

Article

Exploring the Role of the Farmer Entrepreneur in the Sheep Milk Production Value Chain in Thessaly, Greece: A Case Study of 24 Farms

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Abstract

The aim of this study was to identify the challenges and opportunities faced by farmers in the sheep milk value chain and their impact on business activities. Techno-economic data were collected from 24 sheep farms with different capacities, management systems, and market connectivity in the Thessaly region. The results of the study show that a series of factors influence the financial situation of the farms, arising from both internal (e.g., management, performance) and external (e.g., market prices, regulations) factors. Efficient farms can reduce production costs and increase profitability, while cooperative members generally enjoy a better position than independent farmers in terms of feed costs and milk production, strengthening their bargaining power. It should be noted that, given the exploratory sample size ($n = 24$), the between-group differences reported here should be interpreted as indicative trends rather than statistically confirmed findings. The results were analyzed through a full techno-economic analysis, calculating key indicators such as milk production costs, net profit and income of agricultural households. Additionally, a sensitivity analysis was conducted to assess the impact of uncertainty in key input parameters (milk price, feed costs) on the net profit of each farm. Tailoring strategies to the specific characteristics of each farm can significantly enhance profitability. Further research is needed to capture the views of all actors in the value chain.

Keywords: production chain; dairy sheep farming; economic viability; entrepreneurial strategies

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1. Introduction

Sheep farming in Greece makes a significant contribution to the national economy, accounting for 18% of the total agricultural income [1]. Furthermore, this sector accounts for 3% of the gross value of total livestock production and 13% of total agricultural pro-

duction. According to the Hellenic Statistical Authority (2023) [2], the number of sheep farms in Greece is approximately 51,014 farms. Most of these farms (over 98%) have the production of sheep's milk as their primary purpose [3]. In 2023, Greece produced approximately 732,000 tonnes of sheep's milk, representing approximately 32% of the total sheep's milk production in the European Union [1].

According to data collected by ELSTAT [4], in 2024 there were 4953 sheep farms in the region of Thessaly, ranking third behind the regions of Western Greece and Crete. Sheep milk production in Thessaly makes a significant contribution to both the local and national economy of Greece [5]. Thessaly is considered the leading region in sheep's milk production (143,033 tonnes) and provides the raw material for the production of Feta PDO cheese, a national product, and other dairy products [6]. Akrivouli [6] reports that cheese production is an important industry in Thessaly, accounting for 40% of the country's soft cheese, 70% of which corresponds to PDO Feta cheese. The gross domestic product of Thessaly totals €12 billion, with the primary sector and manufacturing contributing around 3.5% [7]. Dairy farming involves a wide range of stakeholders, each with a distinct role and varying degrees of influence [8,9]. The participants in the value chain, ranging from small producers to large corporations with specific market concentrations, develop diverse relationships with each other. These interactions result in the formation of complex networks referred to as value chains [9,10]. By studying value chains, the interactions of economic, social and environmental factors can be recorded, ensuring the sustainability of farms and addressing imbalances between different stakeholders [11,12]. Taylor [13] emphasizes the importance of value chains in improving on-farm practices, increasing efficiency and reducing costs. Efficiency on a sheep farm refers to the optimal use of resources to maximize outputs such as milk, while minimizing inputs such as feed. Efficiency can be assessed in different ways, including technical and economic efficiency [14].

Livestock farmers are upstream in the value chain, and their practices have a significant impact on the quality and quantity of milk produced [15,16]. Intensive systems can achieve higher animal productivity as they include controlled feeding and breeding practices [17,18]. In contrast, semi-intensive systems usually have lower-yielding animals, but this is often offset by lower feed costs due to grazing [19]. Semi-intensive systems are usually characterized by low-yielding herds, which can have a negative impact on the financial situation of the farm [20]. Farmers in these systems often face numerous market challenges, including fluctuations in the prices of inputs, such as feed, as well as in the selling prices of their products and their liquidity, which significantly affect the economic viability of their farms [21,22]. Price volatility in European small ruminant milk markets is similarly documented across Mediterranean livestock systems [19,23]. According to Alvarez et al. [24], livestock farmers often implement various strategies to adapt to market changes and use their entrepreneurial skills to effectively overcome the challenges they face. Techno-economic analysis enables evaluation of farmers' strategic decisions and their effects on farm financial performance [25].

Collaboration among value chain participants can facilitate livestock farmers' access to material and non-material resources, contributing to the resilience of agri-food systems [26].

The research focuses exclusively on sheep farming and deliberately excludes goat farming, as sheep represent a significantly larger population [25]. The prevalence of sheep milk in cheese production highlights the significant economic impact of sheep farming. The literature review shows that most existing studies focus mainly on the techno-economic aspects of farms, often neglecting the impact of market dynamics. For example, Theodoridis et al. [20,27] applied efficiency analysis to Greek and European dairy sheep and sheep-meat farms to identify best practices and productivity gains at farm level, and Papanikolopoulou et al. [28] compared the economic performance of Greek dairy sheep

farms in less-favoured areas by flock size and farming system; both study lines quantify cost and efficiency differences between farms but do not examine how farmers' marketing arrangements (e.g., cooperative versus individual delivery) or their position within the wider value chain relate to those economic outcomes. Ragkos et al. [29] come closer to a market-dynamics perspective by comparing alternative summer milk-sale arrangements for transhumant flocks, but this analysis is limited to a single marketing decision rather than a full mapping of value-chain relationships and entrepreneurial strategies. The present study aims to fill this gap by mapping the sheep milk value chain in Thessaly, with a special focus on the role of farmers as entrepreneurs. It analyzes the relationships between the different actors within the value chain and documents the challenges faced by farmers. In addition, the study investigates the strategies used by farmers to address these challenges and the resulting impact on the technical and economic performance of their livestock farms. Sensitivity analysis is used to assess how uncertainty in the price of sheep's milk affects gross and net profits [30,31]. The study addresses the research objective of examining how strategic responses of farmers and entrepreneurs, together with market dynamics and cooperative membership, influence the financial performance of farms in the sheep milk value chain. The central research question examines the economic viability of livestock farms in the sheep milk value chain in Thessaly and specifically investigates whether participation in cooperative structures provides a significant advantage in terms of production costs, milk yield, and overall profitability. In this context, the opportunities and challenges faced by livestock farmers in this specific value chain are recorded. Finally, the strategies implemented by livestock farmers and their effects on the financial situation of their livestock businesses are analyzed.

2. Materials and Methods

2.1. Study Design and Case Study Rationale

Given the relatively small sample of 24 farms, this study is formally structured as a case study of the sheep milk value chain in Thessaly, rather than a statistically representative survey. This study aimed to collect the views of livestock farmers on the sheep milk value chain and to conduct a techno-economic evaluation of their farms. Farmers hold a crucial position in this system, as they are the first link in the value chain [32–34]. Their management practices can significantly influence both the quantity and quality of the sheep milk produced [35]. Specifically, primary data were collected through interviews with 24 farmers in the sheep milk value chain in the region of Thessaly, selected through a purposive, stratified quota procedure rather than simple random sampling (see Table 1 and further detail below). The farms were selected according to certain criteria, such as the ownership of sheep and active participation in the sheep milk value chain. All farmers who were approached and met these selection criteria agreed to participate; no farmer declined, and no replacement procedure was therefore required. To ensure that our sample reflects the diversity of farms in Thessaly, we used a stratified sampling method in which farms were classified into four main categories based on the number of ewes: tiny, small, medium, and large. The categorization of farms was based on the categories used by [4,35]. Each category includes six farms, three of which supply their milk to cooperatives, while the others work individually with dairies. The allocation of six farms per category was determined on practical and feasibility grounds and is consistent with comparable techno-economic studies of small ruminant farming in Greece and the Mediterranean region [28]. Specifically, an equal number of six farms per category was chosen so that each of the four farm-size categories would be represented by the same number of case studies, given the number of researchers available to conduct the in-depth, two-hour interviews within the study's field-work period. Given the exploratory nature of this study, findings should be interpreted as indicative rather than statistically representative

of all sheep farms in Thessaly. This approach promotes a balanced representation of the different functional relationships within the sheep milk value chain. In the tiny farm category, extensive (smallholder) farming is practised. In the small, medium and large categories, semi-intensive or intensive farming is practiced. The four farm categories allow us to better capture the different business decisions made by livestock farm owners. The sheep breed used on the farms is Lacaune. It should be noted that the exclusive use of the Lacaune breed, while ensuring genetic homogeneity, limits generalizability to farms using indigenous Greek breeds (e.g., Chios, Boutsiko, Karagouniko), which may show different production economics. This limitation is further discussed in Section 4.

Table 1. Farm size class, sample distribution and interviews completed.

Class of Sheep Farm Size (No. of Ewes)	Number of Sheep Farms	Sample Distribution	Number of Interviews Completed
Tiny (<10)	559	6	6
Small (10–49)	1024	6	6
Medium (50–99)	781	6	6
Large (>100)	2589	6	6
Total	4953	24	24

Processing of data by [4] and author's own work.

In January and February 2024, interviews were conducted in Thessaly, using a detailed questionnaire to record the techno-economic situation of the farms. The participants were informed of the study via the local veterinary and agricultural associations. The questionnaire was structured, comprising approximately 20 questions, and was pilot-tested before use in the field. Participation in the survey was voluntary, and informed consent was obtained from all participants. The questionnaire was anonymous, no personally identifying information was collected, and all data were handled confidentially in accordance with the General Data Protection Regulation (Regulation (EU) 2016/679). The collected data were used solely for research purposes and were not shared with any third parties. The researchers calculated the production expenses of milk and the main financial results [36,37]. On all farms, the main product is milk, which holds a significant share in the total production value of the sector (over 10%). The other agricultural products are lamb, meat from old or sterile sheep and wool, each accounting for about 10% (approximately), which is consistent with the standard categorization of agricultural products.

- A main product is the primary output targeted by the production activity, and in this sample also typically corresponds to a significant percentage of the total production value of the sector (more than 10%).
- A secondary product is generated alongside the main product and has economic value, but is not the primary objective of production; in this sample such products typically also account for a smaller share of production value (less than 10%) [36,37].

The typology of the main economic indicators analyzed in this study is presented below:

- The cost of producing 1 kg (kg) of dairy sheep milk is equal to the quotient of the expenses of milk production divided by the total weight produced. Operationally, it is calculated as

$$C_{milk} = \frac{TC_{milk}}{V_{milk}}$$

where TC_{milk} represents the total production costs allocated to the sheep dairy farm and is calculated as the total annual production cost net of the secondary income generated

from lamb carcass sales (using an average carcass weight of 12.5 kg and a price of €6.00 per kg). V_{milk} is the total weight of sheep milk produced (kg). The resulting C_{milk} yields the production cost per kilogram of milk (€/kg) reported for each farm. The total production costs are broken down into variable costs (including purchased concentrates, domestic fodder, veterinary drugs, vaccines, electronic ear tags, temporary milking labour and milking parlor electricity/water) and fixed costs (including milking parlor and building depreciation, insurance and pasture/land rents).

- Gross income is the total value of sales of the agricultural production sector in each period, including potential production subsidies. The mathematical formulation is expressed as

$$GI = \sum (P_i \times Q_i) + S$$

where P_i is the market price of product i and Q_i is the quantity sold. In this dairy-focused system, the products include sheep's milk (primary product), meat from unweaned lambs and slaughtered ewes (secondary product), and wool. S represents direct agricultural subsidies, including coupled support for dairy ewes and decoupled financial aid.

- Net profit is calculated by subtracting all production expenses from gross income. It reflects the final economic return of the dairy sheep farm and is modeled as

$$NP = GI - TC$$

- Gross profit is calculated by subtracting variable expenses from gross income. This indicator isolates the short-term viability of the milking flock before considering fixed overheads, defined as

$$GP = GI - VC$$

where VC represents the total variable costs.

- Agricultural family income is the residual amount obtained by subtracting all apparent expenses (paid expenses + depreciation + self-insurance) from gross income. This metric remunerates the family labor, land and capital invested in the dairy sheep farm [36,37].

The calculation of economic results was conducted in a manner consistent with the FADN database [38]. Specifically, the raw data collected from dairy sheep farms were standardized and mapped to the official FADN structural codes. Farm declarations were aligned to Gross Production (FADN code SE131), total operating costs were mapped to Total Inputs (SE270) and family profits were cross-checked using the Family Farming Income framework (SE420). For farms with small secondary activities, standardized allocation keys based on the contribution of gross production were used to isolate and attribute common overheads (e.g., machinery fuel, multi-crop land rent) exclusively to the dairy sheep sector.

The economic indicators reported throughout the manuscript refer to the 2023 production year, corresponding to the field-work and interview period; the multi-year sheep-milk selling-price series presented for market-context purposes (Section 3.1) was not averaged into these farm-level indicators. A sensitivity analysis was additionally conducted as part of the techno-economic assessment, applying a standard $\pm 10\%$ worst-case/best-case scenario approach: milk price and feed cost were varied simultaneously and in opposite directions (worst case: milk price -10% and feed cost $+10\%$; best case: milk price $+10\%$ and feed cost -10%), with all other inputs held at their base-case (2023) values, to bound the range of short-term net profit outcomes for each of the 24 farms under adverse and favourable market conditions.

Prior to the interview, a questionnaire outline was sent to participants so that they could prepare for the questions. Each interview lasted two hours. While the overall sample size of 24 farms is relatively small, ($n = 24$; Lacaune breed only—results may not extend to farms using indigenous Greek breeds) the use of a stratified, quota-based purposive sampling design enhances the reliability of our findings by allowing meaningful comparisons between different farm sizes. Secondary data were collected through a comprehensive literature review.

2.2. Study Area

This study was carried out in Thessaly, one of the 13 administrative regions of Greece, located in the central-eastern part of the country and bordered by the Aegean Sea to the east. Thessaly covers a total area of approximately 14,037 km², making it the second largest of Greece's regions, and had a population of about 688,000 in 2021. It is administratively subdivided into five regional units; the interviewed farms in this study are located across the four mainland regional units of Larissa, Trikala, Karditsa, and Magnesia (the fifth, Sporades, comprises islands with no relevant sheep milk production). Thessaly is dominated by the largest plain in Greece, which supports intensive arable farming, while sheep and goat farming—the focus of this study—is concentrated mainly in the semi-mountainous and mountainous margins of the region. The region is Greece's leading producer of sheep milk (22.3% of national output) and is also the country's largest producer of Feta cheese, the second most important exportable Greek agri-food product after olive oil [29,39]. This combination of a large, geographically diverse pastoral base and a well-developed downstream dairy-processing sector makes Thessaly a suitable case-study setting for examining the sheep milk value chain and the role of cooperative versus independent marketing arrangements. A more detailed mapping of the sector's farms, cooperatives, and dairies is provided in Section 2.4.

2.3. Statistical Analysis

Given the exploratory nature of the study and the limited sample size ($n = 24$), the analytical approach was primarily descriptive. Continuous variables (e.g., production costs, milk yield, net profit, gross income, agricultural family income) are summarized as means and standard deviations for the cooperative and independent subgroups and, where relevant, per farm-size category. Between-group comparisons (cooperative vs. independent) are reported as descriptive differences in means rather than as results of formal hypothesis tests, consistent with the exploratory, non-representative nature of the sample. The only inferential statistic reported is a Spearman rank correlation coefficient, used to assess the monotonic association between herd size (number of ewes) and net profit (Section 3.2); Spearman's rho was chosen over Pearson's r because herd size and net profit are not assumed to be linearly related or normally distributed at this sample size. All calculations were performed in Microsoft Excel 2019 (Microsoft Corp., Redmond, WA, USA). No correction for multiple comparisons was applied, as this single correlation was specified a priori as a check on the economies-of-scale pattern suggested by the descriptive results, rather than as part of an exploratory multiple-testing procedure. In addition, three further exploratory Spearman correlations were computed across the full sample ($n = 24$, two-tailed, $\alpha = 0.05$) to further characterise the economies-of-scale pattern identified for herd size and net profit: between herd size and production cost per kg, between milk yield per ewe and net profit, and between the feed-cost index and net profit; the corresponding results are reported in Section 3.2.

2.4. Mapping the Value Chain of Sheep Milk in Thessaly

To capture the various relationships that develop between the main stakeholders in the milk value chain, we have distinguished three levels:

- **Farms:** There are 4953 sheep farms in the geographical area of Thessaly, which are categorized according to the number of animals in the following size categories: 5% are tiny (<10 animals), 21% are small (10 to 49 animals), 16% are medium-sized (50 to 99 animals), and 52% are large (100 animals and more) [4]. The size of sheep farms has increased in recent years. Between 2009 and 2020, there was a significant decline in the number of sheep farms (41%) and livestock populations (16.1%). Sheep and goat farming is practiced in extensive, semi-intensive or intensive systems. In recent years, the number of intensive farms has increased [28]. Sheep and goat farms are mainly located in semi-mountainous areas [3]. Key participants in the value chain highlighted that livestock farming plays an important social role. Sheep farm owners often include retirees, people looking to supplement their main income, and young people looking to enter the profession and acquire the necessary skills. Many retirees continue to work on their farms to remain active in their rural communities [40]. This allows farms to operate smoothly while ensuring that knowledge and skills are passed down from generation to generation [41]. Farmers who rely on their farms for supplementary income often maintain a small flock of sheep [42]. Many young people (18 to 44 years old) are drawn to sheep farming because of family ties and a love for nature and animals [43].
- **Cooperative–Producer groups:** In Thessaly, there are 13 agricultural cooperatives involved in livestock production and related products. One of these cooperatives has about 600 members, followed by two with more than 100 members each; one has about 70 members, and the remaining cooperatives have fewer than 50 members. In addition, there are three groups of milk producers in the analysed area [44]. Cooperatives and producer groups are two different forms of cooperation in which farmers can participate. Cooperatives are a legal entity that owns property, while producer groups do not necessarily need to be separate legal entities. Producer groups can operate within the framework of cooperatives, which has been demonstrated in the livestock sector in Thessaly. In addition, they can take the form of limited liability companies or private equity firms. Cooperatives consist of a board of directors and a general assembly, where all members participate. Producer groups are formed by producers of similar products. The National Union of Agricultural Cooperatives represents the agricultural cooperatives of Greece as well as the other legal entities registered in the National Register of Agricultural Cooperatives of the Ministry of Rural Development and Food. Several livestock cooperatives are members of the union [7].
- **Dairies:** Dairy production is considered one of the most important production sectors in the Thessaly region. There is a total of 98 dairies in this region, 46 of which are in the regional unit of Larissa, 28 in the regional unit of Trikala, 15 in the regional unit of Magnesia, and 9 in the regional unit of Karditsa. Most dairies in Larissa process only goat and sheep milk (84%), followed by those that process cow, goat, and sheep milk (13%), and a few that process only sheep milk (3%). Most dairies are located in Ellassona. In the Larissa regional unit, large dairies that process over 10 tonnes of milk per day, account for 22%, while 72% of dairies process between 1 and 10 tons of milk per day. The remaining dairies produce less than one ton of milk per year. The regional units of Karditsa, Trikala, and Magnesia are home to large dairies that produce more than 10 tonnes, with shares of 33%, 50%, and 67%, respectively. Fifty dairies in the region of Thessaly produce cheese with a Protected Designation of Origin (PDO).

The dairies in Thessaly generate twice the turnover and employ twice the average number of personnel compared to dairies of similar size across the country [39,45].

3. Results

3.1. The Governance of Sheep Milk in Thessaly

The region of Thessaly is considered the center of small ruminant milk production, acting as a regulator for the selling prices of goat and sheep milk throughout Greece [45]. The supply and demand for Greek Feta PDO cheese on the market can influence milk prices and payments [46]. Domestic consumption of Feta PDO cheese has decreased significantly, leading to an accumulation of unsold stocks in both dairies and supermarkets. The most dominant actors in terms of bargaining power, such as supermarkets, exert pressure on dairies to lower prices, which is subsequently passed on to livestock farmers. The decline in the wholesale price of Feta abroad may also affect negotiations on goat and sheep milk prices at the national level [47,48]. Since 2023, a decline has been recorded in the selling price of goat and sheep milk in the region of Thessaly. In 2024, the price of sheep's milk was €1.52/kg, while in 2025, the price fell to €1.45/kg [49] (Figure 1).

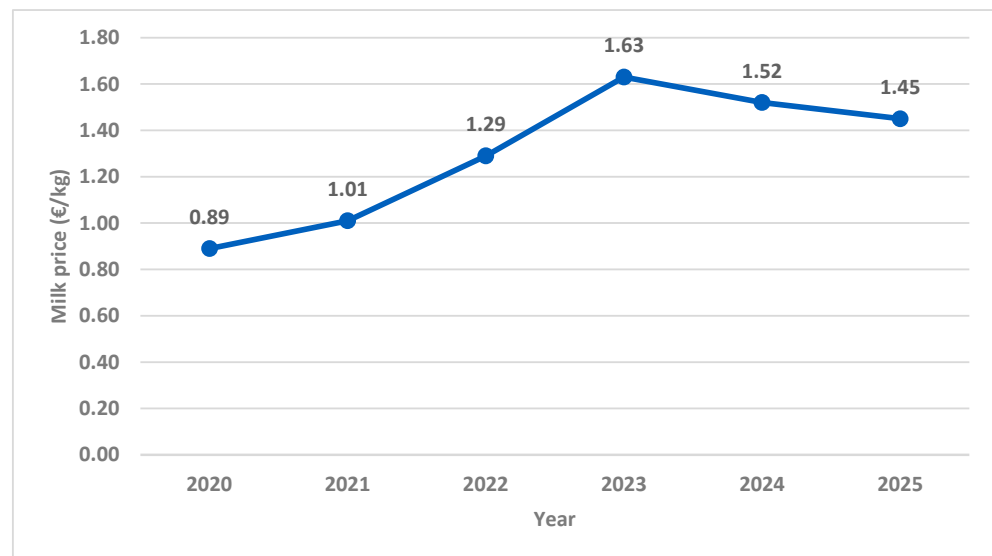


Figure 1. Average selling price of sheep's milk for the years 2020–2025 in the region of Thessaly. Data from [49], edited by the authors.

Figure 2 illustrates the different pathways through which dairy products move from farmers to consumers, highlighting the role of the various intermediaries and processors. There are two main routes for the milk produced by farmers, leading to distinct distribution channels. Path 1 shows that farmers can supply their milk to cooperatives, which then forward it to dairies for processing. Path 2 shows that farmers can choose to supply their milk directly to dairies, bypassing cooperatives altogether. Once the milk is processed by the dairies, the resulting dairy products reach consumers via different distribution channels. Dairies can distribute their products to wholesalers, who subsequently sell them to retailers, who in turn sell them directly to consumers. Alternatively, a more direct route exists where dairies supply products directly to retailers for sale to consumers.

Payment terms for milk vary depending on the agreements between farmers and dairies. Farmers often build long-term relationships of trust with dairies, especially since many dairy farms are family-owned and many dairies supply local markets. Some farmers experience price adjustments or delayed payments, depending on the quantity and quality of the milk and the financial situation of the dairies. Delays can occur if a specific

payment date is not established in advance, and dairies with lower production capacity can occasionally experience cash flow problems. In contrast, farmers who belong to cooperatives usually have formal contracts that guarantee milk purchases and stable prices throughout the season, as cooperatives possess a stronger negotiating position (Figure 2). Furthermore, cooperatives provide access to trained professionals, shared facilities (such as milk analysis laboratories) and essential resources like animal feed. This support can contribute to improving animal performance and reducing the cost of milk production. All survey participants who are members of collective systems indicated that they have participated in training seminars organized by their respective institutions, which enhanced both their animal husbandry and business management skills.

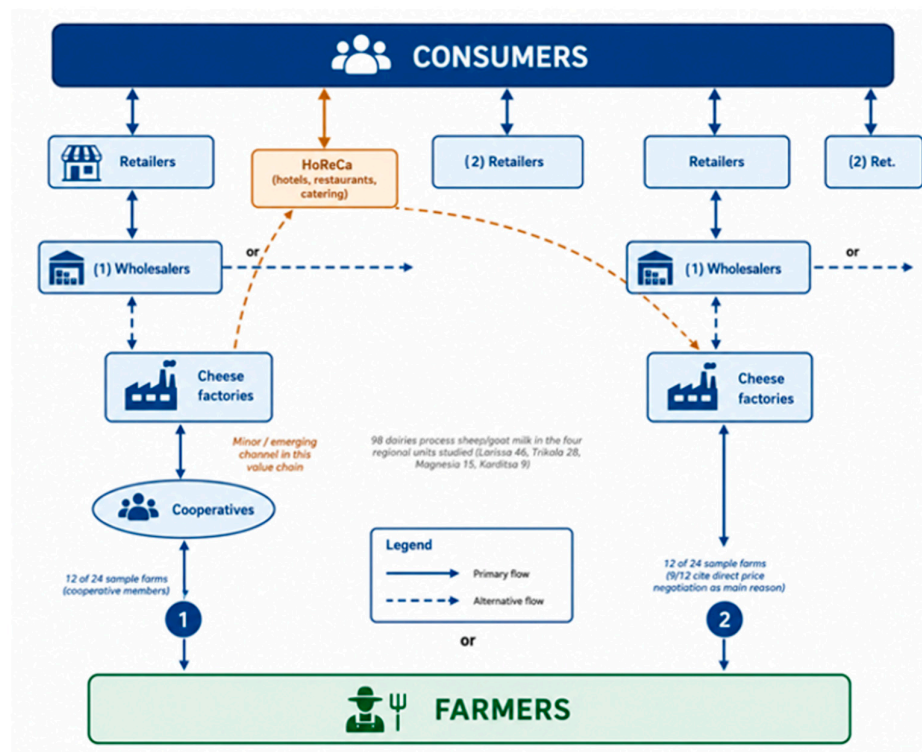


Figure 2. Mapping the players and governance of the sheep milk value chain in Thessaly, including the HoReCa (hotels, restaurants, catering) channel as a minor downstream outlet supplied by both pathways. Numbers indicate the sample distribution across pathways (12 of 24 farms via cooperatives, 12 of 24 direct to dairies) and the number of dairies operating in each regional unit (Section 2.4).

Nine of the twelve farmers who work directly with dairies explicitly stated that the reason for choosing such a partnership is that they negotiate the milk price directly and meet the market without intermediaries, ensuring a direct cash flow without the bureaucracy required by a cooperative. However, all survey participants who deliver their milk individually to dairies emphasized that they lack the security of a stable payment. At the end of the calendar year, which coincides with the start of sheep and goat births and milk production, negotiations commence between dairies and cooperatives to determine milk prices for the following year. Some individual farmers deliver their milk at open (spot) prices to dairies without contracts, which leads to considerable uncertainty in payment terms and milk prices. On the other hand, all farmers who are members of cooperatives stated that they feel confident about improving their businesses, such as expanding their farms, as they receive advice and enjoy better access to resources.

3.2. Techno-Economic Analysis of Sheep Farms

Within the study sample, farmers delivering milk individually to dairies obtained slightly higher average milk prices than those marketing their milk through cooperatives (Tables 2 and 3). Specifically, the average milk selling price for individual farmers is €1.52 per kilogram, while for cooperative farmers, it is €1.51 per kilogram, without rounding. However, the average production expenses of milk are substantially lower for farmers organized in cooperatives (€1.40 per kg) than for individual farmers (€1.90 per kg) (see Figure 3). The annual production cost for each sheep farm is calculated by summing variable costs, fixed capital costs and imputed labour costs. Variable costs mainly include the cost of purchasing feed, which is reflected through the specific feeding costs of each farm (the Feed Cost Index per ewe), veterinary supplies and operating consumables. Fixed capital costs incorporate the annual depreciation of buildings, machinery and livestock, together with maintenance and insurance fees, which are collectively accounted for at a standard rate of €15.00 per ewe (a benchmark rate consistent with comparable FADN-based studies for small ruminant farms in Greece [28]). To protect the economic model from self-reporting and recall biases typically associated with tracking individual farm assets—where investment time, unpaid family labor, and subjective accounting distort the true values of infrastructure [50]—the baseline total invested capital was determined using a uniform normative market valuation of €400.00 per ewe [51]. This baseline is functionally linked as a standard multiplier to herd size and includes the market value of the livestock along with its proportional share of operational infrastructure and equipment. Finally, opportunity costs and imputed family labor costs are incorporated at a standard regional agricultural wage of €6.00 per working hour. To isolate the specific cost of milk production, the total annual production costs are adjusted by deducting the secondary income generated from lamb carcass sales (calculated with an average carcass weight of 12.5 kg and a price of €6.00 per kg). The remaining net costs are then divided by the total volume of milk produced, yielding the final production cost per kilogram of milk (€/kg) for each individual farm (Tables 2 and 3). The average milk production cost for cooperative farmers (Table 2) is substantially lower than the average selling price of milk. In contrast, the average cost of milk production for individual farmers (Table 3) is substantially higher than the average selling price of milk.

Table 2. Basic data for sheep farms that collaborate with a livestock cooperative.

ID	Class of Sheep Farm Size (No. Ewes Per Farm of Ewes)		Total Farm Milk Production (kg)	Milk Yield Per Ewe (kg/Ewe)	Producer Price for Milk (€/kg)	Production Cost per kg of Milk (€/kg)
Co_1	Tiny (<10)	6	1814.00	302.33	1.50	2.13
Co_2	Tiny (<10)	8	2737.00	342.13	1.50	1.81
Co_3	Tiny (<10)	9	3042.00	338.00	1.50	1.77
Co_4	Small (10–49)	26	7072.00	272.00	1.51	1.63
Co_5	Small (10–49)	30	9435.00	314.50	1.50	1.40
Co_6	Small (10–49)	40	12,860.00	321.50	1.53	1.32
Co_7	Medium (50–99)	53	16,440.00	310.19	1.55	1.33
Co_8	Medium (50–99)	65	18,895.00	290.69	1.52	1.39
Co_9	Medium (50–99)	70	23,590.00	337.00	1.48	1.18
Co_10	Large (>100)	240	67,200.00	280.00	1.54	0.93
Co_11	Large (>100)	270	81,000.00	300.00	1.52	0.86
Co_12	Large (>100)	350	84,000.00	240.00	1.53	1.06

Average $\pm$ SD	-	97.25 $\pm$ 118.63	27,515.42 $\pm$ 31,146.41	282.93 $\pm$ 30.22	1.51 $\pm$ 0.02	1.40 $\pm$ 0.38
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Author's own work. Values in the Average row are presented as mean $\pm$ standard deviation (SD).

Table 3. Basic data for individual sheep farms.

ID	Class of Sheep Farm Size (No. of Ewes)	Ewes Per Farm	Total Farm Milk Production (kg)	Milk Yield Per Ewe (kg/Ewe)	Producer Price for Milk (€/kg)	Production Cost per kg of Milk (€/kg)
Ind_1	Tiny (<10)	5	1465.00	293.00	1.53	2.44
Ind_2	Tiny (<10)	8	2360.00	295.00	1.52	2.30
Ind_3	Tiny (<10)	9	2426.00	269.56	1.51	2.47
Ind_4	Small (10–49)	17	4072.00	239.53	1.50	2.38
Ind_5	Small (10–49)	21	5880.00	280.00	1.53	1.86
Ind_6	Small (10–49)	24	5700.00	237.50	1.53	2.12
Ind_7	Medium (50–99)	50	13,325.00	266.50	1.55	1.73
Ind_8	Medium (50–99)	80	17,840.00	223.00	1.48	1.95
Ind_9	Medium (50–99)	92	22,126.00	240.50	1.52	1.73
Ind_10	Large (>100)	220	50,094.00	227.70	1.56	1.35
Ind_11	Large (>100)	310	62,000.00	200.00	1.50	1.34
Ind_12	Large (>100)	400	92,640.00	231.60	1.56	1.17
Average $\pm$ SD	-	103 $\pm$ 133.50	23,327.33	226.48 $\pm$ 29.92	1.52 $\pm$ 0.02	1.90 $\pm$ 0.45

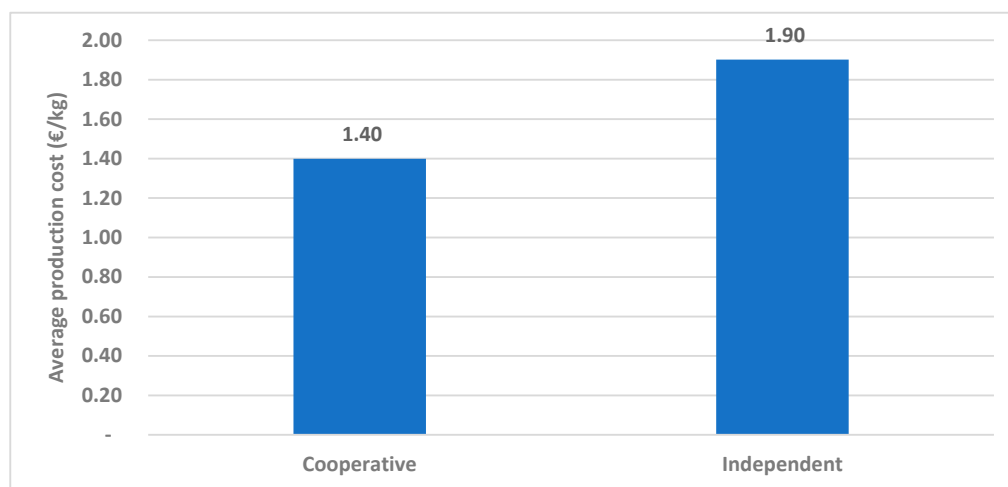


Figure 3. Descriptive comparison of average milk production costs (€/kg) among cooperative members and independent sheep farms in the study sample. Author's own work.

Tables 4 and 5 illustrate the main financial results of each evaluated farm. Tables 6 and 7 selectively present the two main economic indicators—net profit and agricultural family income per ewe—to allow an easy comparison between farms. In this empirical analysis, gross income represents the total accrued value of milk and lamb sales plus production subsidies. Gross profit is obtained by subtracting variable costs from this gross volume, while the net profit reflects the remainder after deducting all operating costs. In this analysis, variable feed costs serve as the main variable cost, as feed systematically represents over 60–75% of total variable costs in Greek sheep farming [20,52]. Accordingly, farm family income is obtained by adding the imputed value of family labor back to the net profit. For example, focusing on farm Co_11, while its net profit is estimated at €72,670.34 after deducting all production costs, the agricultural family income reaches €101,470.34 once the €28,800.00 of imputed family labor is added, presenting the real disposable income remaining in the household. European agricultural subsidies (basic pay-

ment, coupled payment and compensatory payment) reach an average of €9050.00 for cooperative farms and €9941.67 for independent farms, notably affecting financial results. From farm No. Co_2 onwards, the net profit becomes positive. Farms from No. Ind 1 to Ind 4 show a negative net profit (see Table 5 and Figure 4). Figure 4 illustrates a strong positive correlation between herd size and net profit (Spearman's $\rho = 0.91$, $p < 0.001$ for the full sample of $n = 24$), highlighting the role of achieving economies of scale. Three further Spearman correlations computed across the full sample ($n = 24$, two-tailed, $\alpha = 0.05$) reinforce this pattern: herd size was strongly negatively correlated with production cost per kg ($\rho = -0.82$, $p < 0.001$), milk yield per ewe was strongly positively correlated with net profit ($\rho = 0.95$, $p < 0.001$), and the feed-cost index was negatively correlated with net profit ($\rho = -0.71$, $p < 0.001$); these associations are interpreted with the same caution given the exploratory sample size. In addition to this, the financial results of the farms can be affected by various factors, such as the selling prices of milk and lamb, applicable subsidies, production costs, resource management and animal productivity [53–56]. In this context, it is worth noting the difference in average milk yield per ewe between farms collaborating with a cooperative and independent ones (see Tables 2 and 3) and its impact on financial results (see Tables 4 and 5).

Table 4. Economic performance indicators of the sheep farms that collaborate with a livestock cooperative.

ID	Gross Income (€)	Net Profit (€)	Gross Profit (€)	Agricultural Family Income (€)
Co_1	4096.00	−134.00	2656.00	2566.00
Co_2	5830.50	350.50	4070.50	3950.50
Co_3	6563.00	593.00	4628.00	4493.00
Co_4	16,328.72	3148.72	10,738.72	10,348.72
Co_5	20,602.50	5452.50	14,302.50	13,852.50
Co_6	28,300.80	8700.80	20,100.80	19,500.80
Co_7	37,857.00	12,662.00	27,257.00	26,462.00
Co_8	43,845.40	13,395.40	31,170.40	30,195.40
Co_9	51,413.20	19,063.20	38,113.20	37,063.20
Co_10	135,988.00	58,708.00	86,308.00	82,708.00
Co_11	160,870.00	72,670.00	105,520.00	101,470.00
Co_12	173,020.00	61,270.00	99,520.00	94,270.00
Average $\pm$ SD	57,059.59 $\pm$ 62,393.91	21,323.34 $\pm$ 26,704.38	37,032.09 $\pm$ 38,099.61	35,573.34 $\pm$ 36,363.54

Author's own work.

Table 5. Economic performance indicators of the individual sheep farms.

ID	Gross Income (€)	Net Profit (€)	Gross Profit (€)	Agricultural Family Income (€)
Ind_1	3341.45	−533.55	1941.45	1866.45
Ind_2	5137.20	−742.80	2977.20	2857.20
Ind_3	5388.26	−1121.74	2913.26	2778.26
Ind_4	9658.00	−1102.00	5153.00	4898.00
Ind_5	13,546.40	1276.40	8191.40	7876.40
Ind_6	13,721.00	161.00	7721.00	7361.00
Ind_7	31,803.75	5603.75	19,553.75	18,803.75
Ind_8	42,278.20	2678.20	23,078.20	21,878.20
Ind_9	52,256.52	8256.52	30,636.52	29,256.52
Ind_10	126,646.64	45,746.64	76,046.64	72,746.64

Ind_11	125,250.00	25,030.00	54,880.00	50,230.00
Ind_12	193,518.40	61,518.40	103,518.40	97,518.40
Average $\pm$ SD	51,878.82 $\pm$ 62,479.57	12,230.90 $\pm$ 20,933.53	28,050.90 $\pm$ 33,161.67	26,505.90 $\pm$ 31,249.68

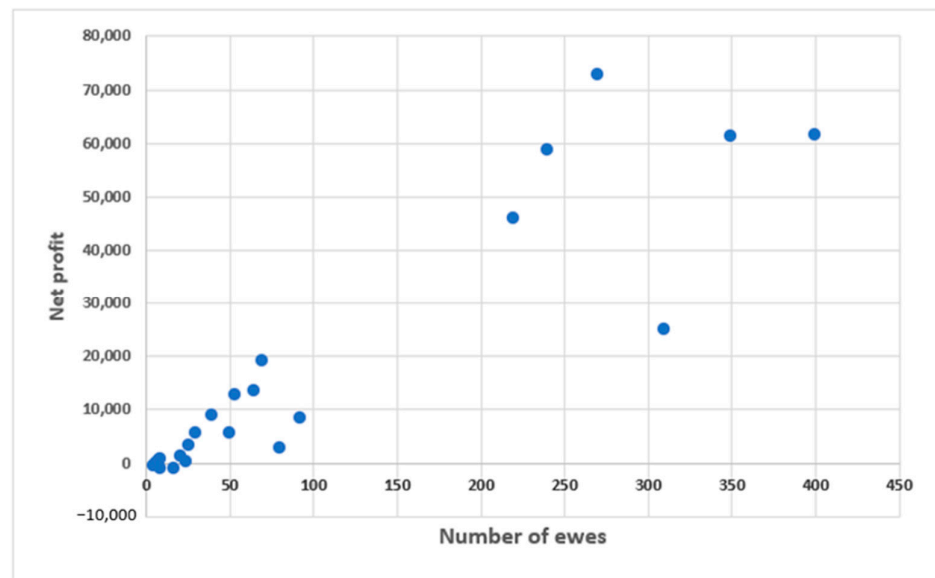


Figure 4. Scatter plot reflecting the relationship between ewe flock size and net profit in the 24 sheep farms studied. Author's own work.

Table 6. Aggregated economic performance indicators presentation per ewe for the sheep farms that collaborate with a livestock cooperative.

ID	Gross Income (€/Ewe)	Net Profit (€/Ewe)	Gross Profit (€/Ewe)	Agricultural Family Income (€/Ewe)
Co_1	682.67	−22.33	442.67	427.67
Co_2	728.81	43.81	508.81	493.81
Co_3	729.22	65.89	514.22	499.22
Co_4	628.03	121.10	413.03	398.03
Co_5	686.75	181.75	476.75	461.75
Co_6	707.52	217.52	502.52	487.52
Co_7	714.28	238.91	514.28	499.28
Co_8	674.54	206.08	479.54	464.54
Co_9	734.47	272.33	544.47	529.47
Co_10	566.62	244.62	359.62	344.62
Co_11	595.81	269.15	390.81	375.81
Co_12	494.34	175.06	284.34	269.34
Average $\pm$ SD	661.91 $\pm$ 75.66	167.82 $\pm$ 95.55	452.59 $\pm$ 77.13	437.59 $\pm$ 77.13

Author's own work.

Table 7. Aggregated economic performance indicators presentation per ewe for the individual sheep farms.

ID	Gross Income (€/Ewe)	Net Profit (€/Ewe)	Gross Profit (€/Ewe)	Agricultural Family Income (€/Ewe)
Ind_1	668.29	−106.71	388.29	373.29
Ind_2	642.15	−92.85	372.15	357.15
Ind_3	598.70	−124.64	323.70	308.70
Ind_4	568.12	−64.82	303.12	288.12
Ind_5	645.07	60.78	390.07	375.07
Ind_6	571.71	6.71	321.71	306.71
Ind_7	636.08	112.08	391.08	376.08
Ind_8	528.48	33.48	288.48	273.48
Ind_9	568.01	89.74	333.01	318.01
Ind_10	575.67	207.94	345.67	330.67
Ind_11	404.03	80.74	177.03	162.03
Ind_12	483.80	153.80	258.80	243.80
Average ± SD	574.18 ± 75.21	29.69 ± 107.90	324.43 ± 62.83	309.43 ± 62.83

Author's own work.

To better understand farm management, Tables 8 and 9 present the feed expenses per ewe and the average capital invested for each farm. As expected, the capital invested is lower in extensive (smallholder) farming than in intensive farming.

Table 8. Feeding cost per ewe and average invested capital per farm that collaborates with a live-stock cooperative.

ID	Feeding Expenses per Ewe (€/Ewe)	Average Invested Capital Per Farm (Value of Buildings/Equipment + Value of Livestock + Value of Land) (€/Farm)
Co_1	240.00	2400.00
Co_2	220.00	3200.00
Co_3	215.00	3600.00
Co_4	215.00	10,400.00
Co_5	210.00	12,000.00
Co_6	205.00	16,000.00
Co_7	200.00	21,200.00
Co_8	195.00	26,000.00
Co_9	190.00	28,000.00
Co_10	207.00	96,000.00
Co_11	205.00	108,000.00
Co_12	210.00	140,000.00
Average ± SD	209.33 ± 12.89	38,900.00 ± 47,451.45

Note: The average invested capital per farm reflects a standardised, normative market valuation of €400.00 per ewe (including livestock and proportional infrastructure), functionally linked to the size of the herd. Consequently, the capital invested expressed per animal unit remains uniform across all scales considered.

Table 9. Feeding cost per ewe and average invested capital per individual sheep farm.

ID	Feeding Expenses per Ewe (€/Ewe)	Average Invested Capital Per Farm (Value of Buildings/Equipment + Value of Livestock + Value of Land) (€/Farm)
Ind_1	280.00	2,000.00
Ind_2	270.00	3,200.00
Ind_3	275.00	3,600.00
Ind_4	265.00	6,800.00
Ind_5	255.00	8,400.00
Ind_6	250.00	9,600.00
Ind_7	245.00	20,000.00
Ind_8	240.00	32,000.00
Ind_9	235.00	36,800.00
Ind_10	230.00	88,000.00
Ind_11	227.00	124,000.00
Ind_12	225.00	160,000.00
Average ± SD	249.75 ± 19.25	41,200.00 ± 53,398.26

Note: The average invested capital per farm reflects a standardised, normative market valuation of €400.00 per ewe (including livestock and proportional infrastructure), functionally linked to the size of the herd. Consequently, the capital invested expressed per animal unit remains uniform across all scales considered.

A sensitivity analysis was conducted by varying milk prices and feed costs simultaneously by $\pm 10\%$ (i.e., worst case: -10% milk price AND $+10\%$ feed cost; best case: $+10\%$ milk price AND -10% feed cost) to approximate the worst- and best-case market conditions, keeping all other parameters constant. The $\pm 10\%$ range was selected as a plausible baseline variation for the sensitivity analysis to safety bracket the magnitude of short-term market shocks in Greek sheep milk markets; while the actual 2024–2025 price decline was approximately 4.6%, the wider 10% threshold allows for testing model robustness against more severe economic uncertainty [57,58]. This analysis assessed the impact of economic uncertainty on the net profit of the 24 farms, which are grouped by organizational structure and classified by herd size. The clustered bar chart in Figure 5 shows the changes in net profits across these three scenarios. Net profits for most cooperative farms maintain a high degree of economic resilience. It should be noted that Co_1, the smallest cooperative farm (6 ewes), already records a negative net profit (−€134.00) under base-case conditions; under the worst-case scenario, its loss deepens further, and it should not be included in claims of universal cooperative resilience. For the remaining eleven cooperative farms (Co_2 to Co_12), income from milk sales plus subsidies is greater than the total cost of production even in the worst market conditions. Operating and fixed costs are fully covered for this group, and production does not operate at a loss on a total cost basis. Subsidies appear to play a stabilizing role. Even if market prices alone were close to or below the cost of production for some farms, subsidies push net profits above zero, preventing short-term cash flow losses and enhancing risk mitigation.

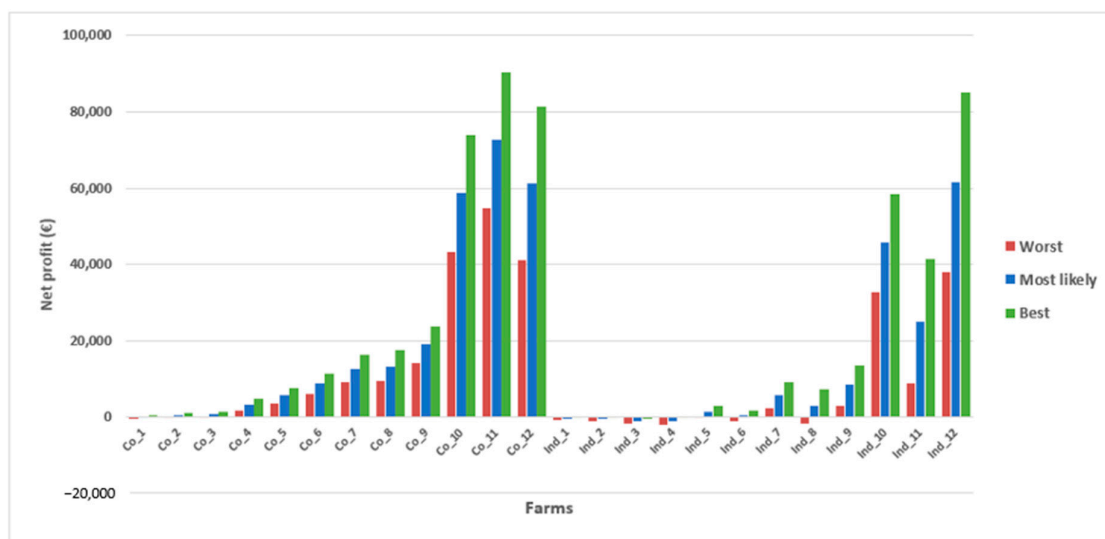


Figure 5. Sensitivity analysis for the net profit of the 24 sheep farms. Author’s own work.

On the other hand, net profits for independent micro and small farms in the worst-case scenario are negative. At lower prices, while variable costs may be covered for these specific farms, the remaining margin is insufficient to cover fixed costs, such as buildings, equipment, insurance and imputed family labor. Consequently, independent micro and small farms rely either on subsidies or on a minimum price floor to balance their profits, meaning they may not be economically viable without government assistance. In the long term, these micro and small independent farms are at an increased risk of being driven out of the sector.

To enable meaningful comparison among farms of different sizes and structural characteristics, the same sensitivity scenarios (worst-case, most-likely, best-case) are additionally expressed per ewe (€/ewe), obtained by dividing each farm’s net profit under each scenario by its herd size (Figure 6).

Expressing net profit per ewe narrows the apparent gap between farm-size categories relative to the absolute-value comparison in Figure 5, indicating that part of the advantage of larger farms reflects scale (more ewes) rather than a proportionally higher return per animal. Nonetheless, cooperative farms consistently retain a higher and more stable per-ewe net profit than independent farms of comparable size across all three scenarios, particularly among small and medium herds, suggesting that cooperative membership is associated with a per-animal profitability advantage rather than a purely scale-driven one. The smallest farms (e.g., Co_1, Ind_1 to Ind_4) remain the most exposed on a per-ewe basis, reinforcing that herd-size vulnerability persists even after accounting for scale.

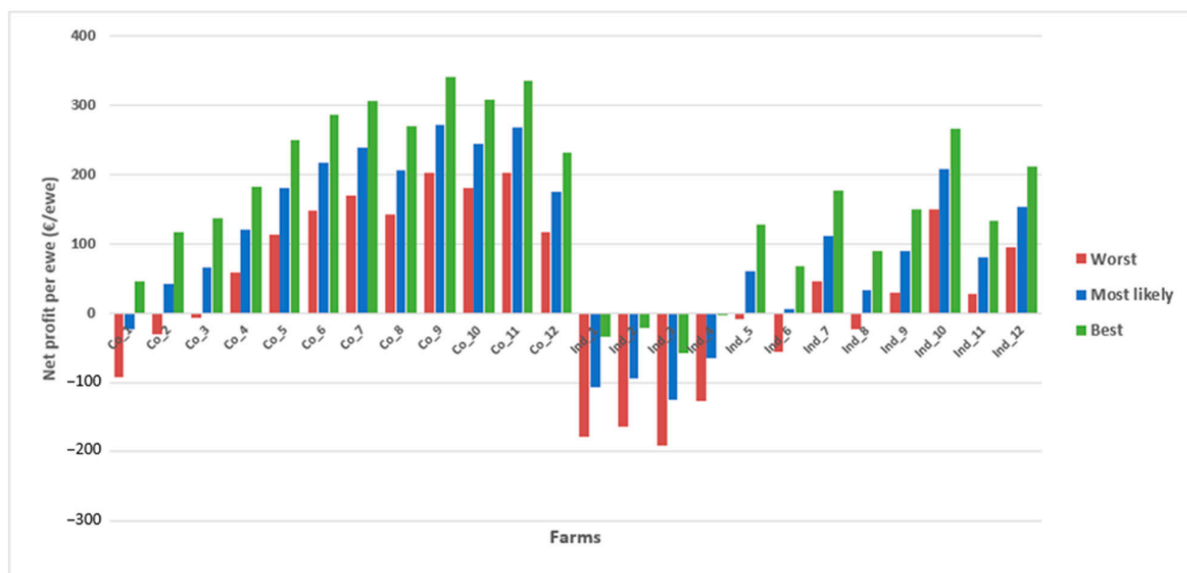


Figure 6. Sensitivity analysis of net profit per ewe (€/ewe) for the 24 sheep farms, under worst-case, most-likely, and best-case market scenarios. Author’s own work.

4. Discussion

Many studies in Europe have shown that the value chain for sheep milk is characterized by asymmetric relationships, with processors and retailers having considerable market power and farmers being in a weaker position, unable to negotiate higher producer prices [59–61]. For livestock farmers to survive in this challenging and competitive market environment, they must make a series of business decisions that affect the financial situation of their farms. Tables 2–5 show that more efficient sheep farms can achieve lower production costs and better economic results. Farms with the most efficient animals, which achieve higher output per animal, can achieve better economic indicators. Farm Co_11, for example, achieves the best economic results, due to its notably low milk production costs. A comparative analysis of the two groups of sheep farmers reveals that independent farmers achieve a slightly higher average price (€1.52/kg) than cooperative members (€1.51/kg). However, this marginal advantage does not lead to higher profitability, as cooperative members leverage collective action to compress their average production costs to €1.40/kg compared to €1.90/kg for independent farmers, suggesting that cost mitigation is far more critical for the long-term viability of the business. It should be noted, however, that this between-group cost difference may be partially confounded by differences in production system intensity and herd management practices that are correlated with, but not necessarily caused by, cooperative membership. A stratified analysis within each farm-size class would be required to fully disentangle these effects. For instance, cooperative farms in this sample are disproportionately semi-intensive or intensive, while tiny farms are all independent—making it impossible to isolate cooperative membership effects from farm-size and system-intensity effects without a larger balanced design.

However, this successful example should be viewed in a broader context, as sheep farming is influenced by various economic factors such as rising operating costs and market volatility. In particular, the specific production system applied in animal husbandry can also affect the profitability of a farm [62–66]. Semi-intensive farming systems cover the nutritional needs of animals through grazing and supplementary feeding, often off-

setting the cost of purchased feed [19,67]. This trade-off between input costs and productivity is well-documented in European small ruminant farming contexts [67]. Intensive farming, while potentially offering higher yields, is usually associated with high input costs, which include feed purchases, significant labor requirements, and complex infrastructure [65,66]. According to Bhatti et al. [68], intensive systems require a significant amount of purchased feed such as concentrates and silage to achieve a high level of productivity. Relying on purchased feed is often more expensive as it contains imported ingredients, which can further increase overall costs [69]. In addition, these feeds are subject to market fluctuations and are associated with transport costs. In contrast, production costs can be reduced by utilising pasture or crop residues. However, this requires improved pasture management, which may include the incorporation of alternative crops such as legumes [67]. Furthermore, managing large herds and ensuring their efficiency often requires significant labor [66]. High costs associated with any of the above factors can negatively impact a farm's financial situation. For example, the intensive cooperative farm Co_11 achieves a high milk yield of 300.00 kg per ewe, which optimizes resource utilization and dramatically reduces unit costs. In contrast, the independent farm Ind_10, despite having a roughly comparable herd capacity (220 ewes) and an invested capital of €88,000.00, achieves only a moderate milk yield of 227.70 kg per ewe. This lower animal productivity, combined with a non-optimized, independent feed supply, leads the business to a higher cost structure and lower profit margins. Intensive sheep farming systems can create economies of scale and significantly reduce costs per unit of product (See milk production costs in Tables 2 and 3 for large farms). This pattern, observed here in Lacaune sheep farms in Thessaly, is consistent with findings from other European small ruminant systems [65,66], but should not be assumed to generalize automatically to indigenous Greek breeds without further study. This shows that herd size alone does not guarantee efficiency. Working with a cooperative creates the necessary conditions for the development of economies of scale through the provision of lower-cost feed and veterinary services [20,28,34,35]. From a veterinary perspective, cooperative membership typically facilitates access to structured herd health programmes, including mastitis surveillance, reproductive management, and parasite control. These health interventions directly support the higher milk yield per ewe observed in cooperative farms (282.93 kg vs. 226.48 kg), as productive losses due to subclinical mastitis, reproductive failure, or gastrointestinal helminthosis are systematically reduced. This is consistent with the One Health framework, which recognizes that farm profitability, animal health, and public health outcomes are closely interlinked [70].

The sensitivity analysis indicates that for tiny and small farms, state support through interventions, such as subsidies, is considered important to stabilize the market and ensure their financial viability (Tables 4 and 5). Given that micro and independent farms are at risk of exiting the market under adverse conditions (as shown by the worst-case scenario in Figure 5), cooperatives could act as a protective shield, enhancing economic resilience by minimizing input costs and providing technical support. In more detail, Figure 5 shows that under severe market shocks (worst-case scenario), most cooperative farms (Co_2 to Co_12) maintain positive net profit margins and remain economically viable. The exception is Co_1 (6 ewes), which is already loss-making at baseline and becomes more so under adverse conditions, underscoring that very small farm scale is a vulnerability irrespective of organizational model. In contrast, small-scale independent units (Ind_1 to Ind_6) immediately fall below the break-even point into negative returns under the worst-case scenario.

Theodoridis et al. [27] report that total production costs are heavily influenced by feed costs. Because cooperatives often buy feed in bulk or produce it themselves, they can offer their members more affordable options. This can significantly reduce production

costs (Tables 2 and 3), since feed cost accounts for 60–70% of total farm costs [71]. The average cost of purchasing feed per ewe for independent farmers is €249.75, while for farmers in cooperative structures it is €209.33 (see Tables 8 and 9) [72,73]. Furthermore, the sharing of knowledge and expertise by cooperatives with producers can contribute significantly to improving animal performance. Specifically, according to the results of this study, the average milk production per ewe during the lactation period for farms working individually with dairies amounts to 226.48 kg, while for cooperative members it is 282.93 kg (see Table 2). These figures represent descriptive group averages; given the exploratory nature and small sample size ($n = 12$ per group), formal inferential tests (e.g., Mann–Whitney U) were not applied, and the between-group differences should be treated as indicative trends rather than statistically confirmed findings. Ayoub et al. [74] confirm the above, stating that participation in cooperatives improves technical efficiency through a more efficient use of resources and knowledge sharing.

The present study shows that some of the sample farmers collaborate directly with dairies to achieve higher producer prices. However, according to their own assessment, these prices are not stable over the entire lactation period and only offer them a short-term economic benefit, as they do not significantly improve their financial results [75]. The average agricultural family income per ewe for independent farms is €309.43, compared to €437.59 for farms that are part of a cooperative (see Tables 6 and 7). Cooperatives and producer groups have greater bargaining power as they operate as a single entity, which often means that they can ensure a stable market channel and the full sale of their members' milk production, at satisfactory fixed prices throughout the year [75]. These conditions are of great value to livestock farmers wishing to expand their businesses [76]. Awareness of the value of collective structures, such as interprofessional organizations, could contribute to better communication between all players in the value chain, thus promoting the development of a common vision and fairer market conditions for all stakeholders [35,77].

All livestock farmers who participated in the survey reported difficulties in accurately determining the production cost of their products, which makes it challenging to make informed business decisions [78]. Training livestock farmers on the financial management of their farms could help them make more informed financial decisions and improve operational efficiency [45,79].

4.1. Future Directions

The results of this study have important implications for the emerging field of Precision Livestock Farming (PLF). PLF integrates digital technologies—including sensors, automation, and data-driven decision-support systems—to monitor and optimize individual animal and herd performance in real time [70]. The techno-economic indicators documented here—particularly milk yield per ewe, feed cost per ewe, and net profit per ewe—constitute exactly the input variables required to parameterize PLF decision-support models. The strong association between herd size, cooperative membership, and production efficiency identified in this study (Figure 4) suggests that data-driven benchmarking tools could substantially improve farm management. In practice, PLF platforms could use the cost and productivity benchmarks established here to flag underperforming farms, recommend feeding adjustments, or simulate the economic impact of joining a cooperative structure. For example, the €40.42/ewe feed cost advantage enjoyed by cooperative members (€209.33 vs. €249.75) could be targeted by a PLF advisory module that prompts independent farmers when their feed expenditure exceeds the cooperative benchmark. Similarly, the sensitivity analysis results—showing that small independent farms turn loss-making under a 10% adverse price shock—could be embedded as a risk-alert function within a PLF dashboard. Furthermore, the difficulties reported by all interviewed farmers

in accurately calculating their own production costs [78] highlight a specific gap that PLF tools can address: automated cost-of-production calculators that integrate real-time input prices, milk volumes, and subsidy data can eliminate the informational asymmetry that currently disadvantages independent small-scale producers. Future research should investigate the willingness of Greek sheep farmers to adopt PLF technologies and quantify the return on investment of sensor-based monitoring in farms of the size categories identified in this study.

Our study has certain limitations that must be carefully considered. The sample size is relatively small, and therefore it may not fully represent the techno-economic diversity that may exist among all sheep farmers in the country. Furthermore, the cross-sectional design (single production year 2023) limits the ability to capture inter-annual variability in production performance or market prices. Additionally, this study did not analyze the perspective of other participants in the value chain. For this reason, it is recommended to conduct interviews and financial assessments at all levels of the value chain in the future. The exclusive use of the Lacaune breed limits generalizability to farms using indigenous Greek breeds (Chios, Boutsiko, Karagouniko), which may exhibit different production economics. Additionally, all cost and production data relied on farmer self-report during interviews, which may introduce recall or social desirability bias in cost estimation. It would also be interesting to map the value chain for other agricultural and food products, such as Feta cheese.

4.2. Predictor Tool for Farm Profitability—Design and Implementation

The techno-economic data collected in this study provide a robust empirical foundation for the development of a data-driven farm profitability predictor tool. All livestock farmers interviewed reported significant difficulties in accurately estimating their own production costs [78], and the sensitivity analysis demonstrated that even modest adverse price movements (−10%) can push small independent farms into negative net profit. A decision-support tool that automates these calculations in real time would directly address this gap and constitutes a practical application of Precision Livestock Farming (PLF) principles at the farm management level.

The calculator is parameterized using the key indicators established in this study: number of ewes, farm category (tiny/small/medium/large), market channel (cooperative member vs. independent), feed cost per ewe per year, milk selling price, and EU subsidy level. It should be emphasized that the tool is a descriptive calculator calibrated to the observed benchmarks from Tables 2–9 and is not a predictive regression model with generalized validity beyond the study sample; users should interpret outputs as indicative benchmarks rather than precise forecasts. From these inputs the tool computes milk yield per ewe, full production cost, net profit, and agricultural family income, together with a three-scenario ($\pm 10\%$) sensitivity analysis and a benchmark comparison against the cooperative and independent group averages from this study; the full input–output specification, formulas, and screen layouts are provided in Supplementary Material File S1. Future iterations of the tool could incorporate a regression model once a larger longitudinal dataset becomes available to improve predictive accuracy.

A fully functional interactive prototype of the predictor tool was developed and is presented as a supplementary online resource accompanying this article (Supplementary Material File S1). The prototype runs entirely in any modern web browser (Windows, macOS, Android, iOS) without installation, making it immediately accessible to farmers via smartphone or tablet. The interface comprises six input sliders and two drop-down menus and updates all outputs in real time as parameters are adjusted. A scatter plot positions the user's farm within the 24-farm sample space (milk yield vs. net profit), providing immediate visual context for the farm's competitive position.

A native, multi-platform re-implementation of the tool (e.g., using a cross-platform framework such as Flutter) is a natural next step for wider offline deployment, but was outside the scope of the present study; only the browser-based prototype described above was developed and is provided as Supplementary Material File S1.

The integration of such a tool into a broader PLF infrastructure represents a natural next step. Sensor data from automated milking systems or individual ewe identification tags (RFID/EID) could feed live yield and health data directly into the predictor, enabling continuous rather than end-of-season profitability monitoring. Furthermore, the model could be extended to multi-breed scenarios by incorporating breed-specific yield coefficients once equivalent datasets for indigenous Greek breeds (Chios, Boutsiko, Karagouniko) become available. The current tool should therefore be regarded as a first validated prototype whose predictive accuracy will improve as the training dataset is expanded through future longitudinal studies.

5. Conclusions

The study of the sheep milk value chain, focusing on livestock farmers, reveals various challenges and opportunities that producers can exploit to strengthen their business activities and improve the financial situation of their farms. As this is an exploratory case study of 24 Lacaune sheep farms in Thessaly, the conclusions below should be read as indicative patterns worth testing in a larger, representative sample rather than as generalizable findings for Greek sheep farming as a whole. However, farm financial management is complex. It depends on a series of factors arising from both the internal environment of the business, such as animal yields, and the external environment, including the selling prices of products, which often depend on large market players. Depending on the specific characteristics of each farm, it is necessary to formulate a strategy that considers the aforementioned factors. Furthermore, it is essential to conduct further research to capture the views of all stakeholders in the analyzed value chain, such as cooperatives and dairies. The European Union, through the Common Agricultural Policy (CAP), aims to increase the value added in the agricultural and food value chain. One way to achieve this specific goal is to enhance the position of livestock farmers and improve their conditions and access to the market.

The study has theoretical implications for enriching the existing literature by highlighting that, within this sample, the microeconomic indicators of a farm are directly influenced by macroeconomic factors, such as the asymmetry of power in the examined value chain. Furthermore, the present research empirically highlights that among the farms studied, participation in cooperatives contributes not only to strengthening bargaining power but also to the transfer of know-how.

In terms of practical implications, the study findings demonstrate that for the farms in this exploratory sample, reducing production costs through the integration of livestock farmers into cooperatives is a more critical parameter for the sustainability of livestock farms than the marginal increase in the selling price that independent livestock farmers can achieve. Genetic improvement and improved animal nutrition are crucial, with the aim of increasing animal performance. Financial and business education of livestock farmers is considered essential, since all survey participants reported difficulty in accurately calculating production costs.

The sensitivity analysis shows that small and independent farmers cannot survive in the long term without subsidies in the event of a price drop. Thus, policy should target coupled and compensatory aid to these vulnerable groups. In the Greek context, this could take the form of continuing and, where possible, increasing the coupled income support for sheep and goat farming already available under Greece's CAP Strategic Plan 2023–2027, together with compensatory allowances (Areas of Natural Constraint payments) for

farms in the semi-mountainous areas where most tiny and small farms in this sample are located. Complementary instruments could include targeted start-up or investment aid for small farms wishing to formalize collective marketing arrangements without becoming full cooperative members (e.g., producer groups with lower administrative and capital requirements), and risk-management tools such as income-stabilization or price-insurance schemes co-financed under the CAP's second pillar, given the price volatility documented in Figure 1. Given that collective schemes appear to be able to act as a protective shield for farmers, financial and tax incentives, as well as a reduction in the bureaucracy surrounding their establishment, should be provided, which would contribute to their survival. Finally, due to the identification of asymmetric relationships between small and large players, it is necessary to develop mandatory, written and long-term contracts with minimum security (floor) prices that will cover production costs and ensure the liquidity of farmers.

Finally, from a broader sustainability perspective, the technical parameters of this study—specifically farm-level management factors such as animal performance, genetic improvement and optimized nutrition—serve as a basis for long-term sustainability. By integrating these technical elements, Lacaune small sheep farms can achieve not only economic viability but also improved social and environmental sustainability. Socially, fairer value chain contracts enhance rural resilience, improve farmers' quality of life and mitigate rural shrinkage in regions such as Thessaly. Environmentally, collective know-how transfer and better resource management can promote more ecologically efficient production practices, aligning Greek sheep farming with the green transition objectives of the Common Agricultural Policy.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/agriculture16151618/s1>. File S1: Sheep Farm Profitability Predictor — Thessaly.

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