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Technical Efficiency of Cooperative and Non-Cooperative Dairies in Poland: Toward the First Link of the Supply Chain

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Abstract: Several studies conducted in various countries have addressed the technical efficiency of dairies. However, there is a paucity of research on the technical efficiency of dairies in Poland, particularly in relation to their legal form (i.e., cooperatives vs. non-cooperatives). The existing literature also does not provide insights into the technical efficiency of these entities with respect to different regions' milk production capacity. Therefore, this paper aims to: (1) evaluate and compare the technical efficiency of cooperative and non-cooperative dairies in Poland, and (2) examine dairies' technical efficiency due to spatial disparities in milk production potential. We use data envelopment analysis (DEA) to investigate the technical efficiency of 108 dairies in Poland for the year 2019. The milk production capacity of provinces is examined by applying the zero unitarization method. The results show that when assuming constant returns to scale (CRS), dairy cooperatives are less technically efficient than non-cooperatives, whereas when assuming variable returns to scale (VRS), these differences are not statistically significant. For inefficient dairies, we observe the greatest potential for improvement in labor costs and depreciation. Both cooperatives and non-cooperatives operate mostly under decreasing returns to scale. Thus, the potential for enhancing the technical efficiency of dairies through the consolidation process seems to be exploited. Our findings reveal that the technical efficiency of dairies in Poland is not differentiated by regional milk production potential.

Keywords: technical efficiency; cooperatives; dairy processing sector; sustainability; milk production capacity; supply chain; data envelopment analysis

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Citation: Ziętek-Kwaśniewska, K.; Zuba-Ciszewska, M.; Nucińska, J. Technical Efficiency of Cooperative and Non-Cooperative Dairies in Poland: Toward the First Link of the Supply Chain. *Agriculture* **2022**, *12*, 52. https://doi.org/10.3390/agriculture12010052

Academic Editors: Adoración Mozas Moral and Domingo Fernandez Ucles

Received: 19 November 2021
Accepted: 29 December 2021
Published: 1 January 2022

1. Introduction

The concept of sustainable development is central to political as well as scientific debate. Although definitions of sustainability are varied and fluid depending on different actors' viewpoints [1], this concept has become the cornerstone of global dialogue on the future of humanity [2].

In the presence of limited resources, a growing world population, and climate change, global food security is a major concern [3]. The significance of this problem is strongly emphasized in the United Nations (UN) 2030 Agenda for Sustainable Development [4] by setting 17 Sustainable Development Goals (SDGs), the second of which refers to ending hunger, achieving food security and improved nutrition, and promoting sustainable agriculture (SDG2). In particular, target 2.4 aims to ensure, by 2030, sustainable food production systems and implement resilient agricultural practices [4].

Food systems are extremely diverse and dynamic [5] as well as intrinsically complex, involving many different processes, value chains, actors, and interactions [6]. The concept of a sustainable food system implies sustainability in three dimensions: economic, social, and environmental [7]. The ability to use resources efficiently in production is a prerequisite for the sustainability and competitiveness of the agrifood sector. The significance of food security has been additionally strengthened at the national level by the COVID-19 pandemic [8].

Milk and dairy products are an essential food for human nutrition worldwide [9,10]. Hence, the dairy sector can be considered one of the key building blocks of food systems. The sustainability of the dairy industry can be seen as providing consumers with the nutritional dairy products they demand in an economically viable, environmentally sound, and socially responsible way, now and in the future [11]. The sustainable milk and dairy production life cycle ranges from on-farm milk production, the industrialization and processing of dairy products, all the way to their marketing [10], creating a network structure [12] and a closely knitted process called a supply chain [13].

Performance evaluation has become a significant topic in supply chain management [12], including the dairy sector. Although a number of studies have been conducted on economic sustainability at the farm level (e.g., [14–17]), the discussion cannot be limited to this initial link of the dairy supply chain. Given that milk is a perishable commodity that cannot be stored in its raw form, its processing and transformation are crucial in the dairy sector [18]. For this reason also, the economic sustainability of dairies, which are the next link in the supply chain, should be given equal attention. Nevertheless, research in this area remains scarce. As economic sustainability is considered a complex problem, in this study, and similarly to Popović and Panić [19], we refer to efficiency as its component.

The dairy processing industry belongs to the major subsectors of the food processing industry in the European Union (EU) [8]. An efficient and competitive milk processing industry has been deemed crucial to maintaining sustainable milk production [20].

The relationship between the initial and the intermediate segments of the dairy supply chain has become the rationale for the establishment of cooperatives. Farmers' cooperative ownership has a long tradition in many parts of the world and is the most prevalent form of vertical integration in dairy supply chains [21]. Dairy cooperatives have played an important role in the dairy processing sector in Europe [22]. Poland is a prime example, as more than 70% of its dairies operate as a cooperative compared to about 20% in most EU countries [23]. Poland is one of the leading cow's milk producers and processors in the EU (12.2 million tons cows' milk delivered to dairies in 2019 [24]), characterized by considerable spatial diversity in its milk production capacity [25].

There is a debate concerning the relative efficiency of cooperatives versus explicitly for-profit forms of organization in the dairy processing industry [22,26]. Empirical analyses in this field have employed various methods. Data envelopment analysis (DEA) is a commonly used approach for measuring the relative efficiency and competitiveness of the food and drink industry worldwide (as reviewed in [27]).

Given the importance of the dairy industry's efficiency, the aim of this study is twofold: (1) to evaluate and compare the technical efficiency of cooperative and non-cooperative dairies in Poland, and (2) to examine dairies' technical efficiency due to spatial disparities in milk production potential. We evaluate the technical efficiency of dairies using the DEA approach. By exploring the issue of the dairy sector's efficiency with a focus on the legal form of milk processors, our study contributes to the stream of research on agricultural cooperatives within the context of sustainability.

The article is structured as follows. Section 2 presents the condition of the Polish dairy sector and provides a literature review. Section 3 describes the data and methods. Section 4 presents and discusses the research results. Finally, Section 5 concludes and outlines areas for future research.

2. Theoretical Background

2.1. The Condition of the Dairy Sector in Poland

The agrifood industry is the largest manufacturing sector in the EU, of which the dairy processing industry is a relevant subsector [8]. The EU is the most important supplier of milk and dairy products on the world market [28].

When it comes to dairy products, Poland remains self-sufficient. Indeed, the country's degree of food self-sufficiency in the case of milk and its products, i.e., the ratio of domestic production to domestic consumption [29], has been practically systematically increasing for the past 20 years [30]. Polish dairy cooperatives ensure food security in dairy products, especially the basic ones, in every region of the country [31].

The number of dairy cows in 2019 amounted to 2.16 million, a continuation of a downward trend. In 2019, the number of farms keeping cows was 220,000, but only 118,000 of these supplied milk to the dairy industry, 95% of which were family farms. Despite the increase in the average herd of cows (from 3.9 in 2005 to 11.2 in 2019), most of the farms are still characterized by their low scale of production [32,33]. According to Eurostat data for 2016, the share of farms with more than 30 dairy cows in Poland was only 20%, while for other major milk producers, the figure was as high as 85–97% (specifically in Germany, the United Kingdom, France, and the Netherlands) [34]. However, the process of concentrating cows in large and efficient farms continues, as does the modernization of milk production through improving production technology and the genetics of dairy cattle (farms with small-scale production and low profitability have abandoned dairy cattle breeding). Since Poland's accession to the EU in 2004, the marketability of its milk production has improved significantly (in 2019, over 84% of the volume of raw material produced went to the dairy industry), although it remains below the EU average (94%) [32,33,35].

From the beginning of the market transformation, we have observed a practically systematic downward trend in the number of dairies. Since 1990, when 348 dairies, all of which were cooperative, operated on the market, the share of the cooperative sector both in the number of dairies and in the purchase of milk has declined (to 62.5% and 72.3% in 2017, respectively [31]). However, the dairy industry is currently the only industry in Poland dominated by cooperatives, strengthening the integration of agriculture with the processing industry. Thanks to the concentration and modernization of the dairy industry, which began in the 1990s and continues to the present day, the technical and economic productivity of the average dairies has systematically improved [32,36].

The value of sales has been growing systematically, especially since Poland's accession to the EU (by 84% to PLN 34.7 billion), as well as the share of direct exports in the value of sales (up to 18.4% in 2019). The milk processing sector is characterized by its continued net sales profitability (for over 20 years), and the level thereof has increased from 0.2% in 1999 to 1.4% in 2019, although the share of profitable entities in the industry changed in that period (in 2019 it amounted to 68.1%). The sector also maintains current financial liquidity, albeit the investment rate in 2019 was 1.45, i.e., lower than 20 years earlier. Throughout this period, investment activity increased in years of good economic conditions on the world market along with growing exports of dairy products. Especially since 2011, it has shown a systematic increase (except for 2018, when it decreased, albeit only slightly). This means that in each year, investment expenditures in relation to the annual depreciation increased. These were intended, to the greatest extent, for the purchase of machinery, equipment, and means of transport, i.e., for the modernization of dairies' production potential [32,35–37].

Given that it deals with the industrial processing of collected milk into finished products for consumption or refined raw material for other industries, the dairy industry is closely related to farms. Domestic milk production is characterized by considerable territorial differentiation [25]. Connecting the spatial distribution of processing plants with their raw material base is important due to the territorial dispersion and fragmentation of the production of agricultural raw materials between many farms [38].

In recent years, the phenomenon of the concentration of a fragmented food industry has been clearly noticeable in Poland, because the scale effect is readily apparent, consisting in the dependence of production costs and profits at the scale of production. Food processing thus follows the footsteps of concentration in agriculture [38]. The entity structure of the food industry in Poland is changing, both as a result of Poland's accession to the EU and continued economic globalization. The fact that processes of concentration and consolidation are underway is reflected by the takeovers of Polish enterprises by foreign and domestic investors, as well as the mergers taking place among Polish enterprises [39]. Although the process of concentration of subjective structures in the dairy industry has been faster since 2004 than the average for the entire food industry [40], the industry itself is characterized by its low degree of internationalization [41]. The growing share of large enterprises in the sold production of the dairy sector [42] further evidences the existing trend of industrialization of production in food processing [43]. Currently, the rapid development of large retail chains (often with foreign capital) has changed the balance of power in the national food chain, causing the dominant position of processing companies to decline [44].

2.2. Efficiency of Dairies: Literature Review

The efficient use of resources is an evident driver of economic development [45]. Hence, improvement in this area often becomes one of the sustainability goals of any industry [46]. Enhancing the productivity and efficiency of agriculture input use is regarded as the first step to meeting the challenge of sustainable use of natural resources as well as reducing environmental impacts [47].

The dairy sector's efficiency has been the subject of a number of studies worldwide. While many of them have addressed the question of efficiency at the farm level [28,47–65], the problem of dairy efficiency seems to have received less attention.

The performance of dairy processors has been assessed with various methods. One stream of literature focuses on the financial performance of dairies. Another explores these entities' technical efficiency using DEA or stochastic frontier analysis (SFA) [66]. The SFA approach has been applied to the dairy processing industry by, for instance, Doucouliagos and Hune [67], Soboh et al. [68], Hirsch et al. [23], Čechura and Žáková Kroupová [8], and Beber et al. [69]. The DEA method has also been widely used in studies on the technical efficiency of dairies in various countries. Table A1 in Appendix A summarizes the literature review on the application of DEA to the dairy processing industry.

Not many papers have been published on the efficiency of the dairy processing industry in Poland. Five such studies using the DEA method [9,70–73] are included in the literature review (Table A1). These studies have addressed the following aspects of dairy efficiency: technical efficiency [73], its changes [9,70,71], and scale efficiency [72]. Furthermore, the aforementioned evaluation of technical efficiency has been supplemented by analyses of selected financial ratios for dairies [9,70,71,73]. The data used in these studies cover a specific region [71,73], a whole country [70,72], or more than one country [9].

The aforementioned studies have examined cooperatives, among other forms of dairy processing entities in Poland. Additionally, Špička [9] has emphasized the significance of cooperatives' prevalence in the Polish dairy industry. As the existing body of literature lacks a comprehensive analysis of the technical efficiency of dairy cooperatives in comparison with other organizational forms of dairies in Poland, our study aims to fill this gap.

Previous studies on the efficiency of dairies vary on many dimensions. While the literature does not provide a complete list of sources of efficiency differences, Berger and Mester [74], though in the context of financial institutions, have indicated three of them: (1) the concept of efficiency employed; (2) the methods used to measure efficiency under these concepts; and (3) potential correlates of efficiency. The third source covers at least partially exogenous characteristics that may explain some of the efficiency differences that remain after controlling for conceptual and measurement issues. Correlates of efficiency include, for example, regulatory, market type, or organizational form [74]. Therefore, following this view, the cooperative as a dominant organizational form of dairies is considered a determinant that may have a significant impact on their (in)efficiency [69].

According to Pietrzak [75], farmer cooperatives can pursue a variety of objectives. They show potential to improve the welfare of farmer-members and society as a whole in comparison with profit-maximizing enterprises (investor-owned firms, IOFs) [75]. It is assumed that differences in objectives and organizational structures between IOFs and cooperatives affect their production technology and technical efficiency [68]. On the one hand, cooperatives are less oriented toward efficient input use (especially members' products) and value-added production than on exploiting economies of scale (Hind, 1999, as cited in [22]). On the other hand, their relatively conservative financial structure, low ownership costs, and the homogeneity of member's interests are recognized as factors that make them succeed [69].

Farmer cooperatives are common and significant commercial organizations in many parts of the world [76]. Previous empirical studies on the technical efficiency of dairy cooperatives and IOFs have indicated that the efficiency of both cooperatives and IOFs can be greater depending on the context, the data employed, and the objective of the performance measured [69]. This provides motivation for further research in this area.

3. Data and Methods

3.1. Data

In this paper, we focus on dairies in Poland (NACE Rev. 2 Class 10.51) that were operating in 2019 and were still active as of 20 February 2021 (thus, excluding entities closed and in liquidation). The data used in this paper were obtained from balance sheets and income statements of dairies for the year 2019 retrieved from the Emerging Markets Information Service database (EMIS) [77]. Considering the scope and type of data required, the following criteria guided the selection of entities for the study: (1) availability of financial statements for the year 2019, and (2) presentation of income statement by nature of expense.

Initially, 116 dairies meeting these criteria were selected, i.e., 71% of 163 dairies operating in 2019 [35]. Entities with missing records were then removed. We also eliminated the outliers due to the sensitivity of efficiency scores to their presence: if there is an outlier among the observations, it can result in a significant reduction in the level of technical efficiency of inefficient units [78,79]. The outliers were identified using output to input ratios [66] according to the following procedure. We identified a unit as an outlier if the value of any of the output to input ratios fell outside the interval of the mean plus/minus three standard deviations. Finally, a sample of 108 dairies was used for the empirical investigation. Taking one output and four inputs in our study, this sample size fully satisfied the rule of thumb for determining the appropriate number of decision-making units (DMUs) in DEA, stating that $n \geq \max\{m \times s, 3(m+s)\}$ where n stands for the number of DMUs, m is the number of inputs, and s is the number of outputs [80]. The sample comprised 65 (60.2%) cooperative and 43 (39.8%) non-cooperative dairies. This corresponded to the structure of dairies in Poland by legal form in 2019 (57.5% and 42.5%, respectively) [77].

Table 1 presents the results of a comparative analysis of the financial ratios for cooperative and non-cooperative dairies in the areas of liquidity, profitability, capital structure, and activity. The Mann–Whitney *U* test was employed for between-group comparisons due to the failure to meet the assumptions of parametric testing. We observed a statistically significant difference between cooperative and non-cooperative dairies in terms of profitability ratios; this applied to ratios based on net profit and operating profit. The profitability ratios were significantly higher in non-cooperative dairies compared to their cooperative counterparts. We also identified statistically significant differences in days receivables outstanding, days payable outstanding, and days inventory outstanding. The Mann–Whitney *U* test revealed that the cooperative dairies managed their inventories more efficiently, collected receivables more quickly, and also paid off their liabilities faster. Nevertheless, as there was no significant difference in the cash conversion cycle between these groups, the above-mentioned differences ultimately canceled out. We also identified a statistically significant difference in the wage efficiency ratio, i.e., non-cooperative dairies generated significantly higher sales revenue per each PLN paid for the labor factor. In the case of liquidity and capital structure ratios, there were no significant differences between the two groups of dairies. Our findings suggest that for cooperative dairies, maintaining financial security is more important than achieving profitability, and this attitude results from their specificity. This is because dairy cooperatives have a bimodal character, i.e., they involve a community of members and are enterprises that this community has established.

The long-term stability of functioning, and thus the ability to achieve the goals for which the cooperatives were instituted, is more important than short-term profit making [75].

Table 1. A comparative analysis of financial ratios for cooperative and non-cooperative dairies for the year 2019 (authors' calculations based on [70,77,81].

Financial Ratio	Formula	Form	*n*	Mean	Med	Mann–Whitney			
						Mean Rank	*U*	*Z*	*p*
		liquidity ratios							
current ratio	current assets/current liabilities	cooperative	65	2.419	1.668	58.00	1170.00	−1.428	0.153
		non-cooperative	43	1.659	1.269	49.21			
cash ratio	cash/current liabilities	cooperative	65	1.026	0.356	59.26	1088.00	−1.942	0.052
		non-cooperative	43	0.455	0.054	47.30			
		profitability ratios							
return on sales	net profit/net sales	cooperative	65	−0.039	0.002	46.80	897.00	−3.141	0.002
		non-cooperative	43	−0.003	0.014	66.14			
return on assets	net profit/total assets	cooperative	65	−0.025	0.003	47.29	929.00	−2.940	0.003
		non-cooperative	43	0.049	0.025	65.40			
return on equity	net profit/equity	cooperative	65	−0.086	0.009	46.66	888.00	−3.198	0.001
		non-cooperative	43	0.162	0.065	66.35			
return on sales II	operating profit/net sales	cooperative	65	−0.037	0.000	45.94	841.00	−3.494	<0.001
		non-cooperative	43	0.001	0.017	67.44			
return on assets II	operating profit/total assets	cooperative	65	−0.023	0.001	46.42	872.00	−3.300	<0.001
		non-cooperative	43	0.052	0.029	66.72			
return on equity II	operating profit/equity	cooperative	65	−0.074	0.009	46.65	887.00	−3.206	0.001
		non-cooperative	43	0.165	0.060	66.37			
		capital structure							
equity to assets ratio	equity/total assets	cooperative	65	0.541	0.571	57.71	1189.00	−1.309	0.191
		non-cooperative	43	0.463	0.526	49.65			
long-term debt to assets ratio	long-term debt/total assets	cooperative	65	0.095	0.076	53.22	1314.00	−0.524	0.600
		non-cooperative	43	0.113	0.056	56.44			
short-term debt to assets ratio	short-term debt/total assets	cooperative	65	0.364	0.347	51.98	1234.00	−1.026	0.305
		non-cooperative	43	0.444	0.392	58.30			
equity to fixed assets ratio	equity/fixed assets	cooperative	65	1.727	1.306	58.48	1139.00	−1.622	0.105
		non-cooperative	43	1.336	1.029	48.49			
		activity ratios							
total asset turnover ratio	net sales/total assets	cooperative	65	2.846	2.730	57.75	1186.00	−1.327	0.184
		non-cooperative	43	2.681	2.377	49.58			
fixed asset turnover ratio	net sales/fixed assets	cooperative	65	10.058	6.200	57.09	1229.00	−1.058	0.290
		non-cooperative	43	10.783	5.053	50.58			
equity turnover ratio	net sales/equity	cooperative	65	5.512	5.008	56.06	1296.00	−0.637	0.524
		non-cooperative	43	5.164	3.602	52.14			
wage efficiency ratio	net sales/labor cost	cooperative	65	9.303	7.966	44.18	727.00	−4.208	<0.001
		non-cooperative	43	17.363	11.730	70.09			
raw material efficiency ratio	net sales/raw materials	cooperative	65	2.643	1.357	52.66	1278.00	−0.750	0.453
		non-cooperative	43	3.120	1.446	57.28			
days inventory outstanding (DIO)	(inventory/net sales) × 365	cooperative	65	16.093	12.884	46.45	874.00	−3.286	0.001
		non-cooperative	43	25.211	20.857	66.67			
days receivables outstanding (DRO)	(short-term receivables/ net sales) × 365	cooperative	65	34.865	32.508	45.42	807.00	−3.706	<0.001
		non-cooperative	43	40.816	39.782	68.23			
days payables outstanding (DPO)	(current liabilities/net sales) × 365	cooperative	65	70.344	42.158	47.92	970.00	−2.683	0.007
		non-cooperative	43	77.130	52.799	64.44			
cash conversion cycle (CCC)	DIO+DRO-DPO	cooperative	65	−19.386	2.915	53.91	1359.00	−0.242	0.809
		non-cooperative	43	−11.103	1.658	55.40			

3.2. Method

Our research design consisted of the following phases: (1) assessment of the technical efficiency of cooperative and non-cooperative dairies in Poland; and (2) examination of the technical efficiency of dairies in the context of spatial disparities in milk production potential.

3.2.1. DEA Method

The technical efficiency of cooperative and non-cooperative dairies in Poland was determined by using DEA, a non-parametric approach used in evaluating the performance of DMUs on the basis of multiple inputs and multiple outputs [12]. This method is described, for example, in [82,83].

In order to evaluate the technical efficiency of dairies in Poland, the constant returns to scale (CRS) model was applied first. Whereas the CRS assumption is regarded as appropriate if all units operate at optimal scale [83], when there are differences in the scale of operation of units, the variable returns to scale (VRS) model is considered more suitable [84]. Therefore, in the next step we applied this approach. Using the VRS specification allowed us to calculate the technical efficiency while excluding scale efficiency (SE) effects [82,83]. The SE score is the result of dividing the technical efficiency (TE) obtained under the CRS assumption by the pure technical efficiency (PTE) score from the VRS model. Thus, differences between CRS and VRS technical efficiency scores indicate the presence of scale inefficiency [52,85]. Under the VRS assumption, scale-inefficient DMUs are compared only with efficient ones of similar size [9,61]. The decomposition of the CRS TE score into the PTE and SE allowed us to determine the extent to which the inefficiency of dairies in Poland is related to management issues and an inappropriate scale size (see [86]).

Within the CRS and VRS assumptions, two approaches (i.e., input oriented and output oriented) can be employed. The choice of orientation should take into account "which quantities (inputs or outputs) the managers have most control over" [83], p. 180. For dairy operations, the input-oriented model has been indicated as being more appropriate [72]. This orientation has also been widely adopted in dairy sector efficiency studies [20,66,72,85]. In the present study, therefore, we followed this approach, viewing the dairies, similarly to [66], as cost minimizers.

One output and four input variables were used in the DEA models. The variables were selected on the basis of the literature review (Table A1). The selected output variable was net sales revenue. Given that dairies may offer a variety of products and data on production in physical terms are not presented in their financial statements, the choice of this variable as the output variable seemed appropriate and reasonable. The input variables were:

- Labor costs—due to the lack of data on labor inputs in physical terms, this cost category represents the factor of production in question; it consists of salaries and social security costs;
- Raw material costs—raw materials are of key importance for dairies; by including this cost category, we refer to the involvement of raw materials, mainly milk, in the production process of dairy products;
- Depreciation expense—capital is one of the major factors of production; given that net sales revenue is used as the output variable, for consistency purposes, depreciation expense is adopted as the input of capital factor due to its flow nature; this cost category can be seen as "the financial value of consumption of the long-term assets" [9], p. 177;
- Other operating costs—including other costs related to the production process.

Table 2 presents the descriptive statistics of the output and input variables.

Table 2. Descriptive statistics of output and input variables; values given in thousands PLN (authors' calculations based on [77]).

Form	Variable	Mean	Med	SD	Min	Max	Q1	Q3
cooperative (n = 65)				output				
	NS	268,525.49	38,130.18	833,695.80	341.98	5,182,216.01	18,958.07	131,452.70
				inputs				
	LC	18,956.04	5282.10	49,499.37	242.75	336,432.51	2707.10	14,289.93
	RM	207,015.94	26,569.23	654,858.48	53.33	4,060,276.85	9255.83	106,025.00
	DE	5063.03	580.20	15,447.84	7.90	96,878.00	193.45	4247.92
	OC	35,502.32	5031.30	107,198.03	109.01	641,033.23	2540.70	20,564.88
non-cooperative (n = 43)				output				
	NS	228,647.14	87,096.48	347,286.35	423.85	1,486,375.50	22,870.88	281,108.00
				inputs				
	LC	13,675.55	6566.71	23,725.76	238.24	131,231.00	2209.23	14,671.11
	RM	144,554.43	48,073.75	224,947.70	95.42	1,192,281.50	14,737.43	175,026.00
	DE	4230.19	1609.79	8957.35	5.46	42,231.00	547.61	3585.27
	OC	56,911.08	12,529.71	116,628.46	140.32	499,853.94	3540.48	51,947.02
total (n = 108)				output				
	NS	252,648.00	60,269.39	680,776.08	341.98	5,182,216.01	21,605.88	191,143.70
				inputs				
	LC	16,853.62	5551.52	41,148.91	238.24	336,432.51	2572.14	14,462.88
	RM	182,147.00	34,267.88	526,600.50	53.33	4,060,276.85	10,448.64	143,293.50
	DE	4731.44	890.42	13,205.95	5.46	96,878.00	250.82	3697.86
	OC	44,026.18	6809.61	111,010.84	109.01	641,033.23	2876.41	26,339.29

Abbreviations: n, number of observations; NS, net sales revenue; LC, labor costs; RM, raw material costs; DE, depreciation expense; OC, other operating costs; Med, median; SD, standard deviation; Min, minimum value; Max, maximum value; Q1, lower quartile; Q3, upper quartile.

3.2.2. Regional Analysis

As part of our research, we also wanted to investigate whether the region in which a dairy is located significantly differentiates the technical efficiency of the DMUs studied. As dairies are the second link in the dairy supply chain and are therefore dependent on the operation of dairy farms, and as the milk production capacity at the level of dairy farms varies spatially in Poland, we first determined the milk production potential of each province in Poland. For this purpose, we used the zero unitarization method [87]. Our approach comprised the following steps:

- Identification of a set of potential diagnostic variables substantively related to the phenomenon under study;
- Selection of diagnostic variables meeting the following statistical criteria: coefficient of variation (CV) at least equal to 0.1; max to min ratio at least equal to 2 [88];
- Normalization of diagnostic variables (all selected variables are stimulants) $X_1, X_2, \ldots, X_s$ according to the following formula [87]:

$$z_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \left(\begin{array}{l} i = 1,2,\ldots,r \\ j = 1,2,\ldots,s \end{array} \right), \quad (1)$$

  where: r—number of objects; s—number of diagnostic variables;
- Determination of a synthetic variable Q_i [87]:

$$Q_i = \frac{1}{s} \sum_{j=1}^{s} z_{ij} \; (i = 1,2,\ldots,\, r) \quad (2)$$

- Division of provinces into three groups (according to the method presented in [87]):

- Group I—provinces with a high level of milk production capacity:

$$Q_i \,\epsilon\, (\max_i Q_i - U,\ \max_i Q_i] \tag{3}$$

- Group II—provinces with a medium level of milk production capacity:

$$Q_i \,\epsilon\, (\max_i Q_i - 2U,\ \max_i Q_i - U] \tag{4}$$

- Group III—provinces with a low level of milk production capacity:

$$Q_i \,\epsilon\, [\min_i Q_i,\ \max_i Q_i - 2U] \tag{5}$$

where:

$$U = \frac{\max_i Q_i - \min_i Q_i}{3} \tag{6}$$

The following variables were selected to assess provinces' milk production capacity: X_1, dairy cow density per 100 ha of agricultural land (in heads); X_2, total cow's milk purchase (in thousands of liters); X_3, share of purchase in milk production (in %); X_4, average milk yield per cow (in liters); X_5, cow's milk production per 1 ha of agricultural land (in liters); X_6, share of cows in farms with more than 50 cows (in %); X_7, average number of cows per farm. All data are for the year 2019 [35,89,90], except for the variable X_7. Due to the lack of more recent data, this variable refers to 2016 [91].

Given the above classification of provinces, each dairy was assigned to an appropriate region (high, medium, or low milk production potential) according to its location. Then, the *H* Kruskal–Wallis test was used to determine the differences in technical efficiency between these three groups of dairies (as the data did not meet the assumptions for parametric testing).

The DEA was conducted using DEAP Version 2.1 [82]. This program has previously been used by Singh et al. [18,92], Gradziuk [71], Ohlan [85,93], Madau et al. [28], Syp and Osuch [57], Silva et al. [60], and Popović and Panić [19], among others, in studies on the efficiency of the dairy sector (whether dairies or dairy farms). Other calculations were performed using IBM SPSS Statistics, version 27. A *p* value less than 0.05 was considered statistically significant.

4. Results and Discussion

4.1. Technical Efficiency of Cooperative and Non-Cooperative Dairies

Table 3 presents the summary statistics for the technical efficiency of the examined dairies. Under the CRS assumption, the TE scores ranged from 0.543 to 1. Although the mean TE score of 0.895 exhibited a high degree of technical efficiency of dairies, this result also indicated that there is still scope for improvement in this area. That is, overall, on average, dairies could proportionally reduce their inputs by 10.5% without reducing their output. For the least efficient dairy, this reduction should be as high as 45.7%.

Table 3. Descriptive statistics of TE scores and results of Mann–Whitney *U* test (authors' calculations based on [77]).

	Form	*n*	Mean	Med	SD	Min	Max	Q1	Q3	Mann–Whitney			
										Mean Rank	*U*	*Z*	*p*
TE	cooperative	65	0.879	0.884	0.081	0.543	1.000	0.832	0.927	48.32	995.50	−2.534	0.011
	non-cooperative	43	0.920	0.932	0.082	0.747	1.000	0.845	1.000	63.85			
	total	108	0.895	0.899	0.084	0.543	1.000	0.839	0.978				

It is generally assumed that cooperatives are less efficient than other legal forms of plants [18]. Due to the specific nature of cooperatives as presented by Soboh et al. [22], cooperative dairies were expected to have a lower value of input-oriented technical efficiency.

Examination of the TE scores by legal form indeed showed that non-cooperative dairies outperformed their cooperative counterparts. The mean and quartile values of the TE scores for non-cooperative dairies exceeded those for cooperatives. In this regard, a Mann–Whitney *U* test indicated that technical efficiency in the group of non-cooperatives was statistically significantly higher than in the group of cooperatives (Table 3).

According to the TE scores, 22 dairies (20.4%) were identified as technically efficient (by efficient units, we mean units for which the efficiency score was 1 and all input and output slack values were zero). In their case, it can be stated that the inputs involved were efficiently consumed in the production process. Most of them (14 out of 22) were non-cooperative dairies. The remaining 86 (79.6%) with TE scores below 1 showed inefficiency in input utilization. For them, it is recommended to make efforts to enhance the efficiency of input use.

The percentage of efficient DMUs was lower in the group of cooperative dairies than in the group of non-cooperative ones. Whereas only 12.3% of the former group of dairies was fully efficient, this was true of almost one third of the latter. In order to examine the association between the legal form of dairy and being technically efficient, a chi-square test of independence was performed. The relationship between the above variables was found to be statistically significant (Table 4). Thus, non-cooperative dairies were more likely to be technically efficient than cooperative ones. In this context, however, it should be noted that the examination of the TE scores of only inefficient dairies did not reveal statistically significant differences between cooperatives and non-cooperatives ($U = 707.50$, $Z = -1.087$, $p = 0.277$).

Table 4. Sample structure according to TE scores (authors' calculations based on [77]).

Form	TE		χ^2	*df*	*p*
	Efficient	**Inefficient**			
cooperative	8 (12.3%)	57 (87.7%)	6.543	1	0.011
non-cooperative	14 (32.6%)	29 (67.4%)			

Note: row percentages are given in parentheses.

While the analysis of the TE scores provides an insight into the overall technical efficiency, its decomposition into PTE and SE gives us additional valuable information on the efficiency performance of the dairies studied. As shown in Table 5, the PTE scores were at least as high as the TE scores, which is in line with the theory that the VRS frontier is more flexible and envelops the data points more tightly than the CRS frontier [51,86]. The mean PTE score reached 0.935, suggesting that given the scale size, the examined dairies could reduce their input consumption proportionally by 6.5% without altering their output. The least efficient DMU had a PTE score of 0.549, indicating the need for a proportional reduction in inputs of 45.1%.

Table 5. Descriptive statistics of PTE scores and results of Mann–Whitney *U* test (authors' calculations based on [77]).

	Form	*n*	Mean	Med	SD	Min	Max	Q1	Q3	Mann–Whitney			
										Mean Rank	*U*	*Z*	*p*
PTE	cooperative	65	0.926	0.949	0.083	0.549	1.000	0.877	1.000	49.81	1092.50	−1.957	0.050
	non-cooperative	43	0.947	0.994	0.075	0.755	1.000	0.902	1.000	61.59			
	total	108	0.935	0.958	0.080	0.549	1.000	0.881	1.000				

The examination of the PTE scores by legal form did not reveal statistically significant differences between non-cooperative dairies and their cooperative counterparts (Table 5). This result is similar to Singh et al. [18] using the DEA method.

According to the PTE scores, 38 (35.2%) dairies were identified as efficient (PTE = 1) and 70 (64.8%) as inefficient (PTE < 1). There was a significant relationship between being technically efficient (in terms of PTE) and the legal form of the dairy in question. The non-cooperative dairies were more likely to be efficient than the cooperative ones. Whereas in the group of cooperative dairies about one in four units was fully efficient, in the group of non-cooperatives it was almost half (Table 6). It should be added, however, that when comparing the PTE scores of only inefficient dairies by legal form, no statistically significant differences were found between cooperatives and non-cooperatives ($U = 516.00$, $Z = -0.152$, $p = 0.879$).

Table 6. Sample structure according to PTE scores (authors' calculations based on [77]).

Form	PTE		χ^2	*df*	*p*
	Efficient	Inefficient			
cooperative	17 (26.2%)	48 (73.8%)	5.84	1	0.016
non-cooperative	21 (48.8%)	22 (51.2%)			

Note: row percentages are given in parentheses.

A more in-depth look at the efficiency reference set (under the VRS assumption), which serves as a benchmark for inefficient DMUs, allowed us to identify the best-practice dairies. Concerning the reference set frequency, the "best performer" (with the highest frequency of 64) was the small dairy from the Wielkopolskie province. The second and third places belonged to the medium dairies from the provinces of Śląskie and Lubelskie (with frequencies of 21 and 20, respectively). All these dairies were non-cooperatives. Of 38 VRS technically efficient dairies, seven (four cooperatives and three non-cooperatives) were never reported as a reference point for inefficient dairies. Another seven (three cooperatives and four non-cooperatives) had a frequency of 1 or 2 in the reference set. Due to a low peer count number, these dairies can hardly be considered best-practice entities.

A more detailed analysis, focusing on the differences between the actual and the target values (under the VRS assumption) of the variables used (taking into account the slacks; slacks represent the remaining inefficiency left after a proportional reduction in inputs or outputs if the DMU cannot achieve the efficiency frontier [94]), was undertaken to reveal the extent to which inefficient dairies should reduce each of the given inputs (no slacks in output were observed) to become efficient. The analysis of inefficiencies in relation to the inputs used in the production process can provide important insights for managers, enabling them to make better decisions [95].

According to the results, the inefficient dairies should reduce their labor costs, raw material costs, depreciation expense, and other operating costs, on average, by 25.0%, 10.1%, 20.8%, and 10.1%, respectively. Therefore, the greatest capacity for improvement can be observed in labor costs and depreciation expense. Given that inefficient dairies could achieve the same output with lower depreciation expense, the above result may suggest that they are not utilizing their fixed assets fully efficiently. Similar to the results of Vlontzos and Theodoridis [20] with regard to the Greek dairy industry, inefficient dairies appear to be overinvested. As Beber et al. [69] have pointed out, it is critical to avoid unplanned overinvestment that could lead to idle capacity. Another possible explanation for this result is that dairies need to maintain spare capacity because of the perishability of their raw materials and products. The issue that seems to be more challenging in the course of business is the reduction of labor costs.

At the aggregate level, that is, considering the total value of inputs consumed by inefficient units, labor costs, raw material costs, depreciation expense, and other operating costs should be reduced by 23.3%, 6.1%, 20.7%, and 6.9%, respectively.

As presented in Table 7, there were no statistically significant differences between cooperatives and non-cooperatives in terms of their potential for input reduction.

Table 7. Potential input reduction in inefficient dairies by legal form (authors' calculations based on [77]).

Input	Form	Potential Input Reduction (%)			Mann–Whitney		
		Mean	Med	Mean Rank	*U*	*Z*	*p*
LC	cooperative	26.1	24.8	34.15	463.00	−0.822	0.411
	non-cooperative	22.4	22.2	38.45			
RM	cooperative	10.0	7.7	35.75	516.00	−0.152	0.879
	non-cooperative	10.3	9.6	34.95			
DE	cooperative	18.7	12.5	36.33	488.00	−0.506	0.613
	non-cooperative	25.5	17.3	33.68			
OC	cooperative	10.0	7.7	35.75	516.00	−0.152	0.879
	non-cooperative	10.3	9.6	34.95			

By comparing the results of the three efficiency scores, i.e., TE (Table 3), PTE (Table 5), and SE (Table 8), it can be observed that the technical inefficiency of the dairies was driven slightly more by managerial inefficiency than by scale inefficiency. This is indicated by the lower mean PTE score accompanied by a higher coefficient of variation. Our results are similar to those of Lima et al. [46] but different from those of Ohlan [85]. As shown in Tables 3, 5 and 8, this observation applies to both cooperative and non-cooperative dairies. In this regard, it should be noted that insufficient knowledge and skills of managers are identified as one of the internal barriers to the development of the dairy processing sector [96,97].

Table 8. Descriptive statistics of SE scores (authors' calculations based on [77]).

	Form	*n*	Mean	Med	SD	Min	Max	Q1	Q3
SE	cooperative	65	0.951	0.962	0.048	0.818	1.000	0.923	0.993
	non-cooperative	43	0.971	0.989	0.042	0.803	1.000	0.957	1.000
	total	108	0.959	0.977	0.046	0.803	1.000	0.930	0.999

The analysis of returns to scale revealed that the majority of the examined dairies (63.0%) were operating under decreasing returns to scale, implying that these DMUs could enhance their overall technical efficiency by reducing their size (Table 9). The results also indicate that 17 DMUs (15.7%) were experiencing increasing returns to scale, meaning that they were operating below their optimal scale size. Therefore, there is scope for them to improve their technical efficiency by increasing their size. Of the 108 dairies, 23 (21.3%) were operating at optimal scale. Our results in this regard differ from those of Baran [72], according to which, in the years 1999–2010, on average 69% of dairy firms experienced increasing returns to scale, while 22% presented decreasing returns to scale. This may suggest that the possibility of improving technical efficiency through the concentration of the dairy sector and increasing the scale of dairy production in Poland has been exploited. The process of concentration of the milk processing sector in Poland started about 25 years ago [32]. In addition, Poland's accession to the EU intensified competition on the milk market [96], which was a driving force for further concentration. This process was initiated mainly by large dairies, which took over smaller units, thus increasing their territorial range and the amount of milk processed. Large dairies began to specialize their plants in the production of technologically similar products [96]. In this regard, it is worth noting that specialization of dairies may result in a decrease in the number of products they offer [31]. In light of the structural changes in the milk processing sector, small dairies need to seek their market niche by, for example, producing regional products [96].

Table 9. Types of returns to scale by legal form of dairy (authors' calculations based on [77]).

Form	drs	crs	irs	χ^2	*df*	*p*
cooperative	46 (70.8%)	8 (12.3%)	11 (16.9%)	7.92	2	0.019
non-cooperative	22 (51.2%)	15 (34.9%)	6 (14.0%)			
total	68 (63.0%)	23 (21.3%)	17 (15.7%)			

Abbreviations: drs, decreasing returns to scale; crs, constant returns to scale; irs, increasing returns to scale. Note: row percentages are given in parentheses.

As can be observed from Table 9, non-cooperative dairies were considerably more likely to be scale efficient, presenting a higher frequency of constant returns to scale than their cooperative counterparts. While the majority of both cooperatives and non-cooperatives showed decreasing returns to scale, the proportion of such units was higher for cooperatives. The relationship between these variables was statistically significant.

To summarize our findings, similarly to Mahajan et al. [98], we grouped the DMUs according to their technical, pure technical, and scale efficiency scores (Table 10).

Table 10. Classification of dairies according to TE, PTE, and SE scores (authors' elaboration).

Case	TE = 1	TE < 1		
		PTE = 1 SE < 1	PTE < 1 SE = 1	PTE < 1 SE < 1
total	22 (20.4%)	16 (14.8%)	1 (0.9%)	69 (63.9%)
cooperatives	8 (7.4%)	9 (8.3%)	0 (0.0%)	48 (44.4%)
non-cooperatives	14 (13.0%)	7 (6.5%)	1 (0.9%)	21 (19.4%)
Recommendation	no action required	adjustment in the scale of operations	improvement in managerial performance	both adjustment in the scale of operations and improvement in managerial performance

Note: percentages for the whole sample are given in parentheses.

4.2. Technical Efficiency of Cooperative and Non-Cooperative Dairies: The Spatial Perspective

In order to ascertain whether the technical efficiency of dairies is spatially differentiated, we divided the provinces of Poland into three groups, i.e., provinces with high, medium, or low milk production capacity. For this purpose, we first assessed the milk production capacity of each province using the zero unitarization method on the basis of the following diagnostic variables: X_1, dairy cow density per 100 ha of agricultural land (in heads); X_2, total cow's milk purchase (in thousands of liters); X_3, share of purchase in milk production (in %); X_4, average milk yield per cow (in liters); X_5, cow's milk production per 1 ha of agricultural land (in liters); X_6, share of cows in farms with more than 50 cows (in %); X_7, average number of cows per farm. Table 11 presents the descriptive statistics for selected diagnostic variables.

Table 11. Descriptive statistics of diagnostic variables (authors' calculations based on [35,89–91]).

Variable	Mean	Med	SD	CV	Min	Max	Max/Min
X_1	12.83	10.85	9.25	0.72	2.80	40.20	14.36
X_2	739,243.69	294,841.00	826,913.82	1.12	77,853.00	2,604,942.00	33.46
X_3	82.80	85.55	11.73	0.14	47.36	94.02	1.99
X_4	5129.50	5416.50	1200.12	0.23	2678.00	6760.00	2.52
X_5	796.63	546.00	613.09	0.77	190.00	2579.00	13.57
X_6	28.03	29.28	13.91	0.50	6.60	53.14	8.05
X_7	0.18	0.13	0.14	0.77	0.04	0.46	12.87

Note: X_3 variable had a max/min ratio of slightly less than 2; however, due to the substantive importance of this variable, we decided to include it in the set of diagnostic variables.

The values of the synthetic variable of milk production capacity and the resulting classification of provinces are given in Table 12 and Figure 1. Based on these results, we assigned cooperative and non-cooperative dairies to distinguished groups of provinces according to their location (i.e., dairies located in a region of low, medium, or high milk production capacity).

Table 12. Values of the synthetic variable and classification of provinces by milk production capacity (authors' calculations based on [35,89–91]).

Rank	Province	Q_i	Group
1	Podlaskie	0.7541	I: high milk production capacity
2	Mazowieckie	0.6077	
3	Wielkopolskie	0.5964	
4	Opolskie	0.5131	II: medium milk production capacity
5	Dolnośląskie	0.4592	
6	Kujawsko-Pomorskie	0.4582	
7	Warmińsko-Mazurskie	0.4581	
8	Śląskie	0.4180	
9	Łódzkie	0.4095	
10	Zachodniopomorskie	0.4016	
11	Lubuskie	0.3764	
12	Pomorskie	0.3627	
13	Lubelskie	0.3083	III: low milk production capacity
14	Świętokrzyskie	0.2550	
15	Podkarpackie	0.2300	
16	Małopolskie	0.1169	

Group I : $Q_i \in (0.5417;\ 0.7541]$
Group II : $Q_i \in (0.3293;\ 0.5417]$
Group III : $Q_i \in [0.1169;\ 0.3293]$

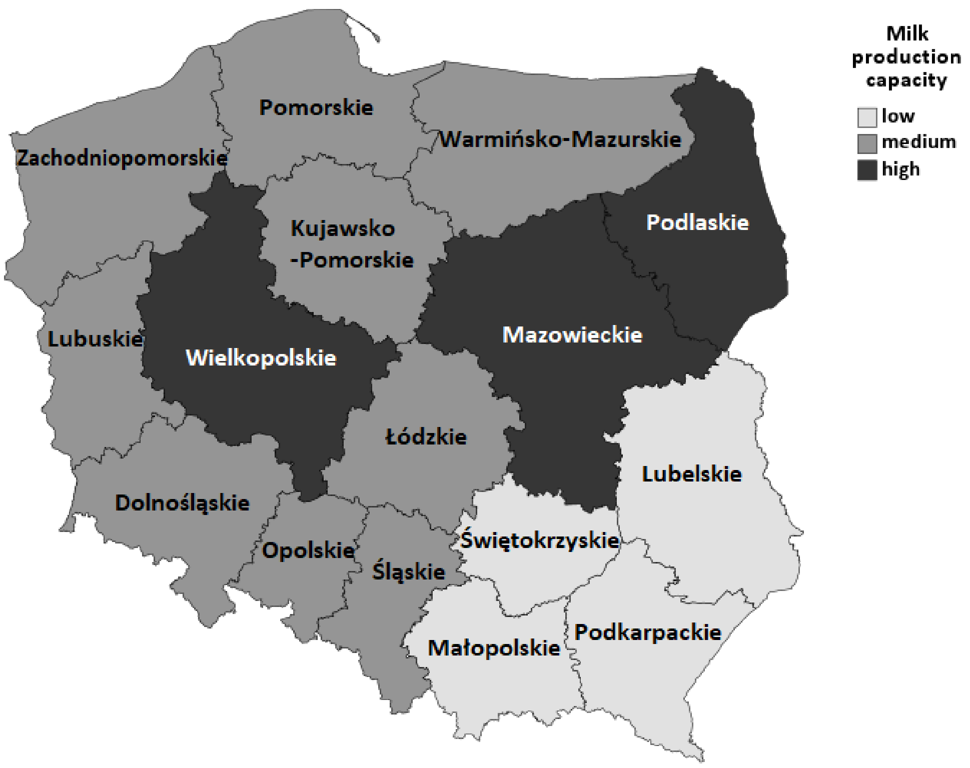

Figure 1. Milk production capacity by province (authors' elaboration based on data from Table 12).

The *H* Kruskal–Wallis test showed that there was no statistically significant difference in technical efficiency scores (in terms of PTE)—this conclusion also held under the CRS assumption—between these three groups of dairies (Table 13). This finding held for both cooperative and non-cooperative DMUs, suggesting that the environmental factor of a region's capacity to produce milk does not significantly differentiate the efficiency of dairies in converting inputs into output. It has been recognized that milk plants prefer milk surplus areas that have higher milk production than their respective milk demand [18], hence we argue that the environmental conditions of a region may influence the location of the dairy processing industry [99]. Moreover, they may affect issues such as the marketability of milk production [25], the organization of raw material transportation, and thus transportation costs and milk prices [100], and the technological quality of milk purchased by dairies [101]. In summary, while the environmental factor may influence the above-mentioned aspects of dairy processors' functioning, we found no evidence of significant difference in PTE scores between groups of dairies distinguished by their location (i.e., dairies located in a region of low, medium, or high milk production capacity).

Table 13. Results of PTE scores analysis for cooperative and non-cooperative dairies by region of location (authors' calculations based on [35,77,89–91]).

	Milk Production Capacity of Region	*n*	Mean	Med	Kruskal–Wallis			
					Mean Rank	*H*	*df*	*p*
cooperative	low	9	0.919	0.924	27.06	1.051	2	0.591
	medium	30	0.930	0.951	33.93			
	high	26	0.924	0.955	33.98			
non-cooperative	low	5	0.990	1.000	29.40	2.482	2	0.289
	medium	19	0.944	0.987	20.05			
	high	19	0.940	1.000	22.00			

5. Conclusions

This paper has examined the technical efficiency of dairies in Poland on the basis of data for the year 2019. Given that the Polish dairy processing industry is predominated by cooperatives, our research has focused on comparing their technical efficiency with that of dairies of other legal forms, thereby contributing to the scientific debate on this issue. Due to the inherent link between dairy operations and their access to raw materials, this study has additionally explored the technical efficiency of dairies in the context of spatial disparities in milk production potential. Thus, we have provided insights into the technical efficiency of dairies from a supply chain perspective. To our knowledge, such an analysis has not previously been conducted.

We have investigated the technical efficiency of dairies using the DEA method by taking net sales revenue as the output and labor costs, raw material costs, depreciation expense, and other operating costs as the input variables. The estimates of efficiency scores were obtained under the CRS and VRS assumptions. We have also identified the types of returns to scale of the given dairies. In order to examine the technical efficiency of the dairies in relation to the milk production capacity of the region in which they are located, we have used the zero unitarization method, dividing the provinces of Poland into three groups: provinces with high, medium, or low milk production capacity.

The results indicate that, assuming CRS, the level of technical efficiency of the dairy processing sector in Poland was on average 0.895. In this regard, we found that non-cooperative dairies were significantly more efficient than cooperatives.

In the search for sources of inefficiencies, in the next step we examined the results for pure technical efficiency and scale efficiency. The PTE score was on average 0.935. On this point, the differences between non-cooperatives and cooperatives were not statistically significant. Thus, when referring to managerial performance in converting inputs into output, we found no evidence of lower efficiency in dairy cooperatives. For both the TE and PTE scores, dairy non-cooperatives revealed a greater proportion of units identified as efficient. However, it is important to note the limitations of such a zero-one approach, as an entity may not be fully efficient (with an efficiency score of 1) and yet still exhibit high efficiency.

According to our results, inefficient dairies presented the greatest potential for reducing labor costs and depreciation expense. This implies that dairies in Poland could reduce these costs while maintaining the same level of output. We did not identify significant differences in potential for input reduction between cooperatives and non-cooperatives.

About one in five of all the dairies studied were scale efficient. For non-cooperative dairies, the proportion of such units was nearly three times that of cooperatives. Most dairies showed decreasing returns to scale, meaning that they were too large relative to their optimal scale. This observation applied to both cooperative and non-cooperative dairies; however, the former group showed a higher proportion of units operating under decreasing returns to scale. The prevalence of dairies exhibiting decreasing returns to scale may be a result of the intensification of the concentration process in the milk processing sector, caused in particular by Poland's accession to the EU. Our results can be perceived as a sign of the saturation of the dairy sector in Poland with the consolidation process. Therefore, in light of the above, the continuation of this process does not seem to be recommended as far as technical efficiency is concerned. Due to structural changes in the milk processing sector, small dairies need to find a market niche if they want to compete with large units.

The examination of the PTE scores taking into account the spatial disparities in milk production potential did not provide evidence for the claim that the technical efficiency of dairies was affected by the milk production capacity of their location region. This finding indicates that although the availability and abundance of raw milk may affect the density of and the competition among dairies, they do not significantly differentiate their technical efficiency.

The results suggest some directions for further research. Given that only one year of data was used in this study, it would be valuable to examine the technical efficiency of cooperative and non-cooperative dairies in Poland over a longer period of time. Moreover, in further research it would be beneficial to investigate technical efficiency from a supply chain perspective more broadly, i.e., taking into account the distribution conditions as the next link in the supply chain. Such a perspective would provide a more holistic view regarding the efficiency of the dairy sector in Poland. Another possible stream of research would consider the economic sustainability of the Polish dairy supply chain in association with its environmental and social dimensions.

Author Contributions: Conceptualization, K.Z.-K., M.Z.-C. and J.N.; methodology, K.Z.-K., M.Z.-C. and J.N.; software, K.Z.-K.; validation, K.Z.-K. and J.N.; formal analysis, K.Z.-K.; investigation, K.Z.-K., M.Z.-C. and J.N.; resources, K.Z.-K., M.Z.-C. and J.N.; data curation, K.Z.-K., M.Z.-C. and J.N.; writing—original draft preparation, K.Z.-K., M.Z.-C. and J.N.; writing—review and editing, K.Z.-K., M.Z.-C. and J.N.; visualization, K.Z.-K.; project administration, K.Z.-K.; funding acquisition, K.Z.-K. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by The John Paul II Catholic University of Lublin, grant number 1/6-20-21-05-0501-0002-0593.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: EMIS data: restrictions apply to the availability of these data; data obtained from EMIS are available from the authors with the permission of EMIS. Publicly available datasets were also analyzed in this study. These data can be found here: https://stat.gov.pl/ (accessed on 6 November 2021); https://ec.europa.eu/eurostat/data/database (accessed on 2 November 2021).

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

Appendix A

Table A1. Review of literature (authors' elaboration based on source publications).

Source Publication	DEA Model	Output Variables	Input Variables	Sample	Year/Period	Country
Singh et al. (2001) [18]	VRS, IO	(1) aggregate dairy products' variable	(1) raw material (mainly raw milk); (2) labor; (3) capital—depreciation, repairs, maintenance, and interests of the machinery and building; (4) other inputs (administration, fuel, power, insurance, etc.)	13 cooperative and 10 private dairy plants from Haryana and Punjab states	1992/93 and 1996/97	India
Baran and Kołyska (2009) [70]	M	(1) net sales revenue	(1) number of staff; (2) fixed assets	205–248 dairy processing firms, including cooperatives	1998–2005	Poland
Gradziuk (2009) [71]	CRS, VRS, OO; M	(1) net sales revenue	(1) sum of depreciation, material and energy consumption, and contracted services costs; (2) labor costs	12 large dairy processing companies from the Mazowieckie province	2001–2007	Poland
Soboh et al. (2012) [22]	VRS, IO	(1) total turnover	(1) fixed assets; (2) material costs; (3) labor costs	133 dairy processing companies: 90 investor-owned firms and 43 cooperatives	2004	Belgium, Denmark, France, Germany, Ireland, the Netherlands
Baran (2013) [72]	CRS, VRS, IO	(1) net sales revenue	(1) labor costs; (2) costs of material and energy consumption; (3) fixed assets	743 observations of dairy processing firms, including cooperatives	1999–2010	Poland
Ohlan (2013) [85]	CRS, VRS, IO	(1) net value added	(1) fixed capital; (2) working capital; (3) labor; (4) raw materials; (5) fuel	Data obtained from Annual Survey of Industry, Ministry of Commerce and Industry, Government of India	1980–2008	India
Kapelko and Oude Lansink (2013) [66]	VRS, IO	(1) turnover	(1) employee costs; (2) material costs; (3) fixed assets	Unbalanced panel of 3509 observations of 264–380 dairy processing firms	2000–2009	Spain
Vlontzos and Theodoridis (2013) [20]	CRS, VRS, IO, M	(1) revenue; (2) mixed profit	(1) overall depreciation; (2) costs of sold products; (3) shared capital; (4) value of stock; (5) short-term liabilities	29 dairy companies, 20% of them cooperatives	2006–2007 for CRS, VRS, IO; 2003–2007 for M	Greece

Table A1. *Cont.*

Source Publication	DEA Model	Output Variables	Input Variables	Sample	Year/Period	Country
Domańska et al. (2015) [73]	VRS, IO	(1) net sales revenue	(1) fixed assets; (2) number of staff	12 dairy processing companies from the Lubelskie province, including 10 cooperatives	2010–2012	Poland
Špička (2015) [9]	VRS, IO, M	(1) sales revenue	(1) material and energy costs; (2) staff costs; (3) depreciation and amortization	130 dairy processors	2008–2013	Czech Republic, Poland, Slovakia
Lima et al. (2018) [46]	CRS, VRS, IO, MS	(1) revenue	(1) payroll; (2) processed milk volume; (3) boiler, fuel, and electricity costs	40 dairy establishments, of which 85% were private and 15% were cooperatives	2014/2015	Brazil
Popović and Panić (2019) [19]	VRS, IO, MS	(1) sales revenue	(1) costs of material (mainly raw milk); (2) labor costs; (3) energy costs; (4) other costs (depreciation, costs of purchased commodities, contracted services, non-material costs, and interest paid)	79 non-cooperative dairy processing companies	2016	Serbia
Ruales Guzmán et al. (2021) [102]	VRS, IO, OO	(1) revenue (2) profit	(1) current assets; (2) property, plant, and equipment; (3) non-current liabilities; (4) equity	19 dairy industry companies	2017	Colombia

Note: CRS, constant returns to scale; VRS, variable returns to scale; IO, input-oriented; OO, output-oriented; M, Malmquist; MS, multi-stage model.

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