU and treated manure.

**Table 2 - Data for variables used as input or output in the model (FAO, 2021)**

Country	Dairy cows (Thousand heads)	LSU (Livestock units)	Grassland (Thousand ha)	Meadows and pastures (Thousand ha)	Production of raw milk of cattle (ton)	Production of meat of cattle (ton)	Manure treated (N content) (ton)
Türkiye	6,111	12,495,380	37,763	14,617	21,370,116	1,460,719	51,067
Romania	1,082	1,096,080	1,505	4,090	3,637,000	82,720	92,100
Spain	809	5,918,670	13,689	9,619	7,623,090	717,880	266,425
Germany	3,833	9,935,694	3,113	4,730	32,506,910	1,080,420	570,238
Italy	1,844	5,652,252	3,159	3,042	13,202,450	747,890	307,702
Poland	2,035	3,827,220	2,759	3,041	14,881,110	555,220	290,826
France	3,322	15,597,072	3,619	9,583	24,778,840	1,424,320	761,253
Greece	91	507,600	2,667	2,647	710,930	33,050	23,527
Hungary	281	545,940	894	754	2,080,230	30,080	41,319
Bulgaria	230	366,720	1,736	1,397	835,780	18,180	28,490
Portugal	230	1,476,585	2,248	2,130	1,995,550	103,000	67,870
Czechia	362	815,652	442	1,006	3,309,910	74,520	60,720
Croatia	102	256,800	738	540	558,000	43,180	19,792
Austria	526	1,683,090	1,339	1,210	3,830,140	213,740	90,495
Slovakia	120	260,454	294	512	902,640	11,930	19,466
Lithuania	225	377,220	1,202	623	1,473,280	45,540	32,819
Sweden	300	1,250,901	2,462	464	2,782,220	137,370	62,702
Denmark	559	1,332,000	193	234	5,644,000	123,430	78,693
Finland	249	746,982	1,286	21	2,271,910	86,250	40,903
Latvia	131	236,082	533	599	990,310	17,040	20,056
Belgium	537	2,079,396	218	476	4,434,000	247,120	106,179
Netherlands	1,554	3,334,500	504	771	14,217,250	429,640	204,681
Slovenia	101	289,572	77	378	639,930	37,540	21,618
Estonia	84	150,480	439	282	838,700	9,950	12,787
Cyprus	39	59,227	419	2	298,140	5,910	251
Ireland	1,505	5,984,379	2,650	3,901	9,039,990	594,510	303,545
Malta	6	8,412	4	0	39,540	1,050	774
Luxembourg	55	168,480	24	69	443,280	10,590	9,152

LSU - Livestock standard unit.

## 2.2. Methods

In this study, statistical analysis and data envelopment analysis have been utilized. All data were analyzed using SPSS 20 and DEAP version 2.1 software.

Technical efficiency is defined as the ability of a decision-making unit, in this case a country, to produce the maximum output from a given set of inputs under the assumption of variable returns to scale. Technical efficiency reflects the effectiveness of managerial practices and production technology, independently of the scale of operation, which is captured separately by scale efficiency. This definition is consistent with the output-oriented Banker-Charnes-Cooper (BCC) model employed in this study (Banker et al., 1984). A technical efficiency score of 1 indicates that a country is operating on its

production frontier and is fully technically efficient, whereas a score below 1 indicates that the country is inefficient in converting inputs into outputs.

Differences in efficiency values across groups of countries were statistically examined using the Mann-Whitney U test for pairwise comparisons. The analysis considered key factors such as the number of dairy cows, milk yield, grassland area, and meadow and pasture area. To further evaluate the impact of these individual factors on efficiency in dairy and cattle farming, a series of separate Mann-Whitney U tests were performed. For each continuous factor, the sample of countries was dichotomized into two independent groups: those with values above the overall sample mean and those with values below the overall sample mean. For each factor, statistically significant differences in total, technical, and scale efficiency were identified, highlighting how these country-level characteristics influence the efficiency of dairy and cattle farming operations. This non-parametric test is suitable for DEA-derived efficiency scores, which are bounded between 0 and 1 and typically exhibit non-normal distributions (Cooper et al., 2007). It compares the ranks of scores between two independent groups, allowing for an assessment of whether one group stochastically dominates the other. The null hypothesis ( $H_0$ ) posits that the distributions of efficiency scores are identical between groups, while the alternative hypothesis ( $H_1$ ) states that differences exist. The test statistic is the z-score, calculated from the difference in average ranks and group sizes, with the associated p-value representing the probability of observing such a difference under  $H_0$ .

There are two general approaches in efficiency measurement: parametric and nonparametric. Parametric methods are examined in three subsections: deterministic frontiers, stochastic frontiers, and panel data models (Battese, 1992). In contrast, data envelopment analysis (DEA) is a non-parametric method suitable for situations with multiple inputs and outputs. DEA was used in this study to determine the efficiency of countries. Data envelopment analysis was first introduced through the boundary production function proposed by Farrell in 1957. The studies of Charnes, Cooper, Banker, and Rhodes have contributed to the current state of DEA in use today (Güler and Saner, 2020).

In DEA, three distinct methods are used. The Charnes-Cooper-Rhodes (CCR) method assumes constant returns to scale, meaning that increases in input lead to proportional increases in output. Although this assumption does not fully reflect the heterogeneity of agricultural production systems, particularly in sectors like dairy, which are known for diminishing returns to scale, testing the CCR model remains methodologically relevant. It provides a critical benchmark for calculating scale efficiency and enables the decomposition of total efficiency into its technical and scale components. The constant returns to scale assumption, although less realistic for the dairy sector, is essential for decomposing total efficiency. In contrast, the variable returns to scale assumption provides a more accurate assessment of technical efficiency under realistic operational conditions in dairy production. Composite methods, such as the non-radial Slacks-Based Measure (SBM), integrate these principles by simultaneously minimizing all input excesses and output shortfalls within a single model. This approach provides a unified efficiency score that captures aspects of performance beyond the scope of individual radial models, making it particularly useful in heterogeneous contexts such as agriculture. Taken together, these models, applied through DEA, allow the calculation of total efficiency, technical efficiency, and scale efficiency, thereby ensuring methodological robustness and comparability across studies (Charnes et al., 1978; Banker et al., 1984; Tone, 2001). Within this framework, total efficiency is defined as the product of technical efficiency and scale efficiency:

$$\text{Total efficiency} = \text{Technical efficiency} \times \text{Scale efficiency} \quad (1)$$

The total efficiency and scale efficiency scores were calculated using the standard DEA decomposition, as established by Banker et al. (1984). This process involves running two linear programming models:

- The CCR model (Charnes et al., 1978) under constant returns to scale (CRS) to obtain total efficiency scores.
- The BCC model (Banker et al., 1984) under variable returns to scale (VRS) to obtain technical efficiency scores.

Scale efficiency for each decision-making unit (DMU) was then computed as the ratio of its CCR efficiency score to its BCC efficiency score (Scale efficiency =  $\theta_{CCR} / \theta_{BCC}$ ). All linear programming models were solved using the DEAP version 2.1 software. This decomposition enables the identification of whether the source of a DMU's inefficiency lies in its scale of operation or its technical processes.

The returns to scale classification for each DMU (i.e., determining whether a country operates under increasing, constant, or decreasing returns to scale) was derived using the standard two-step DEA procedure (Banker et al., 1984). First, if  $\theta_{CCR} = \theta_{BCC}$  (i.e., scale efficiency = 1), the DMU was classified as operating under constant returns to scale (CRS). If  $\theta_{CCR} < \theta_{BCC}$ , the DMU was classified as operating under non-constant returns to scale (non-CRS), and the returns to scale regime was determined from the sum of intensity variables ( $\Sigma \lambda^*$ ) obtained in the CCR solution:

- If  $\Sigma \lambda^* < 1 \rightarrow$  increasing returns to scale (IRS);
- If  $\Sigma \lambda^* = 1 \rightarrow$  constant returns to scale (CRS);
- If  $\Sigma \lambda^* > 1 \rightarrow$  decreasing returns to scale (DRS).

The DEA models use linear programming techniques to analyze proportional changes in inputs and outputs (Streimikis and Saraji, 2022). Depending on whether technical efficiency improvement in a DEA model involves decreasing input levels with fixed outputs or increasing output levels with constant inputs, a DEA model can be classified as either input-oriented or output-oriented (Charnes et al., 1978).

In this study, efficiency values were calculated based on an output orientation under the assumptions of constant returns to scale and variable returns to scale. The output-oriented calculations focus on determining the maximum possible output that can be achieved proportionally without altering the current input levels. The following formulations demonstrate how this procedure is performed:

#### - Output-Oriented CCR Model

Mathematical formulation (envelopment form):

Maximize  $\varphi$

Subject to:

$$\Sigma \lambda_j x_{ij} \leq x_{io}, \text{ for all } i = 1, \dots, m$$

$$\Sigma \lambda_j y_{rj} \geq \varphi * y_{ro}, \text{ for all } r = 1, \dots, s$$

$$\lambda_j \geq 0, \text{ for all } j = 1, \dots, n$$

Here,  $\varphi$  (phi) is the output expansion factor. If  $\varphi = 1$ , the DMU is efficient; if  $\varphi > 1$ , the DMU is inefficient.

#### - Output-Oriented BCC Model

Mathematical formulation (envelopment form):

Maximize  $\varphi$

Subject to:

$$\Sigma \lambda_j x_{ij} \leq x_{io}, \text{ for all } i = 1, \dots, m$$

$$\Sigma \lambda_j y_{rj} \geq \varphi * y_{ro}, \text{ for all } r = 1, \dots, s$$

$$\Sigma \lambda_j = 1$$

$$\lambda_j \geq 0, \text{ for all } j = 1, \dots, n$$

The additional convexity constraint ( $\Sigma \lambda_j = 1$ ) ensures variable returns to scale.

### 3. Results

The variables used for efficiency analysis are as follows: production of raw milk from cattle: 6,261,973 tons, production of cattle meat: 297,957 tons, manure treated (nitrogen content): 128,052 tons, dairy cows: 940 thousand heads, LSU: 2,730,459, grassland: 3,071 thousand hectares, and meadows and pastures: 2,383 thousand hectares (Table 3).

**Table 3 - Descriptive statistics for variables**

Outputs/Inputs	Variables	Unit	Minimum	Maximum	Mean	Std. deviation
Outputs	Production of raw milk of cattle	Ton	39,540	32,506,910	6,261,973	8,356,865
	Production of meat of cattle	Ton	1,050	1,460,719	297,957	427,939
	Manure treated (N content)	Ton	251	761,253	128,052	181,201
Inputs	Dairy cows	Thousand heads	6	6,111	940	1,412
	LSU	Livestock units	8,412	15,597,072	2,730,459	4,010,121
	Grassland	Thousand ha	4	37,763	3,071	7,272
	Meadows and pastures	Thousand ha	0	14,617	2,383	3,501

LSU - Livestock standard unit.

The distribution of output-oriented efficiency values for countries is given in Table 4. In the first model, which evaluates dairy farming efficiency, the total efficiency value was calculated as 0.760, while in the second model, which measures cattle farming efficiency, it was calculated as 0.873. The number of countries with full efficiency in the first model was three, whereas nine countries achieved full efficiency in the second model. In the dairy farming efficiency model, three countries had efficiency values below 50%. In contrast, in the cattle farming efficiency model, no countries had efficiency values below 50%. These results indicate that countries generally have high efficiency in both dairy farming and cattle farming, with cattle farming efficiency being higher than dairy farming efficiency. The difference between dairy farming and cattle farming efficiency values was tested using the Mann-Whitney U test, and the results indicated a statistically significant difference in total efficiency ( $z = -2.462$ ,  $P = 0.014$ ) and technical efficiency ( $z = -3.416$ ,  $P = 0.001$ ) values. For Türkiye, the efficiency values in dairy farming were found to be below the average, with total efficiency at 0.346, technical efficiency at 0.657, and scale efficiency at 0.527. In contrast, for cattle farming, Türkiye's total efficiency (0.771) and scale efficiency (0.771) values were below average, while the technical efficiency value (1.000) was above average.

The study calculated milk yield, production of cattle meat per LSU, and manure treated per LSU for the countries included in the analysis. Accordingly, the average milk yield was 7,438.07 liters/year, meat production per LSU was 10.01 kg/year, and manure production per LSU was 6.09 kg/year.

Among the countries included in the study, Denmark had the highest milk yield (10,096.60 liters/year) and was one of the countries with full efficiency in both models, alongside Malta. Malta also stood out with meat production per LSU at 12.48 kg per year, which was above the average, and led in manure production per LSU at 9.20 kg/year. Additionally, Finland was among the countries with full efficiency in the first model, while Poland, Croatia, Belgium, the Netherlands, Slovenia, Estonia, and Cyprus were among the countries with full efficiency in the second model (Table 5). Examining the efficient countries revealed that Estonia and Cyprus had milk yields above the average, and Poland, Croatia, and Slovenia had meat production per LSU above the average. Furthermore, Finland, Belgium, and the Netherlands were noted for having both milk yields and meat production per LSU above the average.

**Table 4 - Total efficiency, technical efficiency, and scale efficiency by countries**

Model	Efficiency value	Total efficiency		Technical efficiency		Scale efficiency	
		Count	%	Count	%	Count	%
Dairy farming efficiency	1	3	10.71	7	25.00	5	17.86
	0.901-0.999	6	21.43	3	10.71	18	64.29
	0.801-0.900	4	14.29	5	17.86	4	14.29
	0.701-0.800	8	28.57	6	21.43	0	0.00
	0.601-0.700	2	7.14	4	14.29	0	0.00
	0.501-0.600	2	7.14	1	3.57	1	3.57
	0.401-0.500	0	0.00	0	0.00	0	0.00
	0.301-0.400	3	10.71	2	7.14	0	0.00
	0.201-0.300	0	0.00	0	0.00	0	0.00
	0.101-0.200	0	0.00	0	0.00	0	0.00
	0.000-0.100	0	0.00	0	0.00	0	0.00
	Mean		0.76046		0.80007		0.94882
	Std. deviation		0.19408		0.18345		0.09645
	Minimum		0.333		0.358		0.527
Maximum		1.000		1.000		1.000	
Cattle farming efficiency	1	9	32.14	18	64.29	9	32.14
	0.901-0.999	6	21.43	4	14.29	10	35.71
	0.801-0.900	7	25.00	4	14.29	7	25.00
	0.701-0.800	4	14.29	0	0.00	2	7.14
	0.601-0.700	0	0.00	0	0.00	0	0.00
	0.501-0.600	2	7.14	2	7.14	0	0.00
	0.401-0.500	0	0.00	0	0.00	0	0.00
	0.301-0.400	0	0.00	0	0.00	0	0.00
	0.201-0.300	0	0.00	0	0.00	0	0.00
	0.101-0.200	0	0.00	0	0.00	0	0.00
	0.000-0.100	0	0.00	0	0.00	0	0.00
	Mean		0.87289		0.93900		0.92907
	Std. deviation		0.13753		0.11881		0.07894
	Minimum		0.509		0.548		0.707
Maximum		1.000		1.000		1.000	

**Table 5 - The efficient countries by models**

Model	Efficient countries
Dairy farming efficiency	Denmark, Finland, Malta
Cattle farming efficiency	Poland, Croatia, Denmark, Belgium, Netherlands, Slovenia, Estonia, Cyprus, Malta

When examined according to the returns to scale conditions, in the first model, 46.43% of countries (13 countries) were determined to operate under increasing returns to scale, meaning that in this model, an increase in input quantity results in a greater increase in output quantity in most countries. In the second model, however, 64.29% of countries (18 countries) were found to operate under decreasing returns to scale, while 32.14% (nine countries) were found to operate under constant returns to scale (Table 6). Türkiye was among the countries operating under decreasing returns to scale in both dairy farming and cattle farming efficiency models.

**Table 6 - Returns to scale for countries**

Model	Efficiency	Number of countries	Within the group (%)
Dairy farming efficiency	Constant returns to scale (CRS)	5	17.86
	Decreasing returns to scale (DRS)	10	35.71
	Increasing returns to scale (IRS)	13	46.43
Cattle farming efficiency	Constant returns to scale (CRS)	9	32.14
	Decreasing returns to scale (DRS)	18	64.29
	Increasing returns to scale (IRS)	1	3.57

In the study, the dairy farming efficiency values were tested using the Mann-Whitney U test to determine whether there was a difference based on the average number of dairy cows (940.14 thousand heads) and the average milk yield (7,438.07 liters/year) among countries. The results indicated that in countries with below-average dairy cow numbers, both total efficiency (0.802) ( $z = -1.832$ ;  $P = 0.067$ ) and scale efficiency (0.989) ( $z = -3.931$ ;  $P = 0.000$ ) values were higher (Table 7). This finding is further supported by the Mann-Whitney U test, which suggests that smaller dairy farms are generally closer to the optimal scale for efficient management. In contrast, larger dairy farms may encounter managerial, logistical, or resource constraints that limit their capacity to fully exploit scale economies. Consequently, these results indicate that some countries included in the study are not sufficiently utilizing the scale advantages in dairy farming.

Milk yield significantly impacts dairy farming efficiency in countries. A statistical difference in total and technical efficiency was found in countries where milk yield was above average. In these countries, both total efficiency (0.872) ( $z = -3.762$ ;  $P = 0.000$ ) and technical efficiency (0.904) ( $z = -3.556$ ;  $P = 0.000$ ) values were higher (Table 8).

Cattle farming efficiency was determined to be influenced by the available grassland area in countries. In countries with below-average grassland, both total efficiency (0.888) ( $z = -1.799$ ;  $P = 0.072$ ) and scale efficiency (0.954) ( $z = -2.836$ ;  $P = 0.005$ ) values were higher, and these differences were statistically significant. Furthermore, in dairy farming efficiency, the scale efficiency value (0.979) ( $z = -3.162$ ;  $P = 0.002$ ) was significantly higher in countries with below-average grassland (Table 9).

**Table 7 - Efficiency values by the number of dairy cows**

Model	Efficiency <sup>1</sup>	Number of dairy cows	Mean	Std. deviation	Min.	Max.	z	P
Dairy farming efficiency	Total efficiency*	Dairy cows ( $\leq$ average)	0.802	0.170	0.359	1.000	-1.832	0.067
		Dairy cows ( $>$ average)	0.656	0.222	0.333	0.962		
	Technical efficiency	Dairy cows ( $\leq$ average)	0.812	0.175	0.360	1.000	-0.307	0.758
		Dairy cows ( $>$ average)	0.770	0.212	0.358	1.000		
	Scale efficiency***	Dairy cows ( $\leq$ average)	0.989	0.020	0.919	1.000	-3.931	0.000
		Dairy cows ( $>$ average)	0.848	0.136	0.527	0.962		

<sup>1</sup> According to the Mann-Whitney U test, the difference between groups is significant at \*\*\* $P < 0.01$ ; \* $P < 0.1$  level.

**Table 8 - Efficiency values by milk yield**

Model	Efficiency <sup>1</sup>	Milk yield	Mean	Std. deviation	Min.	Max.	z	P
Dairy farming efficiency	Total efficiency***	Milk yield (≤ average)	0.611	0.195	0.333	1.000	-3.762	0.000
		Milk yield (> average)	0.872	0.094	0.739	1.000		
	Technical efficiency***	Milk yield (≤ average)	0.662	0.182	0.358	1.000	-3.556	0.000
		Milk yield (> average)	0.904	0.097	0.750	1.000		
	Scale efficiency	Milk yield (≤ average)	0.926	0.134	0.527	1.000	-0.466	0.641
		Milk yield (> average)	0.966	0.053	0.840	1.000		

<sup>1</sup> According to the Mann-Whitney U test, the difference between groups is significant at \*\*\*P<0.01 level.

**Table 9 - Efficiency values by grassland**

Model	Efficiency <sup>1</sup>	Grassland	Mean	Std. deviation	Min.	Max.	z	P
Dairy farming efficiency	Total efficiency	Grassland (≤ average)	0.771	0.191	0.333	1.000	-0.570	0.569
		Grassland (> average)	0.713	0.224	0.346	0.933		
	Technical efficiency	Grassland (≤ average)	0.787	0.192	0.358	1.000	-0.695	0.487
		Grassland (> average)	0.861	0.140	0.657	1.000		
	Scale efficiency***	Grassland (≤ average)	0.979	0.035	0.880	1.000	-3.162	0.002
		Grassland (> average)	0.812	0.166	0.527	0.955		
Cattle farming efficiency	Total efficiency*	Grassland (≤ average)	0.888	0.142	0.509	1.000	-1.799	0.072
		Grassland (> average)	0.804	0.096	0.707	0.958		
	Technical efficiency	Grassland (≤ average)	0.929	0.129	0.548	1.000	-0.875	0.382
		Grassland (> average)	0.985	0.033	0.926	1.000		
	Scale efficiency***	Grassland (≤ average)	0.954	0.051	0.858	1.000	-2.836	0.005
		Grassland (> average)	0.816	0.092	0.707	0.958		

<sup>1</sup> According to the Mann-Whitney U test, the difference between groups is significant at \*\*\*P<0.01; \*P<0.1 level.

In countries with below-average meadow and pasture areas, total efficiency and scale efficiency were higher in both dairy farming and cattle farming and this difference was statistically significant (Table 10).

**Table 10** - Efficiency values by meadows and pastures

Model	Efficiency <sup>1</sup>	Meadows and pastures (M., P.)	Mean	Std. deviation	Min.	Max.	z	P
Dairy farming efficiency	Total efficiency*	(M., P.) (≤ average)	0.805	0.176	0.359	1.000	-1.796	0.072
		(M., P.) (> average)	0.666	0.207	0.333	0.933		
	Technical efficiency	(M., P.) (≤ average)	0.815	0.181	0.360	1.000	-0.620	0.535
		(M., P.) (> average)	0.769	0.196	0.358	1.000		
	Scale efficiency***	(M., P.) (≤ average)	0.989	0.020	0.919	1.000	-3.828	0.000
		(M., P.) (> average)	0.863	0.135	0.527	0.993		
Cattle farming efficiency	Total efficiency**	(M., P.) (≤ average)	0.909	0.119	0.518	1.000	-2.226	0.026
		(M., P.) (> average)	0.797	0.150	0.509	1.000		
	Technical efficiency	(M., P.) (≤ average)	0.948	0.102	0.583	1.000	-0.143	0.886
		(M., P.) (> average)	0.920	0.154	0.548	1.000		
	Scale efficiency**	(M., P.) (≤ average)	0.957	0.052	0.858	1.000	-2.426	0.015
		(M., P.) (> average)	0.869	0.095	0.707	1.000		

<sup>1</sup> According to the Mann-Whitney U test, the difference between groups is significant at \*\*\*P<0.01; \*\*P<0.05; \*P<0.1 level.

## 4. Discussion

Dairy farming has become more industrialized over time, with a notable shift from primarily pasture-based systems to confinement-feeding systems (Blayney, 2002). Cows are mainly confined, with little or no access to pastures. Improvements in nutrition and genetic selection have led to increased milk yield per cow, while advancements in technology, such as automated calf feeders and cow activity monitors, have further accelerated production (Barkema et al., 2015). Studies have long shown that investments in technologies such as automated concentrate feeders contribute to technical progress in dairy farming (van Asseldonk et al., 1999). Today, the European dairy farming sector is characterized by the prevalence of intensive production methods reliant on significant capital investments, high-yielding animals, purchased feed, and skilled labor hired externally (Bórawski et al., 2020; Britt et al., 2018; Koutouzidou et al., 2022). Since the removal of milk quotas in the European Union in 2015, there have been significant changes, including increased milk yield per cow, higher total milk production, and a decrease in the number of cows (Bórawski et al., 2020). The efficiency outcomes observed in this study clearly reflect these structural adjustments. Specifically, the rise in per-cow productivity and the simultaneous reduction in herd size have enhanced technical efficiency in countries with advanced management systems, while also reinforcing the importance of scale efficiency in explaining cross-country differences. For instance, high-performing countries such as Denmark, the Netherlands, and Cyprus demonstrate how larger herds, combined with productivity gains following quota removal, translate into near-optimal efficiency values. In contrast, smaller-scale member states such as Romania and Bulgaria were less able to capitalize on these structural shifts, which is consistent with their comparatively low efficiency scores. Overall, the post-quota period accentuated pre-existing disparities between large-scale and small-scale production systems rather than uniformly improving efficiency across the Union.

Apart from these efficiency outcomes, the EU dairy sector also faces a distinct set of socio-economic challenges. These include fluctuating market prices, high labor costs, and an ageing population profile (Bas-Defossez et al., 2019). Crucially, rising energy and fertilizer costs are expected to drive up feed prices until 2031. Therefore, strategies to reduce dependency on expensive external inputs have become increasingly relevant. The enhanced utilization of grasslands and pastures for feeding is one such strategy, primarily aimed at lowering production costs rather than directly increasing volumetric efficiency. While a greater reliance on grass may lead to a decrease in milk yield per cow in the absence of premium markets, it can improve long-term economic resilience by reducing input costs, leveraging policy incentives, and securing niche markets. Organic dairy production and the expansion of diverse farming practices are expected to increase the proportion of proteins sourced from grass in livestock feed (EC, 2021), often targeting niche markets that value environmental and animal welfare attributes. However, the proportion of dairy farms with access to pastures in Europe has significantly decreased over the years (Reijs et al., 2013). This rationale is consistent with Schulte et al. (2018), who interpret the decline in pasture access as a cost-reduction strategy in the face of low milk prices. Although the EU's Common Agricultural Policy promotes the use of grasslands for ecosystem services and animal welfare, widespread adoption is often hindered by farmers' economic concerns regarding potential yield reductions. National-level initiatives such as grazing premiums in the Netherlands and Germany (Reijs et al., 2013) illustrate attempts to bridge this policy-practice gap, aligning economic incentives with sustainability goals and making pasture-based systems more viable despite potential trade-offs with conventional efficiency metrics.

Against this background, Schulte et al. (2018) found a positive correlation between animal welfare and technical efficiency in their study conducted in Germany. They noted that, although pasture-based production systems often yield lower milk quantities, they achieve higher technical efficiency due to improved animal welfare. Moreover, Arnott et al. (2017) highlighted that pasture-based systems tend to have lower incidences of lameness, hoof pathologies, hock lesions, mastitis, uterine disease, and mortality in cows compared to continuously housed systems. It is important to note, however, that these animal health benefits can sometimes come with economic trade-offs, such as lower overall milk production per cow and potentially higher land requirements, which may affect farm profitability if not managed strategically through premium markets or cost savings on veterinary bills and feed. In another study conducted by Allendorf and Wettemann (2015) in Germany, no significant correlation between efficiency scores and pasture access was found. This suggests that there is no clear consensus on whether grasslands and pastures have a direct effect on cattle farming efficiency, and the economic outcome likely depends on a complex interplay of management, market access, and policy incentives.

In addition to these mixed findings on pasture access, efficiency outcomes also reflect the intensity of production systems. In countries with below-average meadow and pasture areas, the relatively high efficiency revealed in our analysis (Table 8) can be directly attributed to intensive livestock farming practices that primarily depend on concentrated feed. The use of concentrated feed often results in higher milk yields, and this mechanism is explicitly reflected in the dataset as increased dairy farming efficiency in countries with limited forage resources. This interpretation is consistent with previous studies, which have shown that animals fed predominantly with concentrated feed exhibit greater milk yield, body weight, and feed conversion efficiency (Santra and Karim, 2009). Additionally, factors such as diet balancing, bunk space, water availability, and overall cow comfort are well-documented determinants of milk yield and efficiency outcomes (Erickson and Kalscheur, 2020). Taken together, our results indicate that the observed efficiency patterns are not incidental but rather stem from these intensive feeding strategies, thereby providing a clear link between the empirical evidence and the underlying production practices.

Furthermore, one of the significant findings of the study is that countries with below-average meadow and pasture areas had higher total efficiency values in both dairy farming and cattle farming. Furthermore, in countries with below-average grassland areas, the total efficiency value of cattle farming was higher. When evaluating the results of this study alongside existing literature, it becomes clear that the low utilization of grasslands and pastures is mainly due to farmers' production system preferences, which restricts the effect of grasslands and pastures on dairy farming and cattle farming

efficiency. Although the results of this study show that countries with less grassland and pasture area have higher efficiency values, this seems to be related to production system preferences.

Beyond the role of feed composition, farm size and structure also emerge as important determinants of efficiency (Güler and Saner, 2024). The efficiency of dairy farming was determined to be higher in countries with a below-average number of dairy cows. However, a review of the literature on the number of cattle per farm and the efficiency values of some countries shows that countries benefit from economies of scale. For example, as of 2021, 96.11% of Türkiye's 1,062,547 dairy farms had 49 or fewer cattle, with only 0.95% having herds of 100 or more cattle (TOB, 2024; USK, 2024). This indicates a prevalence of small-scale dairy farms in Türkiye. Indeed, the study calculated Türkiye's dairy farming efficiency value at 0.346. In comparison, Eurostat data from 2010 show that the average number of dairy cows per farm in EU countries was 28 (EC, 2024).

Cross-country comparisons further illustrate how farm size influences efficiency. For example, the efficiency value was 0.333 for Romania with three cows per farm, 0.359 for Bulgaria with five cows per farm, and 0.648 for Lithuania with six cows per farm. These values are lower than the average dairy farming efficiency value calculated in this study. However, the efficiency values for Denmark, Cyprus, and the Netherlands, which were 1.000, with dairy cows per farm being 141, 111, and 79, respectively, demonstrate the positive effect of farm size on the dairy farming efficiency.

A detailed cross-country analysis of dairy farming efficiency across European countries and Türkiye reveals a nuanced picture that challenges any simplistic interpretation of the scale-efficiency relationship. The data demonstrate that while operational scale is a critical determinant, the interplay between technical proficiency and scale efficiency ultimately defines overall performance.

As illustrated in Table 11, countries can be categorized into distinct groups based on their efficiency profiles. The top performers, including Denmark (141 cows/farm), the Netherlands (79 cows/farm), and Cyprus (111 cows/farm), achieve near-optimal efficiency by leveraging large herd sizes combined with strong technical management. Estonia (44 cows/farm) also joins this elite group through excellent technical execution, achieving a remarkable score of 0.992.

**Table 11 - Comprehensive analysis of dairy farming efficiency by country**

Country	Average dairy herd size <sup>1</sup>	Total efficiency	Technical efficiency	Scale efficiency	Key characterization
Denmark	141	1.000	1.000	1.000	Optimal scale and management
Netherlands	79	0.962	1.000	0.962	High-tech, large scale
Cyprus	111	0.919	1.000	0.919	Large scale, highly efficient
Estonia	44	0.992	1.000	0.992	Technical excellence
Czechia	98	0.905	0.905	0.999	Large scale, highly efficient
Belgium	58	0.817	0.817	1.000	Optimal scale, tech potential
Germany	46	0.840	1.000	0.840	Technical excellence, scale limited
Slovakia	25	0.745	0.750	0.992	Medium scale, efficient
France	45	0.739	0.872	0.847	Large scale, underperforming
Austria	11	0.721	0.721	1.000	Small scale, perfect scale efficiency
Latvia	7	0.748	0.751	0.996	Small scale, efficient
Italy	35	0.709	0.798	0.889	Medium scale, moderate efficiency
Poland	6	0.724	0.823	0.880	Small scale, relatively efficient
Lithuania	6	0.648	0.649	0.998	Small scale, tech limited
Bulgaria	5	0.359	0.360	0.998	Small scale, tech inefficiency
Romania	3	0.333	0.358	0.929	Small scale, major tech gap
Türkiye	<10	0.346	0.657	0.527	Extreme fragmentation, inefficient scale

<sup>1</sup> Source: EC, 2024; TOB, 2024; USK, 2024; Ziętara et al., 2024. The table only includes countries with available average dairy herd size data.

A second group, including Germany (46 cows/farm) and Czechia (98 cows/farm), achieves high efficiency through strong technical scores, demonstrating that managerial expertise can significantly enhance performance at various scales. Conversely, France (45 cows/farm) emerges as a notable case of underperformance relative to its scale, suggesting the presence of operational inefficiencies despite its large herd size.

The analysis of smaller-scale operations reveals important insights. Türkiye presents a particularly informative case study of small-scale fragmentation. With 96.11% of its 1,062,547 dairy farms having 49 or fewer cattle, its average herd size falls significantly below the European average. This structural characteristic is reflected in its efficiency scores: a low total efficiency (0.346), moderate technical efficiency (0.657), and particularly constrained scale efficiency (0.527). This pattern aligns with that of other small-scale producers such as Romania (3 cows/farm) and Bulgaria (5 cows/farm), but Türkiye's larger absolute number of very small operations results in even greater efficiency challenges.

Austria (11 cows/farm) and Belgium (58 cows/farm) both achieve perfect scale efficiency (1.000), yet their total efficiency differs due to variance in technical scores. The comparison between Türkiye and Austria is particularly revealing. While both have small average herd sizes, Austria achieves perfect scale efficiency (1.000) and significantly better technical efficiency (0.721), resulting in more than double the total efficiency score (0.721 compared to 0.346). This disparity highlights that, beyond scale, technical and managerial factors play a crucial role in determining efficiency outcomes. Similarly, Poland and Lithuania (both 6 cows/farm) show how technical efficiency becomes the key differentiator, with Poland achieving a higher score (0.724 compared to 0.648). Slovakia (25 cows/farm) and Latvia (7 cows/farm) represent medium and small-scale operations that maintain good efficiency through balanced performance.

Finally, Bulgaria and Romania exemplify the challenges of small-scale fragmentation, where critically low technical efficiency results in the poorest overall performance despite near-perfect scale efficiency scores.

This comprehensive comparative framework underscores that dairy farming efficiency is multi-dimensional. Policy interventions must be targeted: for small-scale countries like Türkiye, Bulgaria, and Romania, the priority is structural consolidation alongside technological modernization and knowledge transfer to address both scale and technical inefficiencies; for large-scale underperformers like France, the focus should be on optimizing management practices; and for countries like Austria and Belgium, improving technical efficiency could yield significant gains. The ultimate goal remains the integration of appropriate scale with exemplary technical execution, as demonstrated by the top performers.

## 5. Conclusions

The findings suggest that policies aimed at increasing the utilization of grasslands and pastures may need to consider farmers' production system preferences. Policymakers could develop incentives or educational programs that promote best practices in utilizing these resources while respecting farmers' established systems.

In conclusion, the significance of this study in the field of agricultural economics stems from its substantial contributions to increasing agricultural productivity, promoting sustainable resource management, and developing effective policies.

In this study, farmers' production preferences were not taken into account. Future studies should incorporate efficiency models that account for farmers' preferences regarding production systems, by integrating factors such as grassland and pasture availability and farm size.

## Data availability

All data used or analyzed in this study are available within the manuscript.

## Author contributions

**Conceptualization:** Güler, D. **Data curation:** Güler, D. **Formal analysis:** Güler, D. **Investigation:** Güler, D. **Methodology:** Güler, D. **Resources:** Güler, D. **Software:** Güler, D. **Validation:** Güler, D. **Visualization:** Güler, D. **Writing – original draft:** Güler, D. **Writing – review & editing:** Güler, D.

## Conflict of interest

The author declares no conflict of interest.

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