Scientific Annals of Economics and Business
72 (X), 2025, 1-23
DOI: 10.47743/saeb-2025-0028

Assessing Operational and Investment Efficiency in the Greek Dairy Industry: A DEA-Based Composite Model

Athanasia Mavrommati*, Fotios Chatzitheodoridis, Alexandra Pliakoura***, Stavros Kalogiannidis§**

Abstract: This study evaluates the efficiency of Greek dairy industry enterprises using a two-stage approach with Data Envelopment Analysis (DEA). The production model analyzes inputs such as personnel, net fixed assets, and operating expenses in relation to outputs like revenues and gross profits, while the investment model examines capital and investment management, assessing inputs such as depreciation and investment expenses against investment returns and EBITDA. The results reveal significant efficiency differences among the enterprises, with a small percentage achieving full efficiency and serving as benchmarks, while many firms display considerable room for improvement, particularly in resource management and investment strategies. Slack analysis identifies areas where excessive inputs can be reduced without affecting output, while the integration of the production and investment models highlights the need for better alignment between these two aspects of efficiency. The findings highlight opportunities for improvement through targeted resource management, sustainable practices, and collaboration within the sector. Policymakers are encouraged to support these efforts through incentives, funding tools, and the promotion of clusters. These insights provide actionable recommendations to enhance competitiveness, foster innovation, and ensure the sustainable development of the Greek dairy industry.

Keywords: two-stage DEA; operational efficiency; investment efficiency; dairy industry; Greece.

JEL classification: C23; Q12; Q14.

* Department of Food Science and Technology, University of Patras, Greece; e-mail: *amavrom@upatras.gr*.
** Department of Management Science and Technology, Faculty of Economic Sciences, University of Western Macedonia, Greece; e-mail: *fxtheodoridis@uowm.gr* (corresponding author).
*** Department of Food Science and Technology, University of Patras, Greece; e-mail: *pliakouralex@gmail.com*.
§ Department of Business Administration, School of Economic Sciences, University of Western Macedonia, Greece; e-mail: *skalogiannidis@uowm.gr*.

Article history: Received 23 January 2025 | Accepted 18 July 2025 | Published online 18 September 2025

To cite this article: Mavrommati, A., Chatzitheodoridis, F., Pliakoura, A., Kalogiannidis, S. (2025). Assessing Operational and Investment Efficiency in the Greek Dairy Industry: A DEA-Based Composite Model. *Scientific Annals of Economics and Business*, 72(X), 1-23. https://doi.org/10.47743/saeb-2025-0028.

1. INTRODUCTION

The dairy industry is one of the most dynamic and strategically important sectors of the agri-food sector, making a substantial contribution to the global economy, human nutrition and sustainable development. According to Fao (2023), global milk production exceeds 900 million tons per year, with India, the United States and the European Union being the main producers. The growing demand for dairy products with high nutritional value and innovation in production are leading to steady growth in the sector (Hill, 2024).

In Europe, the dairy industry represents around 15% of total agricultural production, with countries such as Germany, France and the Netherlands playing a leading role. At the same time, strict quality regulations and a shift towards sustainable practices are strengthening the international competitiveness of European dairy products (Bórawski *et al.*, 2020); Eurostat, 2023).

The Greek dairy industry, with deep roots in tradition, develops by combining small-scale local production with large-scale industrial activity (Ghadge *et al.*, 2017). At the same time, industry faces challenges, such as increasing production costs due to inflationary pressures, changes in consumer preferences and the need to adapt to modern sustainability requirements. However, Greek dairy industries are investing in innovation, introducing new production technologies and diversifying their products to respond to international market trends (Koutouzidou *et al.*, 2022). Large companies control approximately 90% of the market, while smaller units serve local needs and maintain cultural tradition (Icap. CRIF, 2023). Basic products, such as strained yogurt, occupy a dominant position in exports, representing 73.8% of the sector's total exports.

Figure no. 1 shows the changes in the consumption of different categories of milk in Greece for the year 2023. We observe that fresh pasteurized milk recorded a decrease of 9.7%, while categories such as highly pasteurized milk and milk drinks recorded increases. This reflects the changing consumer trends in the Greek market.

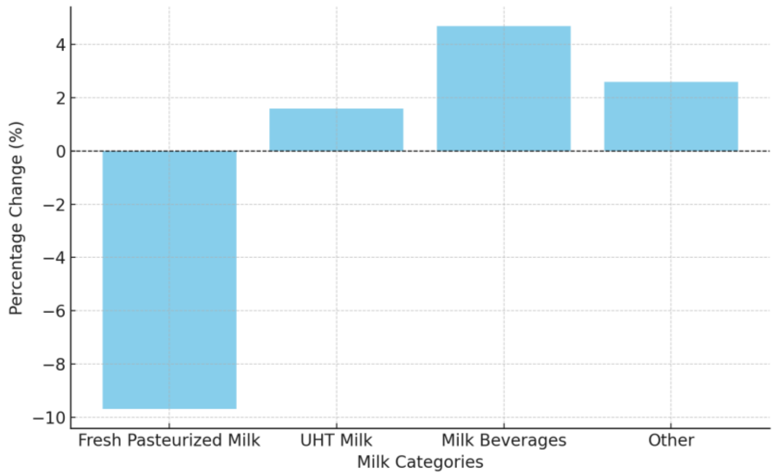

Figure no. 1 – Changes in Milk consumption in Greece (2023)

Source: *Icap. CRIF (2023)*

Figure no. 2 shows the evolution of Greek yogurt exports during the period 2018-2023. Greek yogurt exports remain at high levels, recording a slight increase from 2018 to 2023. Yogurt continues to be a key export product of the Greek dairy industry, strengthening its international competitiveness. The decline in Greek yogurt exports in 2022 is mainly due to the increase in production costs due to inflation and the energy crisis, intense competition from other countries, and supply chain disruptions following the pandemic. At the same time, changes in consumer preferences towards plant-based yogurts and the strengthening of local production in importing countries have affected demand.

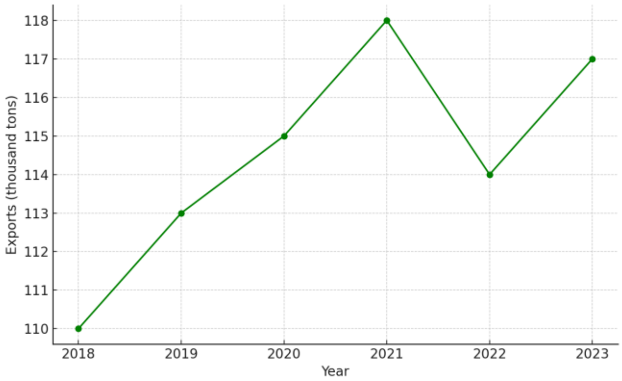

Figure no. 2 – Greek yogurt exports (2018-2023)

Source: *Icap. CRIF (2023)*

Figure no. 3 shows the evolution of milk production in Greece from 2013 to 2023. Milk production in Greece has shown a steady decline over the period 2013-2023, mainly due to structural changes in the sector and reduced demand. This trend reflects the challenges facing the sector, such as increasing production costs and changing consumer preferences.

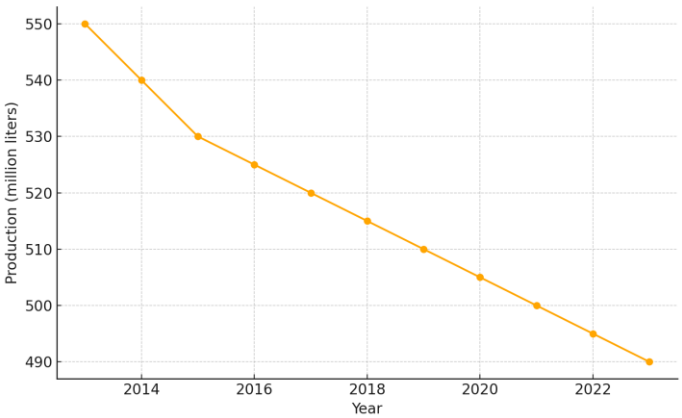

Figure no. 3 – Milk production in Greece (2018-2023)

Source: *Icap. CRIF (2023)*

The decline in milk production in Greece in recent years is due to factors such as the increase in production costs, the decrease in the number of livestock units, the aging of the population involved in livestock farming, climate change and changes in consumer habits, such as the shift to plant-based beverages. At the same time, the lack of strategic support for the sector and structural difficulties intensifies the problem. These conditions make it necessary to analyze the financial data of companies in the sector, to evaluate the productivity of their investments and enhance the efficiency of their operation. Such an approach can provide valuable guidance for improving the competitiveness and sustainability of the sector.

The challenges faced by the Greek dairy industry highlight the critical need for targeted strategic adjustments that will enhance its competitiveness in an ever-changing international environment. The necessity of investments in advanced technologies is of vital importance, as these can contribute to increasing productivity and effectively managing available resources (Koutouzidou *et al.*, 2022). At the same time, the adoption of sustainable practices aligned with global sustainability trends, such as reducing the environmental footprint and implementing circular production models, is essential for maintaining international competitiveness (Bórawski *et al.*, 2020; Pliakoura *et al.*, 2024b).

Furthermore, the cultural value of Greek dairy products, which combine the uniqueness of local raw materials with centuries-old tradition and expertise, can be leveraged as a strategic advantage for international differentiation (Ghadge *et al.*, 2017). Harnessing this identity offers opportunities for penetration into new markets, particularly among consumers seeking high-quality products with an authentic character.

Simultaneously, the analysis of the sector's efficiency assumes a pivotal role, as it enables a scientific understanding of resource utilization, production operations, and investment profitability. Through tools such as Data Envelopment Analysis (DEA), the quantitative evaluation of efficiency is possible at various levels, from operational to regional. Such analyses provide valuable data for policymaking and strategic decisions, ensuring a balance between tradition and innovation while laying the groundwork for the sector's long-term sustainable development (Gardijan and Lukać, 2018; Mavrommati *et al.*, 2024).

While previous studies have examined either production or investment efficiency in agrifood sectors using DEA, the integration of both dimensions into a unified efficiency assessment remains limited, especially in the context of the dairy industry. This paper addresses this gap by applying two DEA models to separately evaluate operational and investment efficiency and then combining their outputs into a composite model that reflects overall performance. In doing so, the study contributes to the literature by offering a comprehensive approach to efficiency analysis and providing practical insights for both policymakers and business decision-makers in the Greek dairy sector.

The remainder of this paper is organized as follows: Section 2 presents the relevant literature on the application of DEA analysis in the food and dairy industries. Section 3 describes the methodology and data used for the analysis, while Section 4 presents and analyzes the results. Finally, Section 5 discusses the findings, and Section 6 provides conclusions and policy recommendations.

2. LITERATURE REVIEW

Data Envelopment Analysis (DEA) is one of the most widely used efficiency assessment tools, introduced by Charnes *et al.* (1978). This method allows simultaneous analysis of multiple inputs and outputs, facilitating the evaluation of the efficiency of decision-making units (DMUs). The flexibility of DEA makes it ideal for the food and dairy industry, and it can be adapted to incorporate external factors, such as environmental indicators and regulatory requirements, providing a more multidimensional picture of efficiency (Halkos and Petrou, 2019; Hermoso-Orzáez *et al.*, 2020).

This method has become much more common, with 82% of the relevant publications recorded in the period 2013–2019. This reflects the growing acceptance and adoption of the method in new areas, such as environmental efficiency and sustainability analysis (Emrouznejad and Yang, 2018). Although DEA is widely applied in industries such as tourism, financial services, and healthcare, its use in the food industry remains relatively limited (Karakitsiou *et al.*, 2007; Lukač and Gardijan, 2017; Mavrommati *et al.*, 2022; Chrysanthopoulou *et al.*, 2023; Mavrommati *et al.*, 2024). This can be attributed to factors such as the lack of specialized data and tools, as well as the reduced adoption of the method by small and medium-sized enterprises that often dominate the agri-food sector (Liu *et al.*, 2013). Despite these challenges, DEA remains a flexible and powerful tool for analyzing multidimensional data, making it ideal for improving efficiency and sustainability in this field (Halkos and Petrou, 2019; Mavrommati *et al.*, 2021).

In literature, the "Food and Beverage" sector attracts great interest, as it is a crucial pillar of the global economy (Karakitsiou *et al.*, 2004; Mavrommati and Migdalas, 2005; Mavrommati and Papadopoulos, 2005; Assaf and Matawie, 2009; Karakitsiou and Mavrommati, 2009; Chatzitheodoridis *et al.*, 2013; Kapelko and Oude Lansink, 2022; Pliakoura *et al.*, 2024a). The use of DEA in this sector has proven to be particularly effective for analyzing efficiency at various levels, such as production, distribution and sustainability. For example, Assaf and Matawie (2009) developed a two-stage approach to assess operational and financial efficiency in the food industry in Australia, offering valuable suggestions for improvement. Similarly, Liu *et al.* (2022) used Two-Stage DEA to analyze environmental efficiency in the Chinese industrial sector, focusing on the interaction of inputs and environmental parameters. Furthermore, Yang and Ma (2019) examined efficiency in vegetable agricultural production, demonstrating the multidimensional application of DEA in agricultural and industrial production. Although the method is widely used, more research is needed in specific sectors and markets with high demands for sustainability and efficiency (Chatzitheodoridis *et al.*, 2016; Kalfas *et al.*, 2024; Kalogiannidis *et al.*, 2024).

The dairy industry is one of the most interesting areas of application of DEA, even though it has been less studied compared to other categories of the food industry. Theodoridis and Psychoudakis (2008) used DEA and Stochastic Frontier Analysis (SFA) to evaluate 165 Greek dairy farms, identifying significant room for improvement through better resource management. Vlontzos and Theodoridis (2013) investigated the efficiency and productivity change in the Greek dairy industry, identifying fluctuations that affect efficiency. At the international level, Jaforullah and Whiteman (1999) analyzed the scale efficiency of the New Zealand dairy industry, while Krause and Nowoświat (2019) assessed the energy efficiency of dairy production systems in the same country, identifying best practices for sustainable production. Furthermore, Aldeseit (2013) used DEA to measure scale efficiencies in Jordanian dairy farms, while Lima *et al.* (2018) analyzed efficiency levels in the Brazilian dairy industry, focusing on improvement strategies. Furthermore, Ruales-Guzmán *et al.* (2021) analyzed the efficiency of 19 dairy companies in Colombia, identifying efficient and inefficient businesses using the VRS model. Mo *et al.* (2014) applied various DEA models to measure efficiency in the dairy industry, providing practical suggestions for improving productivity. A more advanced approach is presented by Khalili-Damghani *et al.* (2011), who applied a hybrid combination of DEA and fuzzy logic to measure efficiency in the flexibility of supply chains in the dairy sector. The improvement strategies proposed by these studies highlight the value of DEA as a tool to support sustainable practices, enhance competitiveness, and increase efficiency in the dairy sector.

The food industry in general benefits from the application of DEA, as it offers a robust framework for assessing efficiency in multidimensional operations. Ghadge *et al.* (2017) analyzed the efficiency of small and medium-sized enterprises in the food industry, incorporating parameters such as environmental investments and regulatory requirements, demonstrating the flexibility of DEA in measuring complex systems. Similarly, Saha (2020) used a Two-Stage DEA approach to analyze efficiency in the food processing industry in India, providing a separation between market and technical efficiency.

The variables used in DEA analyses are numerous and tailored to the requirements of each sector. Inputs traditionally include raw material costs, energy consumption, labor use, technological investments and infrastructure among others. On the output side, variables such as the quantity of products produced, net profit, product quality and environmental efficiency are measured. In the context of Two-Stage DEA, external factors such as geographical location, climatic conditions, regulatory requirements and social responsibility indicators are incorporated to provide a more comprehensive picture of efficiency. In conclusion, DEA and Two-Stage DEA offer powerful tools for understanding efficiency and sustainability in the food and dairy industry. Despite existing studies, there is a need for further research, especially in regions and sectors with limited application of the method.

The two-stage DEA approach is applied for the multidimensional evaluation of efficiency, enabling analysis in two interconnected stages. The first stage may focus on operational or financial aspects, as in the studies by Yang (2006) and Assaf and Matawie (2009), while the second stage incorporates external factors or undesirable outcomes, such as pollutant emissions (Aminuddin *et al.*, 2017). Studies like those by Gutiérrez *et al.* (2017) utilized the first stage to identify sources of inefficiency and the second to analyze exogenous factors. Hanoum *et al.* (2020) highlighted the application of the approach in the creative industry sector, while Liu *et al.* (2022) confirmed its ability to capture multidimensional interactions in complex sectors, such as the dairy industry. This methodology has proven to be flexible and useful for understanding and improving efficiency across various industries.

Despite the increasing use of DEA in agrifood efficiency analysis, most existing studies tend to focus on either production or investment aspects separately. Composite models integrate both remain uncommon, particularly in the dairy sector. This study seeks to fill this gap by applying a combined DEA approach tailored to the structure of the Greek dairy industry.

3. DATA AND METHODOLOGY

This study develops a comprehensive two-stage Data Envelopment Analysis (DEA) model to evaluate the overall efficiency of the Greek dairy industry, using data for the year 2023 obtained from ICAP. The analysis focuses on a sample of 33 enterprises, integrating production and investment perspectives to provide a systematic assessment of efficiency. An input-oriented DEA model was selected, as it reflects the strategic goal of minimizing resource usage—a key concern in a sector facing rising production costs and input inefficiencies. The model aims to minimize inputs in the production stage and maximize outputs in the investment stage, aligning with the specific objectives of dairy enterprises.

Production Approach

The production approach treats firms as units that produce products through the utilization of human, capital and other resources. Inputs include personnel, fixed assets, facilities, working capital and operating expenses, while outputs include sales revenue and gross profit. This approach assesses the ability of firms to achieve efficient production and cost control, supported by the existing literature on efficiency in the food industry.

Investment Approach

In the investment approach, firms are treated as financial intermediaries that invest capital to maximize return and value. Inputs include depreciation, investment expenses and total investment capital, while outputs include investment profits and EBITDA. This approach aims to measure the efficiency of investment strategies, considering the desire of businesses to maximize profits.

Integration of Stages

In the second stage, the efficiency results of production and investment are integrated into a single DEA model to generate a composite efficiency score. A dummy variable (with a constant value across all DMUs) is used as the sole input, while the outputs are the production efficiency and the inverse of the investment efficiency obtained from the first-stage models. This formulation ensures that both aspects contribute to the overall score, with greater weight assigned to the dimension in which each firm performs relatively better. The model is specified under the CCR (Constant Returns to Scale) assumption to ensure comparability across units. The practical objective of this step is to evaluate the overall managerial effectiveness of each enterprise by assessing its ability to balance productive operations and investment performance in an integrated and interpretable framework.

The data used in this study concern the Greek dairy industry for the year 2023. The information was collected from Icap. CRIF (2023), a reliable source of economic and business data, ensuring the accuracy and timeliness of the analysis. The analysis utilizes both the BCC and CCR models to comprehensively examine scale efficiency issues, providing valuable information for improving the operational and investment strategy of Greek dairy businesses. The DEA models were implemented using the R software environment, which supports robust linear programming techniques suitable for efficiency analysis.

Data Envelopment Analysis (DEA) is a mathematical programming approach for evaluating the relative efficiency of decision-making units (DMUs) that utilize multiple inputs to produce multiple outputs. DEA identifies a set of efficient DMUs that define the best practice frontier and evaluates other units against this benchmark. This section presents the two primary models used in DEA: the CCR model (Charnes *et al.*, 1978), which assumes Constant Returns to Scale, and the BCC model (Banker *et al.*, 1984), which assumes Variable Returns to Scale. These foundational models form the basis for evaluating technical and scale efficiency within DEA.

The BCC model assumes variable returns to scale and is formulated as follows. For each DMU_0 under evaluation, the input-oriented model is defined as a linear programming problem:

$$\min(\theta, \lambda_j)$$

$$subject\ to: \sum_{\{j=1\}}^{\{n\}\lambda_j} \lambda j y_{\{rj\}} \geq y_{\{ro\}} \qquad for\ r = 1, 2, \ldots, s$$

$$\sum_{\{j=1\}}^{\{n\}\lambda_j} \lambda j x_{\{ij\}} \leq \theta\, x_{\{io\}} \qquad for\ i = 1, 2, \ldots, m$$

$$\lambda_j \geq 0 \qquad for\ j = 1, 2, \ldots, n$$

In the BCC model, the following convexity constraint is also added: $\sum_k \lambda_k = 1$, where:

θ: Efficiency score of the DMU under evaluation

x_{ij}: Input i for DMU j

y_{rj}: Output r for DMU j

λ_j: Intensity variable for DMU j

n: Number of DMUs

m: Number of inputs

s: Number of outputs

The solution yields the efficiency score θ\thetaθ for the DMU under evaluation, along with the λ\\lambdaλ-weights that form the convex combination of peer units comprising its reference set.

The BCC model evaluates the pure technical efficiency (PTE) of DMUs by excluding scale effects, offering a measure of managerial performance. In contrast, removing the convexity constraint, as in the CCR model, expands the feasible region and may reduce the number of units classified as efficient.

The CCR model assumes constant returns to scale (CRS) and provides a measure of overall technical efficiency. Unlike the BCC model, it does not include the convexity constraint $\sum \lambda_k = 1$, and thus assumes that all DMUs operate at an optimal scale. This model is useful for identifying both technical and scale inefficiencies simultaneously.

A DMU is considered strongly efficient if it lies on the efficient frontier and all input and output slacks are zero. In contrast, weak efficiency is observed when a DMU obtains an efficiency score of 1 but retains positive slacks in some dimensions. This distinction is important for understanding the full potential for improvement (Cooper *et al.*, 2004; Soltani *et al.*, 2021; Oukil, 2024).

Selecting appropriate inputs and outputs is critical for accurate measurement of efficiency. In this study, the selected variables reflect key aspects of the operation of businesses in the Greek dairy industry.

Production model

Outputs

Revenue - Sales: Represents the total income derived from the sale of products or services. This variable provides an indication of the business's commercial performance and position in the market. Coelli *et al.* (2005) highlighted revenue as a central measure in efficiency analyses, particularly in competitive markets. Sellers-Rubio (2010) demonstrated its use in assessing wineries' performance, emphasizing its critical role in financial evaluation.

Gross Profit: Defined as the difference between revenue and cost of goods sold. Gross profit reflects the efficiency of the production model and the ability to control costs. Kaplan and Norton (1996) described gross profit as a foundational indicator of operational efficiency, central to strategic business planning. Färe *et al.* (1994) linked gross profit with technical efficiency in evaluating production models.

Inputs

Personnel: Refers to the total number of employees involved in the operations of the business. Human resources are a critical factor in the production capacity and quality of the products produced. Becker and Huselid (1998) underscored the critical role of effective human resource management in boosting operational efficiency. Voulgaris *et al.* (2013) emphasized personnel's influence on productivity and firm performance in labor-intensive industries.

Net Fixed Assets: Represent the financial value of long-term tangible investments such as buildings, machinery, and equipment, as recorded in company balance sheets. This variable reflects the capital invested in the production capacity of the firm, encompassing both movable and immovable assets that are expected to contribute to productivity over time. Greene (2008) incorporated fixed assets as key inputs in efficiency analyses, emphasizing their role in operational capacity. Karakitsiou *et al.* (2020) examined how the scale of such capital investments affects performance in the hospitality and food sectors using DEA.

Facilities: Denote the physical operating space and structural layout of the business, such as production plants, warehouses, and administrative offices. While these may be part of the assets included under Net Fixed Assets, they are considered here in terms of their spatial-functional role—affecting logistics, capacity utilization, and workflow efficiency. Ray (2004) highlighted the contribution of facility layout to technical efficiency in agricultural enterprises. Seiford and Zhu (1999) also assessed how infrastructure characteristics directly impact production performance.

Working Capital: Defined as the difference between current assets and short-term liabilities. It reflects the liquidity of the business and its ability to meet daily operational needs. Hill et al. (2013) highlighted the importance of working capital management for maintaining operational stability. Reddy *et al.* (2019) reviewed the role of working capital in financial and operational efficiency across industries.

Operational Expenses: These include the costs associated with the daily operation of the business, such as salaries, energy and raw materials. Managing operating expenses is critical to maintaining profitability and competitiveness. Kaplan and Norton (1996) emphasized the role of operational cost management in improving efficiency. Dobos and Vörösmarty (2019) analyzed operational expenses in supply chain performance, linking cost management with competitiveness.

Investment model

Outputs

Investment Gains in Equities and Real Estate: The total profits arising from investments in financial and real estate assets. Evaluates the effectiveness of the company in managing high-risk and high-return investments. Banker *et al.* (1984) incorporated investment gains in efficiency models, showcasing their role in financial stability. Additionally, Karagiannis and Sarris (2005) analyzed the efficiency of Greek tobacco growers, highlighting the significance of scale efficiency and strategic resource allocation in promoting sustainable agricultural performance.

Earnings Before Interest, Taxes, and Depreciation (EBITDA): The company's operating profits before interest, taxes, depreciation, and impairments are deducted. Measures the profitability of the company from its core operations, regardless of financing or accounting policies. Damodaran (2001) advocated EBITDA as a key metric for operational performance and valuation. Latruffe et al. (2008) used EBITDA in multi-criteria efficiency evaluations, emphasizing its relevance across sectors.

Inputs

Total Depreciation: The cost of wear and tear and the reduction in value of fixed assets. Demonstrates the efficiency of the use of fixed assets in operation and investment. Penman (2010) and Battese and Coelli (1995) analyzed depreciation's role in operational efficiency and financial planning.

Investment Expenses: Expenditures incurred to acquire or upgrade assets and investments. Evaluates the effectiveness of investments in relation to their performance. Assaf and Matawie (2009) studied investment expenses in cost efficiency analyses of Australian wine companies. Jensen (1999) explored their impact on firm growth and strategy execution.

Total Investments: The total capital committed to investment activities. Purpose: Reflects the scale and effectiveness of the investment strategy. Färe *et al.* (1994) and Greene (2008) analyzed total investments in efficiency models to assess their impact on long-term growth. Voulgaris *et al.* (2013) linked investment levels to competitiveness and financial stability in volatile markets.

Figure no. 4 illustrates the structure and methodology used to evaluate the efficiency of businesses. In the first stage, two separate processes are analyzed: the production model and the investment model. In the second stage, the efficiencies from the two initial models are integrated into a single index, which assesses the overall efficiency of each business unit.

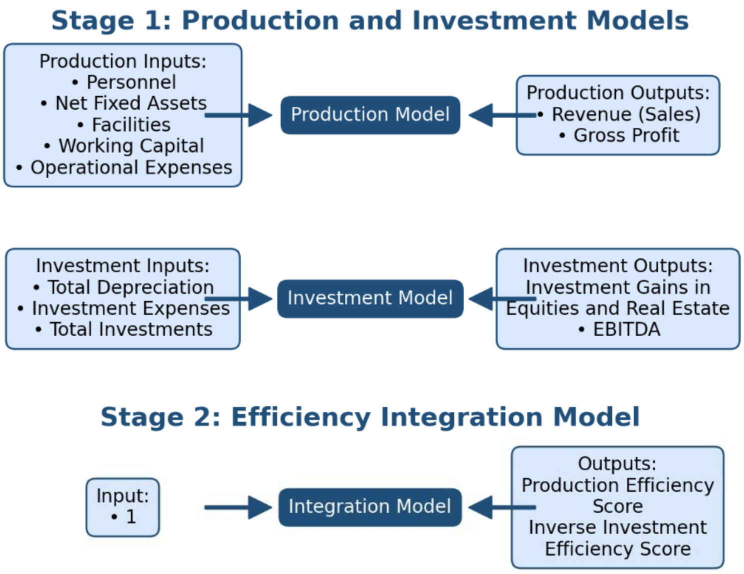

Figure no. 4 – Structure and Methodology of Efficiency Evaluation in Two Stages

The second stage of the analysis serves a critical practical purpose: it enables the integration of two distinct efficiency dimensions – operational and investment – into a single composite indicator that captures the overall performance of each enterprise. While the first-stage models evaluate production and investment efficiency separately, real-world business performance depends on the interplay and alignment between these two domains. The second stage thus reflects the ability of a firm to balance productive operations with sound investment strategies. This composite efficiency score provides actionable insights for both managers and policymakers by identifying firms that excel in both areas, highlighting those with mismatches, and guiding targeted interventions. For example, an enterprise that performs well in production but poorly in investment may need to revise its capital allocation policies. Conversely, high performance in both stages indicates a sustainable and balanced business model that can serve as a benchmark for others in the sector.

4. RESULTS

The results section begins with a statistical overview of the sample firms, which provides context for the efficiency evaluation that follows.

Table no. 1 – Descriptive statistics of outputs and inputs in production model

	Max	Median	Min	Average	Standard Deviation
Outputs					
Revenue (Sales)	328197728	31422000	1117938	67208893.61	82382872.33
Gross Profit	64135000	4550000	358437	13327460.73	17272875.25
Inputs					
Personnel	1025	125	14	250.36	277.64
Net Fixed Assets	254627824	8236059	34294	31730442.27	58798886.14
Facilities	114647263	7087410	95870	17427980.64	25410650.96
Working Capital	181636058	7251000	99929	23004334.88	36789549.26
Operational Expenses	71234000	4214580	438167	11315733.52	16170588.8

Table no. 1 presents the summary statistics for outputs and inputs in the production model of the dairy industry. The analysis of these statistics reveals that, for outputs, revenue (sales) has a significant range, with a maximum value of €328197728, a median of €31422000, and a minimum of €1117938, resulting in an average of €67208893.61 with a standard deviation of €82382872.33. Gross profit exhibits similar variability, with an average of €13327460.73 and a standard deviation of €17272875.25, suggesting disparities in profitability. Personnel size ranges from 14 to 1025 employees, with a median of 125, reflecting diverse workforce sizes.

For inputs, net fixed assets exhibit the largest variability, with a maximum of €254627824 and a minimum of €34294, averaging €31730442.27 with a standard deviation of €58798886.14. Facilities, working capital, and operational expenses follow similar patterns of high variability, with average values of €17427980.64, €23004334.88, and €11315733.52, respectively. The high standard deviations across inputs underscore significant differences in resource utilization among dairy enterprises, highlighting the potential for operational improvements to align performance with industry leaders.

Table no. 2 – Descriptive statistics of outputs and inputs in investment model

	Max	Median	Min	Average	Standard Deviation
Outputs					
Investment Gains in Equities and Real Estate	2943002.8	162361	3247.7	521314.68	695046.76
EBITDA	29410028	912800	32477	5494725.24	8311436.09
Inputs					
Total Depreciation	45114000	2497799	26895	8664110.12	12251936.86
Investments Expenses	7259000	70736	1639	634626.97	1460578.61
Total Investments	54828000	4897085	80061	13403835.5	15332986.3

Table no. 2 presents descriptive statistics for the investment model inputs and outputs. The results indicate high variability across all variables, with significant differences between maximum and minimum values, suggesting the presence of outliers and a wide range of practices. For example, investment gains in equities and real estate range from a minimum of 3247.7 to a maximum of 2943002.8, with an average of 521314.68 and a standard deviation of 695046.76, highlighting substantial dispersion. Similarly, total depreciation varies from 26895 to 45114000, with an average of 8664110.12 and a standard deviation of 12251936.86. These large discrepancies, along with high standard deviations, reflect diverse business profiles and the influence of extreme values.

Table no. 3 – DEA Results for Production and Investment Models

	Production		Investment	
	CCR	**BCC**	**CCR**	**BCC**
Average Score	0.59	0.76	0.40	0.56
Standard Deviation	0.23	0.22	0.36	0.35
Maximum Efficiency Score	1	1	1	1
Minimum Efficiency Score	0.33	0.38	0.02	0.06
Number (and %) of Efficient DMUs	6 (18.18%)	11 (33.33%)	5 (15.15%)	11 (33.33%)
Strongly Efficient DMUs (n, %)	4 (12.12%)	8 (24.24%)	4 (12.12%)	7 (21.21%)
Weakly Efficient DMUs (n, %)	2 (6.06%)	3 (9.09%)	1 (3.03%)	4 (12.12%)
DMUs with Increasing Returns	19	-	4	-
DMUs with Constant Returns	1	3	2	5
DMUs with Decreasing Returns	13	-	27	-
Benchmark DMUs	1, 4, 6, 11	2, 3, 5, 8	1, 5, 9	2, 5, 11

Note: Benchmark DMUs are those used as reference units (with $\lambda > 0$) in at least one other DMU. These units are efficient and form the best-practice frontier under each model.

Table no. 3 presents the DEA-based efficiency scores of Greek dairy enterprises, evaluating both production and investment activities under Constant Returns to Scale (CCR) and Variable Returns to Scale (BCC) assumptions. The comparison across the four models highlights notable differences in performance and inefficiency patterns among firms.

The average efficiency scores indicate better performance under BCC assumptions. In the production model, the average score is 0.76 under BCC and 0.59 under CCR. Similarly, for the investment model, the average score reaches 0.56 under BCC, compared to 0.40 under CCR. These results reflect the ability of the BCC model to account for scale inefficiencies, offering a more flexible representation of firm-level efficiency.

The standard deviation values are relatively similar across models, indicating comparable dispersion. In production, the CCR and BCC models report standard deviations of 0.23 and 0.22, respectively. For the investment model, variability is slightly higher (0.36 CCR, 0.35 BCC), suggesting greater heterogeneity in capital allocation and investment outcomes.

All models include fully efficient firms, as denoted by the maximum score of 1. However, the minimum efficiency scores reveal significant inefficiencies – particularly in investment. While the production model reports minimum scores of 0.33 (CCR) and 0.38 (BCC), the investment model scores drop to 0.02 (CCR) and 0.06 (BCC), indicating major performance gaps in investment efficiency.

The number of efficient firms differs by model. In the production model, 11 firms (33.33%) are efficient under BCC – of which 8 are strongly and 3 weakly efficient – while 6 (18.18%) are efficient under CCR (4 strongly, 2 weakly). In investment, 11 firms (33.33%) are efficient under BCC (7 strongly, 4 weakly), and only 5 (15.15%) under CCR (4 strongly, 1 weakly). These differences illustrate the broader frontier defined by the BCC model.

Returns to scale, identifiable only under BCC, provides further insight into performance dynamics. In production, 19 firms operate under Increasing Returns to Scale (IRS), suggesting potential efficiency gains through expansion, while 13 firms exhibit Decreasing Returns to Scale (DRS), reflecting inefficiencies from over-sizing. Only one firm operates at Constant Returns to Scale (CRS). In investment, most firms (27) are under DRS, with only 4 under IRS and 2 at CRS—highlighting widespread inefficiencies in capital deployment.

Benchmark DMUs—those serving as reference points with strictly positive λ-values—are also identified. For production, BCC models select DMUs 1, 4, 6, and 11, while CCR models identify DMUs 2, 3, 5, and 8. In investment, the benchmarks under BCC are DMUs 1, 5, and 9, and under CCR, DMUs 2, 5, and 11. These units form the efficiency frontier and can serve as practical examples of best performance within the sector.

In summary, production activities show more favorable efficiency patterns than investment. The BCC models uncover a broader set of efficient firms and richer insights into scale characteristics, while CCR models define a stricter efficiency frontier. The results highlight the need for performance improvements, particularly in investment strategy and scale adjustment, and point to specific firms that can serve as role models within the industry.

Beyond the numerical results, the DEA findings offer deeper insights into the structural and strategic conditions prevailing in the Greek dairy industry. The significant gaps in efficiency – particularly within the investment dimension – highlight challenges in capital deployment, financial planning, and long-term strategic orientation. The widespread presence of decreasing returns to scale in the investment model suggests over-investment or suboptimal resource utilization, indicating the need for more targeted and sustainable growth strategies.

In contrast, the prevalence of increasing returns to scale among several enterprises in the production model points to unrealized efficiency potential, especially for firms operating below optimal scale. Strategic expansion or improved resource management could help these enterprises move closer to the production frontier.

Benchmark units identified in all four models act as reference points and illustrate best-practice operations in both production and investment contexts. Their role is critical, as they offer evidence of managerial effectiveness and coherent operational strategies. Promoting the practices of these efficient units could foster learning and drive convergence across the sector.

Furthermore, the divergence in efficiency performance between production and investment activities in some enterprises suggests a lack of integrated management. Firms with strong production capabilities but weak investment efficiency may jeopardize long-term competitiveness if they fail to align operational success with strategic financial planning. This underlines the importance of two-stage DEA models as tools for diagnosing multi-dimensional inefficiencies and supporting comprehensive, evidence-based decision-making.

Table no. 4 presents the second-stage DEA efficiency scores, which integrate production and investment performance for each DMU. The results show that the mean efficiency score is 0.402, indicating that, on average, the DMUs achieve 40.2% of the ideal efficiency, with significant variability as reflected in a standard deviation of 0.348. Only 5 DMUs (15.15%) are fully efficient (score = 1.0), while the minimum score of 0.023 underscores substantial inefficiencies. These findings highlight the need for many DMUs to improve both operational and investment strategies to enhance overall performance.

Table no. 4 – Overall Efficiency (Based on CCR Analysis)

Efficiency Metric	Results
Mean Efficiency Score	0.402
Variation (Standard Deviation)	0.348
Top Efficiency Achieved	1.0
Lowest Efficiency Score	0.023
Number of Efficient DMUs	5
Percentage of Efficient DMU	15.15%

Table no. 5 presents the efficiency scores of Decision-Making Units (DMUs) at two levels: Average First-Stage Efficiency and Overall Efficiency (Second Stage). The first-stage scores reflect the average CCR-based efficiency results from the separate production and investment DEA models. These scores indicate how well each enterprise performs in each dimension individually. The second-stage score represents the integrated efficiency score obtained from the CCR-based composite DEA model, where a dummy input and the first-stage outputs (production efficiency and inverse investment efficiency) are used. This comparison enables the identification of firms with consistent performance across both stages, as well as those showing a mismatch between operational and investment efficiency. The practical objective of this step is to assess the overall strategic alignment of each enterprise by measuring its ability to effectively manage both resource use and capital deployment within a unified framework.

A notable finding is the presence of fully efficient DMUs in both stages. In the first stage, DMUs 1, 2, 3, 10, 20, and 22 achieve a perfect efficiency score of 1.0, reflecting their ability to optimize both production and investment operations. In the second stage, DMUs 1, 2, 3, 10, 13, 20, and 22 maintain their efficiency, demonstrating robust integration of production and investment efficiencies. These DMUs serve as benchmarks for best practices within the dataset.

Several DMUs exhibit high efficiency across both stages, with scores close to 1.0. For instance, DMUs 25, 21, and 29 show consistently strong performance, indicating effective operations and minimal inefficiencies during the integration phase. However, some DMUs experience significant drops in efficiency between the stages. DMU 7, for example, drops from 0.66 in the first stage to 0.37 in the second stage, while DMU 24 decreases from 0.69 to 0.40. These declines suggest challenges in harmonizing production and investment model.

Table no. 5 – DMU-Level Efficiency Comparison

DMU	*Average First Stage Efficiency*	*Overall Efficiency (Second Stage)*
1	1.00	1.00
2	1.00	1.00
3	1.00	1.00
4	0.77	0.68
5	0.76	0.60
6	0.71	0.55
7	0.66	0.37
8	0.69	0.41
9	0.83	0.68
10	1.00	1.00
11	0.73	0.56
12	0.74	0.48
13	0.69	1.00
14	0.75	0.50
15	0.68	0.48
16	0.77	0.56
17	0.75	0.52
18	0.75	0.51
19	0.69	0.49
20	1.00	1.00
21	0.85	0.70
22	1.00	1.00
23	0.85	0.69
24	0.69	0.40
25	0.93	0.91
26	0.69	0.41
27	0.73	0.49
28	0.67	0.50
29	0.85	0.70
30	0.71	0.46
31	0.81	0.74
32	0.74	0.59
33	0.82	0.64

Moderately efficient DMUs, such as 4, 5, and 9, maintain efficiency scores between 0.55 and 0.83 across both stages. These units demonstrate potential for improvement but also highlight the need for targeted interventions to optimize their operations further. On the other hand, DMU 13 shows an improvement in the second stage, reaching a score of 1.0 despite a first-stage score of 0.69. This indicates that the integration analysis benefits certain DMUs, likely due to better alignment of production and investment activities.

The efficiency scores across the DMUs display a broad range, with second-stage scores spanning from 0.37 to 1.0. Similarly, first-stage scores range from 0.66 to 1.0, reflecting varying levels of baseline efficiency. The variation suggests opportunities to analyze underperforming DMUs and identify the factors contributing to inefficiencies.

In summary, while some DMUs consistently excel across both stages, others face integration challenges or underperformance. The analysis highlights fully efficient DMUs as benchmarks, identifies areas for improvement for moderate performers, and emphasizes the need for strategic interventions to align production and investment efficiencies effectively. These findings provide actionable insights for enhancing overall operational performance within the dairy industry.

The analysis focused on the slacks of the production model, as these provide direct insights into the management of key resources such as personnel and fixed assets. This choice was made because improvements in productive efficiency are more immediate and actionable, whereas addressing slacks in the investment model often requires long-term planning and capital strategies. Additionally, the available data for the inputs of the production model were more detailed, enabling a more precise analysis.

Table no. 6 – Slacks for CCR Production Models

DMU	Personnel	Net Fixed Assets	Facilities	Operational Expenses	Working Capital
1	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00
4	-30.60	-2857695.61	-3190110.74	0.00	0.00
5	-23.72	-2263970.46	-1681872.15	0.00	15854955.10
6	-5.09	-1189571.38	-642489.99	0.00	3826609.08
7	-15.15	-3039307.65	-1683792.68	0.00	18028793.16
8	-26.89	-2242743.09	-2834184.07	0.00	30494574.23
9	-65.43	-527155.04	-639370.24	0.00	9574292.72
10	0.00	0.00	0.00	0.00	0.00
11	0.00	-101792533.70	-26682792.38	0.00	315417301.2
12	-16.46	-17218483.73	-2267626.35	0.00	110274112.3
13	-6.45	-7852218.913	-6641702.99	0.00	16262604.84
14	0.00	-122166286.1	-46188767.04	0.00	174896858.70
15	-15.27	-2728434.288	-2046931.09	0.00	12760248.70
16	-90.46	-17345582.91	-16625422.80	0.00	9599318.42
17	-6.42	-3506242.43	-2452293.02	0.00	8728612.64
18	-73.00	-35577003.45	-10889047.08	0.00	81659406.17
19	-4.18	-2535309.96	-2673525.82	0.00	5340302.67
20	0.00	0.00	0.00	0.00	0.00
21	0.00	-45389813.55	-9483749.61	0.00	254740660.40
22	0.00	0.00	0.00	0.00	0.00
23	-33.45	-800926.44	0.00	0.00	11245124.94
24	-5.22	-3062916.82	-1130403.21	0.00	17444220.27
25	-269.30	-26284230.98	-23817828.80	0.00	42587518.64
26	-0.05	-18355090.74	-2138103.45	0.00	75966312.74
27	-10.55	-2766958.06	-2759233.76	0.00	11343859.81
28	-1.57	-45816.43	-404679.06	0.00	2532310.68
29	-533.02	-5687288.81	0.00	0.00	77120180.67
30	-14.61	-890358.10	-1071963.16	0.00	15082984.69
31	-116.94	-9025289.21	-4653474.17	0.00	33817534.22
32	0.00	-31420197.97	-20022387.02	0.00	117786020.10
33	0.00	-8907076.52	-4637880.69	0.00	62789692.07

Slacks for CCR Production Models (Table no. 6) highlights critical inefficiencies in the utilization of inputs across dairy industry enterprises (DMUs). This table provides valuable insights into areas where input reductions are possible without compromising production levels, revealing significant opportunities for optimization.

Several DMUs, such as 1, 2, 3, 10, 20, and 22, exhibit zero slacks across all input categories. These DMUs are fully efficient under the CCR model and can serve as benchmarks for others. Their effective resource utilization offers valuable lessons in workforce management, asset optimization, and cost efficiency. These efficient DMUs demonstrate the potential for balancing input utilization with production output, setting the standard for less efficient enterprises.

However, other DMUs show substantial inefficiencies, with notable overuse of inputs. For instance, DMU 25 displays the largest slack in both Personnel (-269.30) and Net Fixed Assets (-26284231), signaling significant overstaffing and underutilization of fixed assets. Similarly, DMU 29 has the highest inefficiency in Personnel (-533.02), suggesting opportunities to reduce staffing levels without affecting production. These inefficiencies highlight the need for targeted cost optimization strategies, including workforce restructuring and better asset allocation.

The slacks in Facilities and Working Capital also present important findings. DMUs such as 16, 18, and 25 show considerable inefficiencies in facilities management, indicating potential misallocation or underutilization of physical resources. On the other hand, DMUs like 8 and 25 exhibit significant slacks in working capital, pointing to inefficiencies in cash flow or inventory management. Addressing these issues could unlock financial and operational improvements.

Interestingly, Operational Expenses exhibit zero slack across all DMUs. This suggests that operational costs are being allocated efficiently across the industry, providing a strong foundation for further optimization efforts. This insight underscores the importance of focusing on other input categories, such as personnel and fixed assets, for greater impact.

In conclusion, the CCR production model slacks reveal a clear dichotomy between efficient and inefficient DMUs in the dairy industry. Enterprises with significant slacks should prioritize targeted interventions in workforce management, capital utilization, and facilities optimization. By benchmarking against fully efficient DMUs, less efficient enterprises can identify best practices and move closer to the efficient frontier. This analysis underscores the potential for improved resource allocation and productivity, driving the overall competitiveness of the sector.

5. DISCUSSION

The efficiency analysis of Greek dairy industry enterprises through the two steps DEA model revealed significant findings that can guide improvement strategies. The production and investment models provided a comprehensive view of efficiency, while the integration of the two models highlighted notable differences in enterprise performance.

The production model showed that some enterprises are fully efficient, while others have significant room for improvement. The observed slacks in inputs such as personnel and fixed assets indicate that many enterprises manage resources inefficiently. The large efficiency discrepancies among the DMUs underline the need to adopt best practices employed by the most efficient units. Specifically, operational cost management appears generally efficient, as most DMUs showed no slack in this area. This suggests a focus on cost control, although improvements in other inputs are needed to fully unlock their potential.

The investment model revealed poor performance for most enterprises, with results indicating ineffective investment strategies. Enterprises need to focus on optimizing capital utilization and increasing profitability through more efficient investments.

The integration of the two models in the second stage exposed inconsistencies between productive and investment efficiency. Only a small percentage of enterprises were fully efficient, highlighting the need for better alignment of productive and investment activities. The analysis showed that enterprises performing well in the production model are not necessarily equally efficient in the investment model, and vice versa. This mismatch underscores the need for a comprehensive strategy that integrates both domains.

The analysis provides critical insights for improving efficiency in the dairy industry, laying the groundwork for strategic adjustments and sustainable development. Enterprises must reduce excessive input usage, such as personnel and fixed assets, through optimal resource management, adapting their processes to increase productivity and reduce operating costs. Simultaneously, revising investment policies is crucial, with an emphasis on innovation, profit growth, and sustainability. Innovation involves adopting technologies that enhance production and reduce environmental impact, while profit growth can be achieved through targeted investments in high value-added products that meet market demands. For sustainability, ensuring long-term economic robustness requires green practices and responsible strategies that maintain environmental balance.

Furthermore, efficient enterprises can serve as benchmarks for less efficient ones, sharing expertise and best practices to align strategies and achieve overall sector improvement. By implementing these strategies, the dairy industry can enhance its efficiency, achieve greater economic robustness, and create a sustainable future for the sector.

6. CONCLUSIONS AND IMPLICATIONS

Conclusions

The efficiency analysis of Greek dairy industry enterprises using the composite DEA approach highlights critical strategic implications for both businesses and policymakers seeking sustainable development and enhanced competitiveness. Greek dairy firms can capitalize on global trends in sustainability and innovation. The rising demand for high-nutritional-value products, such as strained yogurt and functional foods (e.g., probiotics), creates opportunities for differentiation in international markets. At the same time, the integration of advanced technologies, such as automation in production processes, can help reduce costs and improve product quality. The analysis also reveals considerable room for improvement in investment strategies. With average investment efficiency (0.40) significantly lower than production efficiency, there is a clear need to revise capital allocation practices. Enterprises should focus on enhancing profitability through targeted investments in high value-added products and more efficient management of working capital.

Strategic implications

Policymakers can play a critical role in supporting the sector by:

- Providing tax incentives for investments in sustainable practices, such as the use of renewable energy sources and waste reduction.
- Offering financial tools to support small producers in improving their efficiency.

- Promoting clusters and collaborations to disseminate best practices and reduce costs through shared infrastructure.

Collaboration among enterprises can act as a catalyst for achieving better efficiency. The creation of sectoral clusters and the exchange of expertise can enhance the dissemination of advanced technologies and reduce costs. Efficiency improvement, especially among businesses operating near the efficient frontier, can enhance the competitiveness of Greek products in international markets. The exports of strained yogurt, already a cornerstone of the sector's global presence, can be strengthened through product diversification and quality improvement. Transitioning to sustainable practices, such as reducing the environmental footprint, can provide a competitive advantage, particularly in environmentally conscious markets. The adoption of green technologies and compliance with international standards (e.g., ISO 14001) enhance product credibility and market penetration in demanding markets. Enterprises in the sector must adopt a comprehensive strategy that combines optimizing efficiency in production and investments, aligning with international trends, and integrating sustainable practices. Fully efficient enterprises can serve as benchmarks, helping disseminate best practices across the sector. Collaboration with policymakers to implement the above recommendations can strengthen the Greek dairy sector's position in global markets.

ORCID

Athanasia Mavrommati https://orcid.org/0000-0003-0260-5831
Fotios Chatzitheodoridis https://orcid.org/0000-0003-2008-1023
Alexandra Pliakoura https://orcid.org/0000-0002-9630-9867
Stavros Kalogiannidis https://orcid.org/0000-0002-2337-5775

References

Aldeseit, B. (2013). Measurement of Scale Efficiency in Dairy Farms: Data Envelopment Analysis (DEA) Approach. *Journal of Agricultural Science, 5*(9), 37-43. http://dx.doi.org/10.5539/jas.v5n9p37

Aminuddin, A. S. A., Jaini, N. I., Mat Kasim, M., & Mohd Nawawi, M. K. (2017). *A Two-Stage Data Envelopment Analysis Model with Undesirable Output.* Paper presented at the Journal of Physics: Conference Series.

Assaf, A., & Matawie, K. M. (2009). A Two-Stage Approach to Efficiency Modeling: An Application to the Australian Hospital Food Production Industry. *Journal of Hospitality & Tourism Research (Washington, D.C.), 33*(3), 284-304. http://dx.doi.org/10.1177/1096348009338510

Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. *Management Science, 30*(9), 1078-1092. http://dx.doi.org/10.1287/mnsc.30.9.1078

Battese, G. E., & Coelli, T. J. (1995). A Model for Technical Inefficiency Effects in A Stochastic Frontier Production Function for Panel Data. *Empirical Economics, 20*(2), 325-332. http://dx.doi.org/10.1007/BF01205442

Becker, B. E., & Huselid, M. A. (1998). High Performance Work Systems and Firm Performance: A Synthesis of Research and Managerial Implications. *Research in Personnel and Human Resources Management, 16*(January), 53-101.

Bórawski, P., Pawlewicz, A., Mickiewicz, B., Pawlewicz, K., Bełdycka-Bórawska, A., Holden, L., & Brelik, A. (2020). Economic Sustainability of Dairy Farms in The EU. *European Research Studies Journal, XXIII, Special Issue*(1), 955-978. http://dx.doi.org/10.35808/ersj/1864

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the Efficiency of Decision-Making Units. *European Journal of Operational Research, 2*(6), 429-444. http://dx.doi.org/10.1016/0377-2217(78)90138-8

Chatzitheodoridis, F., Kontogeorgos, A., Litsi, P., Apostolidou, I., Michailidis, A., & Loizou, E. (2016). Small Women's Cooperatives in Less Favored and Mountainous Areas under Economic Instability. *Agricultural Economics Review, 17*(1), 63-79. http://dx.doi.org/10.22004/ag.econ.262883

Chatzitheodoridis, F., Michailidis, A., Theodosiou, G., & Loizou, E. (2013). Local Cooperation: A Dynamic Force for Endogenous Rural Development. In A. Karasavvoglou & P. Polychronidou (Eds.), *Balkan and Eastern European Countries in the Midst of the Global Economic Crisis* (pp. 121-132). Heidelberg: Physica-Verlag HD. http://dx.doi.org/10.1007/978-3-7908-2873-3_9

Chrysanthopoulou, X., Mavrommati, A., & Migdalas, A. (2023). Assessing The Efficiency of Occupational Pension Funds in Greece. *Operations Research, 23*(4), 1-30. http://dx.doi.org/10.1007/s12351-023-00807-4

Coelli, T., Rao, D. S. P., O'Donnell, C. J., & Battese, G. E. (2005). *An Introduction to Efficiency and Productivity Analysis* (2nd ed. Vol. 1). New York, NY, United States: Springer. http://dx.doi.org/10.1007/b136381

Cooper, W. W., Seiford, L. M., & Zhu, J. (2004). *Handbook on Data Envelopment Analysis* (W. W. Cooper, L. M. Seiford, & J. Zhu Eds. 1st edition ed. Vol. 71): Springer New York, NY. http://dx.doi.org/10.1007/b105307

Damodaran, A. (2001). *The Dark Side of Valuation: Valuing Old Tech, New Tech, and New Economy Companies*: Prentice Hall.

Dobos, I., & Vörösmarty, G. (2019). Inventory-Related Costs in Green Supplier Selection Problems with Data Envelopment Analysis (DEA). *International Journal of Production Economics, 209*(March), 374-380. http://dx.doi.org/10.1016/j.ijpe.2018.03.022

Emrouznejad, A., & Yang, G. (2018). A Survey and Analysis of the First 40 Years of Scholarly Literature in DEA: 1978–2016. *Socio-Economic Planning Sciences, 61*(March), 4-8. http://dx.doi.org/10.1016/j.seps.2017.01.008

Fao. (2023). *Global Milk Production and Trends*: Food and Agriculture Organization of the United Nations.

Färe, R., Grosskopf, S., & Lovell, C. A. K. (1994). *Production Frontiers*: Cambridge University Press.

Gardijan, M., & Lukać, Z. (2018). The Role of The Food and Beverages Sector in The European Union Economy. *Economic Research, 31*(1), 1460-1478.

Ghadge, A., Kaklamanou, M., Choudhary, S., & Bourlakis, M. (2017). Implementing Environmental Practices within The Greek Dairy Supply Chain: Drivers and Barriers for SMEs. *Industrial Management & Data Systems, 117*(9), 1995-2014. http://dx.doi.org/10.1108/IMDS-07-2016-0270

Greene, W. H. (2008). *Econometric Analysis* (6th ed.): Pearson Prentice Hall.

Gutiérrez, E., Aguilera, E., Lozano, S., & Guzmán, G. I. (2017). A Two-Stage DEA Approach for Quantifying and Analysing the Inefficiency of Conventional and Organic Rain-Fed Cereals in Spain. *Journal of cleaner production, 149*(4), 335-348. http://dx.doi.org/10.1016/j.jclepro.2017.02.104

Halkos, G., & Petrou, K. N. (2019). Assessing 28 EU Member States' Environmental Efficiency in National Waste Generation with DEA. *Journal of Cleaner Production, 208*(January), 509-521. http://dx.doi.org/10.1016/j.jclepro.2018.10.145

Hanoum, S., Ade Putri, A., & Syafitri, A. N. (2020). *Two-Stage DEA Analysis for MeasuringThe Performance Efficiency of Creative Industry in East Java.* Paper presented at the Proceedings of the 3rd Asia Pacific International Conference of Management and Business Science (AICMBS 2019).

Hermoso-Orzáez, M. J., García-Alguacil, M., Terrados-Cepeda, J., & Brito, P. (2020). Measurement of Environmental Efficiency in The Countries of the European Union with The Enhanced Data Envelopment Analysis Method (DEA) During The Period 2005-2012. *Environmental Science and Pollution Research International, 27*(13), 15691-15715. http://dx.doi.org/10.1007/s11356-020-08029-3

Hill, J. (2024). Science, Technology, and Innovation in The Dairy Sector. *International Journal of Food Science & Technology, 59*(9), 6717-6723. http://dx.doi.org/10.1111/ijfs.17385

Icap. CRIF. (2023). *Greek Dairy Industry Report: Performance and Challenges*: ICAP CRIF Reports.

Jaforullah, M., & Whiteman, J. (1999). Scale Efficiency in The New Zealand Dairy Industry: A Non-Parametric Approach. *The Australian Journal of Agricultural and Resource Economics, 43*(4), 523-541. http://dx.doi.org/10.1111/1467-8489.00093

Jensen, M. C. (1999). Agency Costs of Free Cash Flow, Corporate Finance, and Takeovers. *SSRN, 76*(2), 323-329. http://dx.doi.org/10.2139/ssrn.99580

Kalfas, D., Kalogiannidis, S., Papaevangelou, O., Melfou, K., & Chatzitheodoridis, F. (2024). Integration of Technology in Agricultural Practices Towards Agricultural Sustainability: A Case Study of Greece. *Sustainability, 16*(7), 1-24. http://dx.doi.org/10.3390/su16072664

Kalogiannidis, S., Kalfas, D., Papadopoulou, C. I., & Chatzitheodoridis, F. (2024). Perspectives on The Role of Peri-Urban Dynamics on Environmental Sustainability: The Case Study of Greece. In M. B. Sahana (Ed.), *Remote sensing and GIS for peri-urban research* (Vol. 11, pp. 597-616): Academic Press. http://dx.doi.org/10.1016/B978-0-443-15832-2.00026-5

Kapelko, M., & Oude Lansink, A. (2022). Measuring Firms' Dynamic Inefficiency Accounting for Corporate Social Responsibility in the U.S. Food and Beverage Manufacturing Industry. *Applied Economic Perspectives and Policy, 44*(4), 1702-1721. http://dx.doi.org/10.1002/aepp.13261

Kaplan, R. S., & Norton, D. P. (1996). *The Balanced Scorecard: Translating Strategy Into Action*: Harvard Business School Press.

Karagiannis, G., & Sarris, A. (2005). Measuring and Explaining Scale Efficiency with The Parametric Approach: The Case of Greek Tobacco Growers. *Agricultural Economics, 33*(s3), 441-451. http://dx.doi.org/10.1111/j.1574-0864.2005.00084.x

Karakitsiou, A., Kourgiantakis, M., Mavrommati, A., & Migdalas, A. (2020). Regional Efficiency Evaluation by Input-Oriented Data Envelopment Analysis of Hotel and Restaurant Sector. *Operations Research, 20*(4), 2041-2058. http://dx.doi.org/10.1007/s12351-018-0406-1

Karakitsiou, A., & Mavrommati, A. (2009). Measuring Large Firm's Profitability with Panel Data Models: Application to Greek Food Industry. *Journal of Financial Decision Making, 5*(2), 111-120.

Karakitsiou, A., Mavrommati, A., & Migdalas, A. (2004). Measuring Production Efficiency in the Greek Food Sector. In P. M. Pardalos (Ed.), *Supply Chain and Finance* (pp. 137-151): Kluwer Academic Publishers. http://dx.doi.org/10.1142/9789812562586_0008

Karakitsiou, A., Mavrommati, A., Migdalas, A., & Tsiakali, K. (2007). Efficiency Measurement and Evaluation of The Greek Hotel Industry. *Journal of Travel & Tourism Research, 7*(2), 96-110.

Khalili-Damghani, K., Taghavifard, M., Olfat, L., & Feizi, K. (2011). A Hybrid Approach based on Fuzzy DEA and Simulation to Measure the Efficiency of Agility in Supply Chain: Real Case of Dairy Industry. *International Journal of Management Science and Engineering Management, 6*(3), 163-172. http://dx.doi.org/10.1080/17509653.2011.10671160

Koutouzidou, G., Ragkos, A., & Melfou, K. (2022). Evolution of The Structure and Economic Management of The Dairy Cow Sector. *Sustainability, 14*(18), 1-12. http://dx.doi.org/10.3390/su141811602

Krause, P., & Nowoświat, A. (2019). Experimental Studies Involving the Impact of Solar Radiation on The Properties of Expanded Graphite Polystyrene. *Energies, 13*(1), 1-17. http://dx.doi.org/10.3390/en13010075

Lima, L. P., Ribeiro, G. B. D., Silva, C. A. B., & Perez, R. (2018). An Analysis of The Brazilian Dairy Industry Efficiency Level. *International Food Research Journal, 25*(6), 2478-2485.

Liu, J., Lu, L., Lu, W., & Lin, B. J. Y. (2013). Data Envelopment Analysis 1978–2010: A Citation-based Literature Survey. *Omega, 41*(1), 3-15. http://dx.doi.org/10.1016/j.omega.2010.12.006

Liu, X., Ji, X., Li, M., & Wu, J. (2022). A Two-Stage Environmental Efficiency Evaluation of China's Industrial Sector Considering Ratio Data. *Annals of Operations Research*. http://dx.doi.org/10.1007/s10479-022-04981-0

Lukač, Z., & Gardijan, M. (2017). *Measuring the Efficiency of the Food Industry in Central and East European Countries by using the Data Envelopment Analysis Approach.* Paper presented at the Proceedings of the 6th International Conference on Operations Research and Enterprise Systems (ICORES 2017.

Mavrommati, A., Chatzitheodoridis, F., Pliakoura, A., & Kontogeorgos, A. (2024). DEA-based Malmquist Productivity Indexes for Assessing Greek Tourism Regions. *Scientific Annals of Economics and Business, 71*(1), 75-90. http://dx.doi.org/10.47743/saeb-2024-0002

Mavrommati, A., Kontogeorgos, A., & Chatzitheodoridis, F. (2021). Greek Fish Farming: Measuring Profitability and Efficiency of The Sector at The Peak of Economic Crisis. *WSEAS Transactions on Business and Economics, 18*(September), 1272-1279. http://dx.doi.org/10.37394/23207.2021.18.118

Mavrommati, A., & Migdalas, A. (2005). Hierarchical Modeling for The Agricultural Sector in Greece and Bilevel Programming. *Journal of Financial Decision Making, 1*(2), 53-65.

Mavrommati, A., & Papadopoulos, A. (2005). Measuring Advertising Intensity and Intangible Capital in The Greek Food Industry. *Applied Economics, 37*(15), 1777-1787. http://dx.doi.org/10.1080/00036840500217267

Mavrommati, A., Tsiouni, M., Kontogeorgos, A., & Chatzitheodoridis, F. (2022). Performance of The Greek Fish Farming Sector: Technical Efficiency Evaluation via Data Envelopment Analysis. *Reg Sect Econ Stud, 22*(1), 5-17.

Mo, J. E., Mok, Z. Y., Tan, S. M. S., & Khezrimotlagh, D. (2014). Measuring The Efficiency of The Dairy Industry: Using DEA Models. *Scholars Journal of Economics, Business and Management, 1*(11), 563-567. http://dx.doi.org/10.36347/sjebm.2014.v01i11.005

Oukil, A. (2024). Devising The Best Prospective Merger Plan for A Banking Sector Through A Hybrid DEA-based Methodology: An Inverse DEA Perspective *Handbook on Data Envelopment Analysis in Business, Finance, and Sustainability: Recent Trends and Developments* (pp. 273-306): World Scientific. http://dx.doi.org/10.1142/9781800615786_0009

Pliakoura, A., Beligiannis, G., Mavrommati, A., & Kontogeorgos, A. (2024a). Agricultural Entrepreneurship Research: Challenges and Sustainable Development Issues. *Agricultural Economics Review, 25*(1), 33-51.

Pliakoura, A., Beligiannis, G. N., Mavrommati, A., & Kontogeorgos, A. (2024b). Strengths and Weaknesses for The Young Farmers To Abide in The Greek Countryside: A Triangulation Approach. *Journal of Agribusiness in Developing and Emerging Economies, 14*(4), 733-748. http://dx.doi.org/10.1108/JADEE-10-2022-0235

Ray, S. C. (2004). *Data Envelopment Analysis: Theory and Techniques for Economics and Operations Research*: Cambridge University Press. http://dx.doi.org/10.1017/CBO9780511606731

Reddy, K. J. M., Rao, A. N., & Krishnanand, L. (2019). A Review on Supply Chain Performance Measurement Systems. *Procedia Manufacturing, 30*, 40-47. http://dx.doi.org/10.1016/j.promfg.2019.02.007

Ruales-Guzmán, B. V., Rodríguez Lozano, G. I., & Castellanos Domínguez, O. F. (2021). Measuring Productivity of Dairy Industry Companies: An Approach with Data Envelopment Analysis. *Journal of Agribusiness in Developing and Emerging Economies, 11*(2), 160-177. http://dx.doi.org/10.1108/JADEE-05-2020-0100

Saha, D. (2020). *Economics of The Food Processing Industry: Lessons from Bihar*: Springer. http://dx.doi.org/10.1007/978-981-13-8554-4

Seiford, L. M., & Zhu, J. (1999). An Investigation of Returns to Scale in Data Envelopment Analysis. *Omega, 27*(1), 1-11. http://dx.doi.org/10.1016/S0305-0483(98)00025-5

Sellers-Rubio, R. (2010). Evaluating The Economic Performance of Spanish Wineries. *International Journal of Wine Business Research, 22*(1), 73-84. http://dx.doi.org/10.1108/17511061011035215

Soltani, A. A., Oukil, A., Boutaghane, H., Bermad, A., & Boulassel, M. R. (2021). A New Methodology for Assessing Water Quality, based on Data Envelopment Analysis: Application to Algerian Dams. *Ecological Indicators, 121*(February), 1-18. http://dx.doi.org/10.1016/j.ecolind.2020.106952

Theodoridis, A., & Psychoudakis, A. (2008). Efficiency Measurement in Greek Dairy Farms: A Comparison of DEA and SFA Methods. *Agricultural Economics Review, 9*(1), 49-60.

Vlontzos, G., & Theodoridis, A. (2013). Efficiency and Productivity Change in the Greek Dairy Industry. *Agricultural Economics Review, 14*(2), 1-15. http://dx.doi.org/10.22004/ag.econ.253542

Voulgaris, F., Papadogonas, T., & Lemonakis, C. (2013). Drivers of Competitiveness in The Manufacturing Industry: The Case of Technology Sectors in Greece. *Journal of Economics and Development Studies, 1*(3), 32-40.

Yang, H., & Ma, X. (2019). Uncovering CO2 Emissions Patterns from China-Oriented International Maritime Transport: Decomposition and Decoupling Analysis. *Sustainability, 11*(10), 1-19. http://dx.doi.org/10.3390/su11102826

Yang, Z. (2006). A Two-Stage DEA Model To Evaluate The Overall Performance of Canadian Life and Health Insurance Companies. *Mathematical and Computer Modelling, 43*(7–8), 910-919. http://dx.doi.org/10.1016/j.mcm.2005.12.011