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Efficiency Analysis and Identification of Best Practices and Innovations in Dairy Sheep Farming

Alexandros Theodoridis [1,*], Sotiria Vouraki [2], Emmanuel Morin [3], Georgia Koutouzidou [4] and Georgios Arsenos [2]

1 Laboratory of Livestock Production Economics, School of Veterinary Medicine, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece
2 Laboratory of Animal Husbandry, School of Veterinary Medicine, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece
3 Institut de l'Élevage, Castanet Tolosan, 31321 Toulouse, France
4 Institute of Plant Breeding and Genetic Resources, Hellenic Agricultural Organization-DIMITRA, 57001 Thermi, Greece
* Correspondence: alextheod@vet.auth.gr; Tel.: +30-6938-118-749

Abstract: The adoption of the best practices is crucial for the survival of the dairy sheep farms that operate under extensive and/or semi-extensive systems. In this study, an efficiency analysis was implemented to reveal the best observed practices applied by the more efficient dairy sheep farms. Data Envelopment Analysis was used on data from 60 dairy sheep farms that rear Manech or Basco-bearnaise, and Lacaune breeds under semi-extensive systems in France. The main characteristics of the most efficient farms are presented and a comparative economic analysis is applied between the fully efficient and less efficient farms, highlighting the optimal farm structure and determining the major cost drivers in sheep farming. The most efficient farmers provided information within the iSAGE Horizon 2020 project regarding the management practices that enhance their sustainability. The results show that there is room for improvement in semi-extensive dairy sheep farming. The most efficient farms rear smaller flocks than the less efficient farms and achieve higher milk yields. Fixed capital, labor, and feeding constitute the main cost drivers. Results show that farms should exploit economies of scale in the use of labor and infrastructure to reduce their cost per product, as well as their uptake practices and innovations, related mainly to modern breeding and reproduction methods, efficient feeding practices and digital technologies.

Keywords: dairy sheep farming; technical efficiency; best practices; economic performance; data envelopment analysis

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1. Introduction

Sheep farming is a significant agricultural activity in the European Union (EU), with the latest statistics reporting a total population of approximately 63 million heads within EU-27 [1]. The sector is mainly focused on meat production, but milk production is also of economic importance in Southern European countries. Most of EU's sheep milk (ca. 46%) is produced in Greece, Spain, France, and Italy, and is mainly processed into cheese products, many of which are products of Protected Designation (PDOs) [2–4]. In these countries, the majority of dairy sheep are reared under extensive or semi-extensive systems in marginal and mountainous regions. The latter has important socio-economic and environmental impacts in rural areas, providing employment opportunities, as well as a wide range of ecosystem services, such as ensuring environmental sustainability, and preserving biodiversity [2,5–8].

The dairy sheep sector in EU faces many structural, operational and environmental challenges that threaten its future sustainability. On one hand, farmers and processors face an increasing pressure for production intensification in order to meet market demands, while on the other hand, they need to address consumer expectations for high animal welfare status and environmentally friendly management practices [4,7,9]. Other major challenges are associated with the ageing of farmers and limited numbers of new entrants; the absence of proper training and adoption of innovations; as well as a reluctance to invest in new technologies and management practices [3]. Limited adoption of innovations is highly related to their perceived complexity by farmers, which has been associated with a number of socio-demographic and structural factors such as age, educational status and farm size [10,11]. Moreover, the livestock sector in Europe has had to address the mandate of the Grean Deal that sets new standards to deal with climate change. To cater to those needs, the livestock sector must incorporate significant changes in farm management, putting emphasis on improving environmental performance through nutrient management, reduction of greenhouse gas emissions and agroecology [12].

During the last few decades, the European dairy sheep sector has undergone a large-scale transition, towards an intensive production pattern that depends heavily on capital investments, purchased feedstuff, hired labor and improved breeds of high milk yields. Over this trajectory, many dairy sheep farmers that operate under extensive and semi-extensive pastoral systems leave the profession or change their business orientation, jeopardizing the traditional character and the survival of sheep farming. Only farms that adopt innovative solutions and modernize their management practices will likely be able to increase their competitiveness and remain sustainable [3].

Management practices in livestock enterprises vary significantly and are dictated by the production system and animal species. Qualitative and quantitative assessment of such practices is the most challenging in such studies. The concept of Technical Efficiency (TE) was introduced in 1951 [13]. It was based on the management competence of individual producers, expressed as differences in the level of managerial skills. The concept engages productivity with management ability and skills of farmers, and refers to a maximum attainable level of output, taking into account a set of inputs and the production technology available to them. Assessing the level of TE in a farm reveals the difference between actual and potential performance of each production unit. Therefore, TE is a useful decision support tool for revealing management strategies and policies that can make farms more productive. The efficiency analysis identifies the farms that use the full potential of the existing production technology and those that allocate their resources less rationally. Efficient farms are identified, and their management and production practices can potentially be replicated in similar farming systems to increase their productivity and consequently their sustainability.

Previous research has investigated the efficiency of French, Spanish and UK meat sheep farms, and best observed practices and innovations were identified towards increasing the sustainability of the meat sheep sector [14]. The identified innovations include feeding practices, marketing strategies, breeding programs and digital technologies [14]. Relevant literature regarding the dairy sheep sector is limited, with most available studies focusing only on technical and environmental factors related to the level of TE in Greek, Spanish and Sardinian farms [15–20]. These studies highlight farm size, management of resources, and feeding practices as important determinants of the technical efficiency of dairy sheep farms. To the best of our knowledge, however, there is no study that involves a comprehensive technical and financial analysis of pasture-based, semi-extensive dairy sheep farming systems, and that provides an estimation of their productive capacity and reveals the practices that could increase the economic performance of the sector.

The present study focuses on exploring the TE of semi-extensive dairy sheep farms in France, with the aim of identifying the best practices that could be adopted by other farms, following the same farming system. In France, the majority of sheep farms specialize in milk production, rearing mainly indigenous breeds under semi-extensive farming conditions in mountainous regions. The highest producing regions are Roquefort and Pyrenees, accounting for 88% of the total national dairy ewe production [2]. In this regard, data from 60 French dairy sheep farms located in Western Pyrenees and Roquefort areas, rearing either Manech or Basco-bearnaise and Lacaune breeds, are used to investigate their profile and identify the best practices that differentiate them from other farms.

2. Materials and Methods

2.1. Data Envelopment Analysis—DEA

DEA is a non-parametric method which uses linear programming techniques to construct a non-parametric piece-wide frontier over the data, and to estimate the TE score of production units relative to that frontier [21,22]. Each unit uses different amounts of inputs to produce outputs and the level of efficiency is measured, relative to the highest observed performance in the sample, creating an efficiency frontier [23]. The units that lie on the frontier are efficient (efficiency score = 1).

Assuming that there are n production units, each producing one output, by using m different inputs and the $\mathrm{Unit_o}$, which represents one of the n units under assessment, produces y_o units of output using x_{io} units of the ith inputs, the variable returns to scale (VRS) single output-oriented model for $\mathrm{Unit_o}$ is as follows:

$$\mathrm{Max}\ \phi \tag{1}$$

subject to

$$\begin{aligned} &\sum_{j=1}^{n} \lambda_j x_{ij} = x_{io} \quad i = 1, 2, \ldots, m \\ &\sum_{j=1}^{n} \lambda_j y_j = \phi y_o \\ &\lambda_j \geq 0 \quad j = 1, 2, \ldots, n \\ &\sum_{j=1}^{n} \lambda_j = 1 \end{aligned} \tag{2}$$

where i = 1, . . . , m inputs; j = 1, . . . , n units; where $1 - (1/\phi)$ is the proportional increase in output possible for the ith unit. In the output orientation models, the efficiency score corresponds to the largest feasible proportional expansion in outputs for fixed inputs [24]. Hence, through the implementation of DEA, the maximum output per unit of input that can be achieved without new technology is estimated. The output-oriented measure of technical efficiency of a production unit, denoted by TE, can be estimated by

$$\mathrm{TE} = \frac{1}{\phi} \tag{3}$$

If $\phi = 1$, then the production unit is on the efficiency frontier and it is fully efficient, i.e., there are no other units that are operating better than this unit [25]. Comprehensive treatments of the methodology and extensions of the various DEA models are available in Cooper et al. [23], Coelli et al. [21], Fried et al. [26] and Sickles and Zelenyuk [27].

2.2. Empirical Model

Technical and economic data collected from 60 dairy sheep farms in 2015 were used for this DEA application. These farms were located in the Western Pyrenees and Roquefort areas in France, and reared either Manech or Basco-bearnaise and Lacaune breeds, respectively. Selected farms were representatives of the semi-extensive dairy sheep production system, according to the typology developed within the iSAGE (Innovation for Sustainable Sheep and Goat Production in Europe) HORIZON 2020 Project (www.isage.eu/ (accessed on 28 August 2022)). Data were collected by the technical organizations of both basins, within the French Livestock farms network, "INOSYS Réseaux d'élevage". An output-oriented VRS DEA model was implemented using the DEA Frontier software [24]. Following the specification chosen in Theodoridis et al. [14], the empirical model included as input variables: the flock size (number of ewes, including barren ones); the total labor (including family and hired workers), measured in Annual Labour Unit (ALU); the variable cost in € and the fixed cost in €; while gross revenue (including subsidies, measured in €) was used as the output variable.

2.3. Best Observed Practices in Efficient Farms

To identify management and husbandry practices that are implemented in the efficient farms, the methodological approach developed and applied in Theodoridis et al. [14] was followed. Specifically, a template of innovations and best-practices was created based on workshops and an online survey that took place within the iSAGE project (File S1). The latter was used by animal husbandry experts who supervise these dairy sheep farms, on behalf of the INOSYS breeding network, to report farmers' feedback on the applied practices. Following the collection of data, best observed practices and innovations were grouped into categories, as follows:

- Farm Management, including: 1. Feeding; 2. Health; 3. Reproduction; 4. Breeding, involving any form of husbandry in rearing animals; 5. Human resource organizations.
- Farm Technology, including: 1. Information and Training; 2. Gadgets/Apps.
- Product marketing.

This two-step approach ensures the disclosure of the practices applied by the best farms and sets up a methodological framework for determining practices that could potentially be innovative solutions for enhancing the sustainability of farms.

3. Results and Discussion

3.1. Efficiency Analysis

The frequency distribution of the technical efficiency estimates obtained from the output-oriented DEA model are presented in Table 1.

Table 1. Frequency distribution of farms by technical efficiency (TE) estimates from the DEA model.

TE Score	Number of Farms	%	Mean TE
<0.60	4	6.67	0.542
0.60–0.69	8	13.33	0.671
0.70–0.79	7	11.66	0.729
0.80–0.89	13	21.67	0.846
0.90–0.99	6	10.00	0.963
1.00	22	36.67	1.000
Total	60	100.00	0.857

Results show that there is considerable scope for progress in the utilization of the production technology. The TE score of the studied farms varies from 49% to a high of 100%, the latter being efficient farms. Most of the farms (22, accounting for 36.7% of the sample size) were allocated in the fully efficient group, while only 4 farms had a TE level less than 60%, 15 farms (25%) had TE between 60% and 79% and 19 farms (31.7%) operated relatively close to the DEA frontier, with a TE between 80% and 99%. The mean TE of the 60 farms was 85.7%, showing that, according to the level of inputs, the average semi-extensive dairy farm could increase its output, if it was operating efficiently. The reported TE was higher than that found for organic dairy sheep farms in Spain (66% in Toro-Mujica et al. [16]), and intensive dairy sheep farms in Greece (80% in Theodoridis et al. [5]). Moreover, Theodoridis et al. [14] reported a lower mean TE value for French semi-extensive meat sheep farms (71%). Nevertheless, the analytical results of the present study suggest that a 20% increase of the gross income is possible, given the inputs, provided that the farmers optimize their management, adopting best practices. The presence of inefficiencies in the combination of the available resources indicates that farmers do not fully utilize the entrepreneurial factor, a factor that severely affects the economic performance of a decision-making unit.

The output-oriented DEA model enables the identification of optimal targets (feasible increases in output) while keeping the inputs fixed [24]. Efficiency improvement projections based on the DEA model for the dairy sheep farms in France are presented in Table 2. The last column of the table shows the maximum output value (optimal target) of the farms under evaluation according to the DEA projection.

Table 2. Average existing and efficient frontier gross revenue for French dairy sheep farms by farm size.

Farm Categories	Number of Farms	Existing Output (Gross Revenue in €)	Optimal Target (Gross Revenue in €)
Small (≤350 ewes)	21	86,776	97,666
Medium (350–450 ewes)	23	126,884	157,484
Large (>450 ewes)	16	186,442	221,512
Average farm	60	128,728	153,622

French dairy sheep farms could increase their revenues, if they fully valorized the current production technology by approximately 20%. Such results indicate that these farms could substantially improve their profitability and, therefore, their competitiveness. At flock-size level, it was found that small-sized farms (less than 350 ewes), medium-sized (350–450 ewes) and large-sized (more than 450 ewes) farms could, on average, increase their output by 12.6%, 24.1% and 18.8%, respectively. These findings indicate that small-sized semi-extensive dairy sheep farms in France were more efficient than larger farms. Flock size is an important factor affecting the profitability of sheep farms, however, relevant results differ between farming/production systems and countries. Contrary to the present results, Theodoridis et al. [5,14] found that large-sized herds were more efficient than small-sized herds in both Greek intensive dairy sheep farms and French extensive meat sheep farms. Small-sized French intensive and Spanish semi-intensive meat sheep farms have been shown to have a higher TE than large-sized ones. In all cases, results suggest that sheep farms could increase the value of their production and adjust to the optimal size that maximizes factors' productivity. In this study, the efficiency score is related to small scale farms due to the more extensive system, that does not depend on capital endowments and high investments on infrastructure and machinery.

3.2. Comparative Financial Analysis

The efficiency score was used as a classification criterion and the studied farms were classified into two groups: the fully efficient and the less efficient (relatively inefficient) farms. The composition of gross revenue per ewe is presented in Table 3. As expected, results showed that milk production is the predominant activity of these farms and the main source of income, contributing 70.8%, on average, in their gross revenue. The second most important activity is meat production, which was found to contribute 18.6%, on average, in gross revenue, a share which is higher in the relatively inefficient (19.3%) than in the efficient farms (17.5%). The least important activity is selling lambs, which does not differ substantially between the efficient and the average farm (2.0% and 2.1%, respectively). In general, the dependence of income on one product reduces resilience to income shocks [28]. In our case study, the high share of meat production in gross revenue makes French sheep farms less vulnerable to milk price shocks. Vulnerability is also intensified by the contribution of subsidies in gross revenue. For the average farm, the share of coupled support payments in output is not large, accounting for about 8% of the gross revenue. This shows that French dairy farms are resilient to policy changes and have been integrated in the competitive market to a high degree. Among the efficiency groups, the share of support payments in output does not vary substantially; however, it is lower for the efficient farms (7.3% compared to 8.5% for the relatively inefficient farms). Such results are in accordance with previous research within the meat sheep sector (extensive and intensive farms) [14], the transhumance sector [17] and the overall agricultural sector [29,30], which showed an unfavourable association of public support on farms' efficiency. The share of the value of the wool is only 0.3% of the gross revenue and it does not differentiate among farm groups.

Table 3. Composition of gross revenue per ewe for all farms and for the relatively inefficient and efficient farms.

Composition of Gross Revenue	**Inefficient (TE = 0.774) n = 38**		**Efficient (TE = 1) n = 22**		**Average Farm (TE = 0.857) n = 60**	
	€/ewe	**%**	**€/ewe**	**%**	**€/ewe**	**%**
Milk (sold to dairies and manufactured in farms)	207	69.9	249	72.8	221	70.8
Meat	57	19.3	60	17.5	58	18.6
Lambs sold for breeding	6	2.0	7	2.1	7	2.3
Coupled support payments	25	8.5	25	7.3	25	8.0
Wool and other products	1	0.3	1	0.3	1	0.3
TOTAL	296	100.0	342	100.0	312	100.0

Technical and economic characteristics per efficiency group, and for the average farm, are presented in Table 4. The comparison of these characteristics between efficiency groups partly indicated their contribution to the overall improvement of efficiency. Results showed that efficient farms reared less ewes, however, this achieved higher yields (35 L of milk more per ewe annually). It has to be mentioned that both efficiency groups include both Lacaune and Manech or Basco-bearnaise farms. Moreover, efficient farms appear to manage human labor more wisely, using 16.3% less labor per ewe, and were found to supply more feed per ewe. The latter indicates a lower dependency of efficient farms on pasture and/or very limited use of supplementary feeds by the inefficient ones.

Table 4. Technical and economic characteristics of the technically efficient and relatively inefficient farms.

Technical and Economic Data	**Efficiency Groups**		**Average Farm (TE = 0.857)**
	Inefficient (TE = 0.774)	**Efficient (TE = 1.000)**	
TECHNICAL			
Number of farms	38 (63.33%)	22 (36.67%)	60 (100.00%)
Number of ewes	428	387	413
Total Production (L/farm)	89,470	94,250	91,230
Yield (L/ewe)	209	244	221
Total labor (ewes/ALU)	221	265	235
Feed supplied (Kg DM/ewe)	602	620	608
ECONOMIC			
Labor cost (€/ewe)	116	99	110
Feed cost (€/ewe)	69	73	70
Home-grown feed (€/ewe)	*21*	*19*	*20*
Purchased feed (€/ewe)	*48*	*54*	*50*
Other variable costs * (€/ewe)	32	32	32
Fixed capital cost (€/ewe)	188	177	184
Production cost (€/ewe)	405	381	396
Gross revenue (€/ewe)	296	342	312
Gross margin (€/ewe)	195	237	210
Profit or Loss (€/ewe)	−109	−39	−84

* includes veterinary and drug expenses, expenses for bedding, detergents, etc.

Following the trend in labor use, labor costs, which includes the opportunity cost of family labor and the wages of hired labor, was reduced by 17 €/ewe in the efficient farms, and the feeding cost was increased by 4 €/ewe. However, results showed that efficient farms rely more on the procurement of feed from the market. Moreover, the fixed cost per ewe was much higher in inefficient compared to efficient farms, indicating that less efficient farms are characterized by higher, and sometimes irrational, investments and poor capital management. This is in accordance with previous studies investigating the technical efficiency of the meat sheep sector [14,31]. The lowest production cost and highest gross output was found in efficient farms, indicating a positive relationship between efficiency score and production value. As a result, in efficient farms, the gross margin (gross revenue minus variable cost) was increased from 195 € to 237 € per ewe.

According to the analytical results presented in Table 5, the percentages of efficient farms did not differ between the two studied areas (Roquefort and Western Pyrenees); 34% and 40% of farms in the Roquefort and Western Pyrenees areas were deemed as efficient, respectively. In the Roquefort area, efficient farms reared less ewes (432) compared to inefficient ones (457). However, the former achieved higher milk yields (51 L per ewe per lactation period), having the same feeding cost (67 €/ewe) and almost the same fixed capital cost (200 €/ewe and 204 €/ewe for efficient and inefficient farms, respectively). Thus, the gross margin was 50 €/ewe higher in efficient farms. Moreover, results showed that efficient farms in the Roquefort area rear more ewes per Annual Labour Unit, resulting in lower labor costs (92 €/ewe in the efficient farms and 122 €/ewe in the relatively inefficient).

Table 5. Technical and economic characteristics of the efficient and inefficient farms in both study areas (Roquefort and Western Pyrenees).

Technical and Economic Characteristics	**Roquefort Area (Lacaune Breed)**			**Western Pyrenees Area (Manech/Basco-Bearnaise Breed)**		
	Inefficient Farm (TE = 0.810)	**Efficient Farm (TE = 1.000)**	**Average Farm (TE = 0.875)**	**Inefficient Farm (TE = 0.720)**	**Efficient Farm (TE = 1.000)**	**Average Farm (TE = 0.832)**
Number of farms	23	12	35	15	10	25
Number of ewes	457	432	449	383	332	363
Labor (ewe/ALU)	212	287	232	241	237	239
Total production (L/farm)	106,870	122,866	112,354	62,798	59,918	61,646
Yield (L/ewe)	234	285	250	164	180	170
Milk (€/ewe)	216	260	230	189	234	206
Meat (€/ewe)	69	75	71	36	36	36
Lambs sold for breeding (€/ewe)	9	11	9	1	1	1
Coupled subsidies (€/ewe)	25	26	25	25	25	25
Other products (€/ewe)	2	−2	1	1	3	2
Gross revenue (€/ewe)	320	370	336	253	299	270
Feed supplied (kg DM/ewe)	712	750	724	401	417	407
Labor cost (€/ewe)	122	92	112	106	110	107
Feed cost (€/ewe)	67	67	67	73	80	76
Purchased feed (€/ewe)	*40*	*43*	*41*	*63*	*70*	*65*
Home-grown feed (€/ewe)	*27*	*24*	*26*	*10*	*10*	*10*
Other variable costs (€/ewe)	31	29	30	35	36	35
Fixed capital cost (€/ewe)	204	200	203	158	141	152
Production cost (€/ewe)	423	389	412	372	367	370
Gross revenue (€/ewe)	320	370	336	253	299	270
Gross margin (€/ewe)	222	273	239	145	183	159
Profit or loss (€/ewe)	−103	−19	−76	−119	−68	−100

In the Western Pyrenees area, efficient farms also achieved higher milk yields compared to inefficient farms (by 24 litres per ewe per lactation period). Efficient farms had, on average, a higher milk price, due to the highest proportion of farms that process the milk into cheese. The gross margin was 38 €/ewe higher in efficient farms and the fixed capital cost was less important (141 €/ewe and 158 €/ewe in efficient and relatively inefficient farms, respectively). In both studied areas, the cost share of purchased feed was higher than the cost share of the home-grown feed (expenses for fertilizers, seeds, pesticides etc.). These results highlight the importance of feed self-sufficiency in reducing costs and improving farm income. In general, the feeding cost does not differ among the efficiency groups in the Roquefort area, and it is marginally higher for the efficient farms in the Western Pyrenees area. In both cases, the feeding cost is not a major efficiency driver; however, the results provide insights regarding the appropriate feeding strategy (on-farm production or purchase from the market).

3.3. Best-Observed Practices

The best observed practices implemented by efficient French farms were analyzed and classified into nine general categories (Table 6). The categories are presented in descending order, based on the number of efficient farms that selected them.

Table 6. Categories of best observed practices and innovations in efficient farms.

General Category of Practices	Number of Efficient Farmers That Selected at Least One Practice	Types of Practices Selected at Least Once
Breeding	14	4
Reproduction	13	2
Feeding	12	5
Gadgets and Applications	12	4
Product marketing	10	2
Health	6	3
Information and training	5	4
Human resources organization	3	1
Product processing	0	0

Breeding practices were shown as the most important to improve the farms' efficiency. Specifically, 14 out of 60 farmers (23%) selected at least one breeding practice amongst four different practices. Such practices included, amongst others, criteria for choosing the best animals for replacement, routine data collection of milk yield and quality, use of elite flocks and DNA data collection. Of almost equal importance were reproduction practices, such as assisted reproduction techniques, and the improved use of rams and reproduction plans, which were implemented by 13 farmers (22%).

Feeding practices and innovations related to gadgets and applications were also considered by 12 farmers in each case (20%), indicating that the certification and branding of products for more local and direct markets are important practices. Finally, health, information and training, and the organization of human resources were considered to be less important for the performance of farms with only 6 (10%), 5 (8%) and 3 (5%) farmers implementing relevant practices, respectively.

Based on all the above, breeding and reproduction, feeding, modern technologies and product marketing practices are the most implemented categories by the most efficient sheep farmers, and these could therefore be adopted by other farms in order to increase their sustainability. These results are in accordance with those reported for the sheep meat production sector through relevant analysis of French extensive and intensive farms and Spanish semi-intensive farms [14], suggesting a uniform perspective of efficient sheep farmers, regardless of the production system.

Analysis within the categories described above revealed the specific best practices and innovations that are most often applied by efficient farmers (Table 7). Most of the studied farmers (23%) selected routine data collection, use of a specific criteria for choosing the best replacement animals and assisted reproduction technologies as the most important practices that differentiate them from their peers. Collection of performance data and pedigree recording is a prerequisite for a successful genetic selection and implementation of breeding schemes [32,33]. In France, breeding schemes have been efficiently practiced for more than 50 years, leading to the improvement of milk production and udder morphology [2,34]. Moreover, artificial insemination is known to be of high importance for the increase of genetic gain and for the introduction of genes that are able to improve production traits [35]. According to previous research, more than 410,000 inseminations of Lacaune ewes are performed every year in France [34]. Additionally, artificial insemination minimizes the risk of disease transmission and is cost-effective for farmers as it reduces the need for rams for natural service, although the success of AI in sheep varies [36]. The use of elite flocks and DNA data collection were also highlighted as important breeding practices by 18% of farmers. Indeed, elite flocks can be a significant pool of high breeding value rams, speeding up the genetic improvement process [37]. Genomic selection can further benefit farmers by enabling the estimation of an animal's breeding value early in its life, thus decreasing generation interval [38]. However, as previously indicated in the case of the meat sheep sector, further uptake of genetic and genomic practices and innovations requires the efficient collaboration of farmers with scientists and government bodies [14].

Table 7. Most observed best practices and innovations in fully efficient farms.

Categories of Practices	Practices	No of Farms
Breeding	System/criteria on place to choose best animals for replacement	13
Breeding	Routine data collection (i.e., milk yield/quality)	13
Reproduction	Assisted reproduction technologies	13
Gadgets and Applications	Electronic identification systems	12
Breeding	Use of elite flocks	11
Breeding	DNA data collection and use in programs	11
Product marketing	Certification	10
Feeding	Good understanding of matching animal requirements and supply	8
Feeding	Increased forage quality	7
Feeding	Increased pasture quality	6
Health	Identification tests to spot animals with illness	4
Feeding	Innovative Grazing Practices	3
Feeding	Use of by-products to replace conventional feeds	3
Human resources organization	Staff training courses/regular meetings to get feedback and keep positive stimulation	3
Information and training	Tools to monitor BCS and pasture state	3
Gadgets and applications	On-farm data collection linked to animal ID and feedback to farmer to help decision making	3
Health	Sound and scientific proven use of antibiotic alternatives in feeding	2
Reproduction	Improved/frequently reviewed of use of rams and reproduction plans	2
Information and training	Access to abattoir feedback on carcass quality and health	2
Information and training	Computer farm management programs	2
Product marketing	Branding and provenance of products for more local and direct markets	2
Health	Use regionally integrated plans	1
Information and training	Integrated and easy-to-use tools	1
Gadgets and applications	Temporary electric fencing in mountainous areas	1
Gadgets and applications	Drones	1

Within the category of gadgets and applications, electronic identification systems were indicated as a best practice by 22% of farmers. Currently, electronic identification systems are the only precision livestock farming technology mandatory within the EU, due to the purposes of traceability. The electronic identifiers used by sheep farmers are ear tags, and sometimes ruminal boluses, and when scanned with electronic readers they facilitate accurate and quick collection of individual animal data [39,40]. However, on-farm data collection linked to animal-ID was selected as an important practice by only

5% of farmers. Finally, only 1 out of 60 farmers indicated the use of electric fencing and drones as important innovations. Overall, the adoption of precision livestock farming technologies is hampered in the extensive and semi-extensive sheep farming sector, mainly due to age, cultural and financial barriers. In this regard, training on the usefulness of such technologies is considered imperative. Moreover, future challenges and opportunities, relating to animal welfare and government policies, that the farmers will need to adapt could help to further increase the adoption of such technologies [39,40].

Product marketing was also considered important for the sustainability of the dairy sheep sector by some of the studied farmers. Specifically, 17% of farmers emphasized the certification of dairy products. France has successfully managed to maintain the share of French cheese in international markets, given the high animal performance accomplished [2,3]. According to previous studies, branded products such as PDO and PGI are highly recommended.

4. Conclusions

At present, the reinforcement of the sustainability of extensive and semi-extensive sheep production systems sits in line with the Green Deals targets, in particular, those stemming from the Farm to Fork Strategy and the Biodiversity Strategy in the EU for 2030. The extensive and semi-extensive production systems provide a wide range of ecosystem services and have integrated principals of circular economy and environmental practices. The identification and upscaling of the best practices applied in those systems can valorize their full potential as drivers towards agro-ecological transition in livestock production.

In this study, the efficiency analysis was used as a tool for identifying such best practices, innovations and management strategies that could be replicated by semi-extensive, pasture-based sheep farms to increase profitability and achieve resilience. Furthermore, the results of this study revealed the positive and negative attributes in the operation of a dairy sheep farm, indicating the major cost drivers of semi-extensive farming systems. To the best of our knowledge, this study is the first to provide a comprehensive technical and financial analysis for semi-extensive dairy sheep farms. The efficiency analysis of 60 semi-extensive French sheep farms indicated their high potential for increasing their performance, if they were to properly utilize the available technology. The most efficient farms comprise smaller flocks than the less efficient farms, generate better economies of scale in the use of human labor and achieve higher milk yields. Fixed capital, labor and feeding expenses were the main cost categories. Only sheep farms which take up innovative solutions to reorganize their operational methods will be able to remain in the sector by placing emphasis on increasing flock size, proper nutritional management and grazing practices and powerful marketing strategies. Breeding programs incorporating genomics, advanced methods of reproduction, efficient feeding strategies and innovations related to digital technologies and applications were indicated as the main practices that must be used to upscale and support the sheep dairy sector. Towards this end, a multistakeholder approach is required, prioritizing policy interventions on the uptake of the above best management practices and actions, and aiming to increase farmer awareness regarding available innovations. Collaboration between farmers, scientists and government bodies is essential in order to: (i) increase the use of assisted reproduction technologies, especially AI, (ii) design and implement appropriate breeding programs, according to specific objectives, (iii) enable systematic and accurate record keeping and (iv) introduce digital technologies that could help dairy sheep farmers to efficiently manage their enterprises. In all cases, technical and financial support are warranted.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su142113949/s1, Table S1: Technical and economic data collected from dairy sheep farms in France; File S1: Template for innovations and best observed management practices used to record the feedback of most efficient farms.

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