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Massese, Sarda and Lacaune Dairy Sheep Breeds: An Environmental Impact Comparison

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Abstract: The dairy sheep sector is an important sector in semiarid and arid areas. So far, the environmental impact of sheep milk production in these areas is scarcely known. This study aimed to assess the environmental impact of milk production on three farms that differ in the breed reared, namely Sarda (S), Lacaune (L) and Massese (M), in Tuscany (a Mediterranean region in central Italy). The Life Cycle Assessment methodology was applied to calculate the environmental performance of the farms, and the following impact categories were studied: climate change, freshwater, marine and terrestrial eutrophication, acidification, water use and land use. The L farm showed the lowest values for most impact categories and the M farm the highest. These results can be attributed to the greater productivity and efficiency of the L breed compared to the other two. Only for water use did the M farm cause a lower impact, underscoring the importance of applying characterization factors at the sub-watershed level.

Keywords: sheep breed; milk production; sustainability; life cycle assessment

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1. Introduction

The sheep sector plays a significant role in the economies of arid and semiarid areas, especially in the Mediterranean region, where sheep and goats are typical livestock compared to other species [1]. In Italy, the sheep production sector has a value of approximately EUR 814 million, of which EUR 630 million derive from milk production [2]. In addition, about 78% of the overall national ovine milk production is generated in only three regions due to the solid territorial concentration of the flocks: Sardinia, Tuscany and Lazio [2].

In Tuscany, 288,801 sheep are reared, of which 85% are dairy sheep [3]. In this area, the dairy sheep sector is characterized by semi-extensive farms, with seminatural pastures being the main feeding source for the sheep. The animals graze for several hours during the day and are kept in barns in the evening, where they receive feed supplements [4].

The main breed reared in Tuscany is the Sarda breed, accounting for a total of 157,000 heads [3]. The Sarda dairy sheep is an Italian breed originally from Sardinia Island, and it is one of the most productive dairy breeds in the Mediterranean region [5]. Massese is a local and important breed (16,263 heads) [3] native to the Forno Valley, in the Apuan Alps (province of Massa Carrara), and it is mostly bred in Tuscany for its milk production [6]. This breed is also characterized by high fertility and prolificacy, enabling farmers to sell many lambs and provide satisfactory meat. The females of Massese undergo estrous cycles nearly all year round, and they can give birth three times every two years [4].

In recent years, many farmers in Tuscany have converted to rearing Lacaune sheep. The breed originated from the Roquefort area of France and has become the second-most reared breed in Tuscany, after Sarda and before Massese, with a total of 36,832 heads [3]. There are two main reasons for this breed's popularity in Tuscany. Firstly, the Lacaune breed is highly productive and is considered one of the world's high-yielding milk ovine breeds [7]. Secondly, the increase in the wolf population in the region [8] has led to an increase in sheep predation [9], which has forced farmers to reduce the grazing hours and increase the time animals spend indoors, in a safer and more controllable environment. This has resulted in a decrease in the extensive dairy sheep farming from 1239 to 748 farms in Tuscany over the last 15 years, while the intensive farming increased from 26 to 80 farms [3]. As a result, farmers have turned to breeding Lacaune sheep, which are better adapted to intensive farming. Lacaune sheep is a less rustic breed if compared to Sarda and Massese, which have not undergone intense genetic selection and are considered excellent grazers. So far, the intensive production system is regarded as the most profitable method for producers to fully exploit the genetic animal potential of the Lacaune breed [10].

The livestock sector is highlighted as a relevant contributor to global warming potential, accounting for approximately 12% of the total anthropogenic greenhouse gas (GHG) emissions, and it must face the challenge of reducing its environmental impact by replying to the increasing demand for animal food products [11]. Small ruminants, in particular, emit 596 million tons of CO_2 eq per year globally [12]. The sheep sector also contributes to the emissions of N compounds to the atmosphere, such as ammonia (NH_3) and nitrogen oxides (NOx), which release hydrogen ions (H^+), acidifying the soil and water [12]. In addition, NH_3 volatilization, nitrate (NO_3) leaching and phosphate (PO_4^{3-}) run-off from the manure stored or spread on fields as fertilizer are the main contributors to the eutrophication of natural habitats [13]. The use of natural resources such as water and land represents another relevant environmental impact of livestock production [12].

The environmental impact of sheep farming is influenced by a variety of factors, including but not limited to feed composition, manure management, housing systems and pasture management [12,14]. Differences in breed can affect the feed conversion efficiency, milk yield, growth rates and resource utilization [15,16]. Consequently, breed choice can have implications for the sustainability of sheep production systems.

In this context, this study aimed to apply the Life Cycle Assessment (LCA) methodology to carry out a descriptive analysis of the effect of the breed on the environmental impacts of sheep milk production on three semi-extensive farms located in Tuscany. The farms under study were similar in terms of the rearing system and flock size and differed by the breed reared: Sarda, Massese and Lacaune.

2. Materials and Methods

2.1. Farms' Characteristics

The farms correspond to a semi-extensive rearing system where sheep graze for a few hours each day (Table 1) and spend the night indoors. As shown in Table 1, the flock size was very similar, with an average of 350 heads per farm. Similarly, none of the three farms under study uses synthetic fertilizers or other active ingredients applied to their forage crops, all of which are rainfed. The analytical composition of the feed used and the feeding regime of farms are reported in Tables S1–S3.

The Massese farm is located in the province of Pisa. It is certified organic [17], and all the animal feed is produced on the farm. Lactating sheep are milked twice daily using a mechanical milking machine with a 12-point standing, except from the end of July to the beginning of September, when they are milked only once a day because of the low production. Adult sheep lambed three times in two years with a twin rate of 30%. About 610 lambs are sold per year at 30 days and a body weight (BW) of about 14 kg. Culled sheep sent to slaughter are about 50 head yr^{-1} at a BW of 60 kg.

Table 1. Main characteristics and primary data of the three farms analyzed.

Data	Unit	Massese	Sarda	Lacaune
Farmland	ha	100	85	47
Altitude	m ASL	3	116	40
Grazing	hours day^{-1}	7	5	4
Flock size	n	400	350	300
Lactating sheep	n	370	303	225
Young sheep	n	25	40	70
Rams	n	5	7	5
Lactation duration	days	120	240	150
Unit Milk production	kg $head^{-1}$ yr^{-1}	108	180	220
Total Milk production	kg yr^{-1}	40,000	54,000	50,000
Milk protein	g 100 g^{-1}	4.93	5.80	5.83
Milk fat	g 100 g^{-1}	5.67	6.70	7.21
Fat and protein corrected milk	kg FPCM yr^{-1}	53,244	82,344	79,487
Feed efficiency	kg FPCM DMI^{-1}	0.25	0.36	0.36
Feed self-sufficiency [1]	%	100	87	100
Lamb meat production	kg BW yr^{-1}	8540	4128	2422
Sheep meat production	kg BW yr^{-1}	3000	1600	3000
Manure production	t yr^{-1}	343	367	346
Bedding straw production	t yr^{-1}	25	24	33
Water consumption on farm	m^3 yr^{-1}	865	731	701
Electricity consumption	kWh yr^{-1}	3005	4798	6400
Diesel consumption	L yr^{-1}	7632	8316	3162

ASL: above sea level; DMI: dry matter intake[1], expressed as kg dry matter produced on farm regarding kg of total DMI; BW: body weight.

The Sarda farm is in the province of Grosseto, and lactating sheep are supplemented with commercial feed and dehydrated beet pulp produced off the farm. The milking is carried out twice a day with a 12-point standing mechanical milking machine, except for the period from the end of September to the second half of December as there is no milk production. Adult sheep lambed once a year with a twin rate of 40%. About 344 lambs are sold per year at the age of 30 days and with a BW of about 12 kg. The culled sheep sent to slaughter are about 40 head yr^{-1} at a BW of 40 kg.

The Lacaune farm is in the province of Grosseto, and, as with the Massese one, it is certified organic and feed-self-sufficient. The herd is divided into two groups, with a lambing period starting in November and in March to produce milk all year round. The lactating sheep are milked twice daily with a 20-point standing mechanical milking machine. Adult sheep lambed once a year with a twin rate of 20%. About 173 lambs a year are sold at the age of 30 days and with a BW of about 14 kg. The culled sheep sent to slaughter are about 50 head yr^{-1} at a BW of 60 kg.

2.2. Life Cycle Assessment

LCA is an internationally accepted methodology for assessing the potential environmental impact of products and processes [18]. This method was applied in agreement with ISO 14040 and 14044 [19] and the FAO's LEAP guidelines for small ruminant supply chains [20], which were developed by the United Nations Food and Agriculture Organization under the Livestock Environmental Assessment and Performance Partnership to introduce a harmonized international approach to the assessment of the environmental performance of livestock systems. The selected system boundary was "from cradle to farm gate" and included the following stages: animal emissions (enteric fermentation, water perspiration and respiration), manure management (emissions due to manure storage or application to soil, and dung and urine deposited during grazing), crop production (all on-farm processes related to the crops for the production of forage and concentrate), purchased feed (the production and transport of commercial purchased feed) and energy (referring exclusively to farm consumption). Following the FAO's LEAP guidelines [20], the production of capital goods such as stables, animal shelters, other structures or milking machines with a lifetime greater than one year were excluded because they are used in successive seasons within the farm, which implies an intensive use, and, consequently, their environmental impact per functional unit (FU) is negligible.

The FU was 1 kg of fat and protein-corrected milk (FPCM) calculated following the formula from the International Dairy Federation [21]:

$$\text{FPCM (kg)} = \text{raw milk production (kg)} \times (0.1226 \times \text{fat\%} + 0.0776 \times \text{protein\%} + 0.2534) \quad (1)$$

To allocate shared inputs and emissions to the main product, the milk and the coproducts, the meat from surplus lambs and cull sheep, following the LEAP guidelines [20], a biophysical allocation based on the energy requirement for milk and meat production was applied (Table 2). Manure and straw were not considered co-products because they are used as fertilizer and bedding material.

Table 2. Biophysical allocation coefficients (%) for milk, lamb and sheep meat of the three farms.

Farms	Milk	Lamb Meat	Sheep Meat
Massese	81.70	1.46	16.85
Sarda	92.93	0.46	6.61
Lacaune	83.35	0.25	16.40

Primary data corresponding to the cropping season 2021/2022 were collected on-site from a survey to the farmers about the herd (number and weight for each animal category), the feeding regime (type, quantity and quality of feed produced on the farm or purchased), milk production (milk yield, protein and fat content), on-farm crop production (area, yields, soil tillage practices, machinery and fuel consumption), the manure management (manure production, storing and distribution on field systems) and the transport of raw materials (type of raw materials, quantity, origin and frequency of transport).

Total energy and water consumption of the farms were taken from the corresponding electric and water bills. Following the FAO's LEAP guidelines for water use in livestock production systems [22], within the animal, inflows include water intake (drinking water and water in feed) and the outflows include respiration, perspiration, excretion with feces and urine as well as the water incorporated into livestock products that can be transported off-farm. Consequently, for the estimation of water consumption due to the vapor losses through animal respiration and perspiration and the water content of milk and meat sold from the farm, an animal-balance approach was used, which accounts for water intake from drinking and feed and water output in dung and urine.

Secondary data were taken from *Ecoinvent 3.9.1* database [23]. The main primary data of the three farms are reported in Table 1 and the secondary processes are reported in Table S4.

The calculation of GHG emissions associated with animal rearing requires data on total feed intake and some feed quality parameters [20]. As it is preferable to use real data on daily feed intake composition instead of estimating from other parameters [24], at the time of data collection on the farms, samples of feed (hay, straw and grain) produced on each farm were also collected and analyzed. Dry matter (DM) and ash were determined following the methods suggested by the Association of Official Analytical Chemists [25]. The Kjeldahl method [26] was used to estimate the nitrogen content, the ether extract through the Soxhlet method [27] and the crude fiber with the Weende method (978.10) [22]. The results of these analyses were used to calculate the dry matter intake (DMI) (kg DM), N intake (g N) and gross energy intake (MJ) for each animal category, i.e., lactating sheep, dry sheep, young sheep for replacement and rams (Table 3). For the calculation of the gross energy of each feed source, the equation of McDonald et al. [28] was used:

$$GE = 0.0226\ CP + 0.0407\ EE + 0.0192\ CF + 0.0177\ NFE \quad (2)$$

where GE is the gross energy of feed (MJ/kg); CP is the crude protein content (g/kg); EE is the ether extract fraction (g/kg); CF is the crude fiber (g/kg) and NFE is the nitrogen-free extractives (g/kg) calculated as the subtraction from 1000 of the sums of the amounts of moisture, ash, CP, EE and CF.

Table 3. Feed, nitrogen and gross energy intake of sheep from the three analyzed farms for each animal category.

Animal Category	Dry Matter Intake kg DM * head^{-1} day^{-1}			Nitrogen Intake g N head^{-1} day^{-1}			Gross Energy Intake MJ head^{-1} day^{-1}		
	Massese	**Sarda**	**Lacaune**	**Massese**	**Sarda**	**Lacaune**	**Massese**	**Sarda**	**Lacaune**
Lactating sheep	2.14	2.00	2.73	55.39	33.90	52.26	38.61	35.75	48.30
Dry sheep	1.24	1.32	1.75	27.29	19.66	25.07	21.93	23.61	30.47
Young sheep	1.06	0.91	1.34	22.76	10.58	23.55	18.81	16.05	24.04
Rams	1.70	1.40	1.99	39.19	21.35	31.40	30.12	24.77	34.75

* DM: dry matter.

The nutrient content (N, CP, EE, CF and NFE) of the feed and hay was estimated by analyzing the samples (Tables S2–S4); the nutritional composition of pasture was taken from the literature [29], while the label values were used for purchased feed.

Feed, nitrogen and gross energy intake, reported in Table 3, were then used in the IPCC and EEA emissions calculation models to obtain the most accurate estimates possible. In particular, CH_4 emissions from enteric fermentation and manure management and the direct and indirect N_2O emissions from manure and soil management were estimated following the Tier 2 model from IPCC (Chap 10 and 11) and Tier 1 for NO_3 emitted into groundwater [24]. Emissions of NH_3 to air due to manure storage were calculated with the Tier 2 model from EEA [30]. NOx in air from manure and soil, PO_4^{3-} and phosphorus (P) released into ground and surface water were estimated with the equations reported by Nemecek and Kägi [16].

The impact categories studied included those most relevant for the livestock sector [17], namely climate change (CC), freshwater eutrophication (FE), marine eutrophication (ME), terrestrial eutrophication (TE), acidification (AE), water use (WU) and land use (LU). Environmental impacts were calculated using the Environmental Footprint (EF 3.1) method recommended by the European Commission Recommendation 2021/2279 and the OpenLCA software (1.11 version).

Regarding WU, the FAO's LEAP guidelines [22] recommend using the AWARE characterization factors (CFs) for the detailed resolution at which they are provided. For the indirect water flows related to water consumed in the background processes, the world average CF for unknown use of water (42.95 m^3 world eq/m^3 consumed) was chosen, following the EF 3.1 impact assessment method. Instead, the AWARE CFs specific to the locations of the three farms involved in the study were used for the direct water flows of the foreground processes of the farms (Table 4). For this aim, the farm coordinates and the Google Layer applicable to Google Earth, available on the AWARE website, were used [31].

Table 4. Annual AWARE characterization factors for agricultural use of water chosen to calculate farm impact regarding water use.

Farms	Characterization Factors
Massese	4.8 m^3 world eq/m^3
Sarda	62.4 m^3 world eq/m^3
Lacaune	62.4 m^3 world eq/m^3

3. Results

The results of the impact assessment of the three farms (Table 5) for most of the impact categories studied showed substantial differences among the farms. The Massese farm is the one that shows the greatest impact scores and Lacaune the least. The exceptions to this are ME and WU, for which the Sarda farm exhibited the greatest impact scores. In general, Lacaune showed impact scores 14% to 48% lower than Sarda, and, with the exception of the WU, 19% to 68% lower than Massese (Figure 1).

Table 5. Impact assessment results of 1 kg of FPCM produced on the three farms analyzed.

Impact Category	Unit	Massese	Sarda	Lacaune	Mean ± SE
Climate Change, CC	kg $CO_{2\ eq}$	3.76	2.56	1.78	2.70 ± 0.58
Freshwater eutrophication, FE	kg P_{eq}	2.83×10^{-4}	2.49×10^{-4}	1.40×10^{-4}	$2.24 \times 10^{-4} \pm 4.31 \times 10^{-5}$
Marine eutrophication, ME	kg N_{eq}	4.83×10^{-3}	5.63×10^{-3}	3.79×10^{-3}	$4.75 \times 10^{-3} \pm 5.33 \times 10^{-4}$
Terrestrial eutrophication, TE	mol N_{eq}	0.30	0.23	0.18	0.24 ± 0.03
Acidification, AE	mol H^{+}_{eq}	0.07	0.05	0.04	0.05 ± 0.01
Water use, WU	m^3 world $_{eq}$	0.14	1.30	0.68	0.71 ± 0.34
Land use, LU	dimensionless	821.63	538.37	265.53	546.02 ± 156.96

SE: standard error.

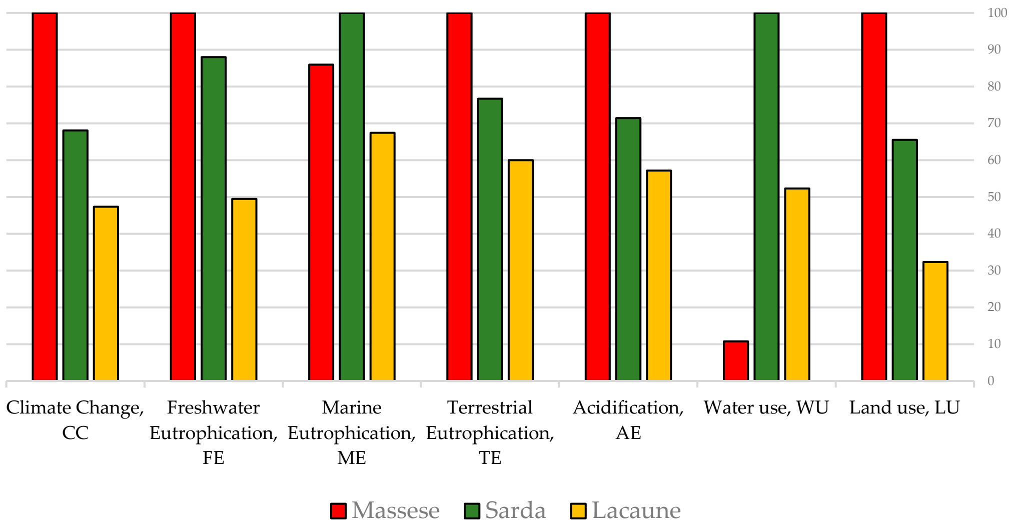

Figure 1. Comparison of the impact results between farms, with the highest values reported as 100%.

The CC scores of the Sarda and Lacaune farms are, respectively, 32% and 53% lower than that of the Massese farm. Regarding eutrophication, the FE score of the Lacaune farm is half that of the Massese farm, and the Sardinian one is only 10% lower than the Massese farm. For TE, the differences are minor as the Lacaune and Sarda scores are, respectively, 40% and 23% lower than for the Massese farm. The differences in the AE are similar to those of the TE, with Lacaune and Sarda showing, respectively, 43% and 29% lower scores than Massese. For LU, the scores of the Sarda and Lacaune farms are 35% and 68% lower, respectively, compared to the Massese farm. Regarding ME, the score of the Sarda farm is 14% greater than that of the Massese farm and 33% greater than Lacaune. The only category where the Massese farm has the lowest impact is WU, with a score, respectively, 90% and 42% lower than those of the Sarda and Lacaune farms (Figure 1).

The contribution analysis (Figure 2) showed that, for the three farms, CC is mainly caused by the CH_4 enteric emissions, and this occurred more on the Massese (70%) and Lacaune (71%) farms than the Sarda (56%) farm. Manure management is the main driver of TE and AE, without substantial differences between the three breeds, with the shares ranging from 85% for the Sarda farm to 94% for Lacaune for TE, and from 84% to 93% for AE. Manure management is also an essential driver for FE, especially for the Massese farm (60% of the total impact score), whereas a lower contribution was found for the Lacaune (47%) and Sarda (40%) farms. Crop production is the main contributor to ME and LU. In particular, the contribution of this stage to the ME of Massese and Lacaune is similar, 62% and 67% of the total impact score, respectively, whereas it has a lower contribution regarding the Sarda farm (16%) due to the higher impact contribution of the purchased feed (41%). Regarding WU, the water consumed by the animals is the main contributor for the Lacaune (81%) and Massese (54%) farms, while, for the Sarda farm, the purchased feed has a significant role (55%). Almost all the LU impact is due to the use of the soil to cultivate forage. It concentrates on the farms, with a contribution of 99% for Massese and Lacaune and 92% for Sarda, and the remaining 7% is due to the cultivation of raw materials for the purchased feed production off the farm. As can be observed in Figure 2, the contribution of the on-farm electricity consumption is practically irrelevant for all the impact categories studied since it never exceeds 8% of the total impact score.

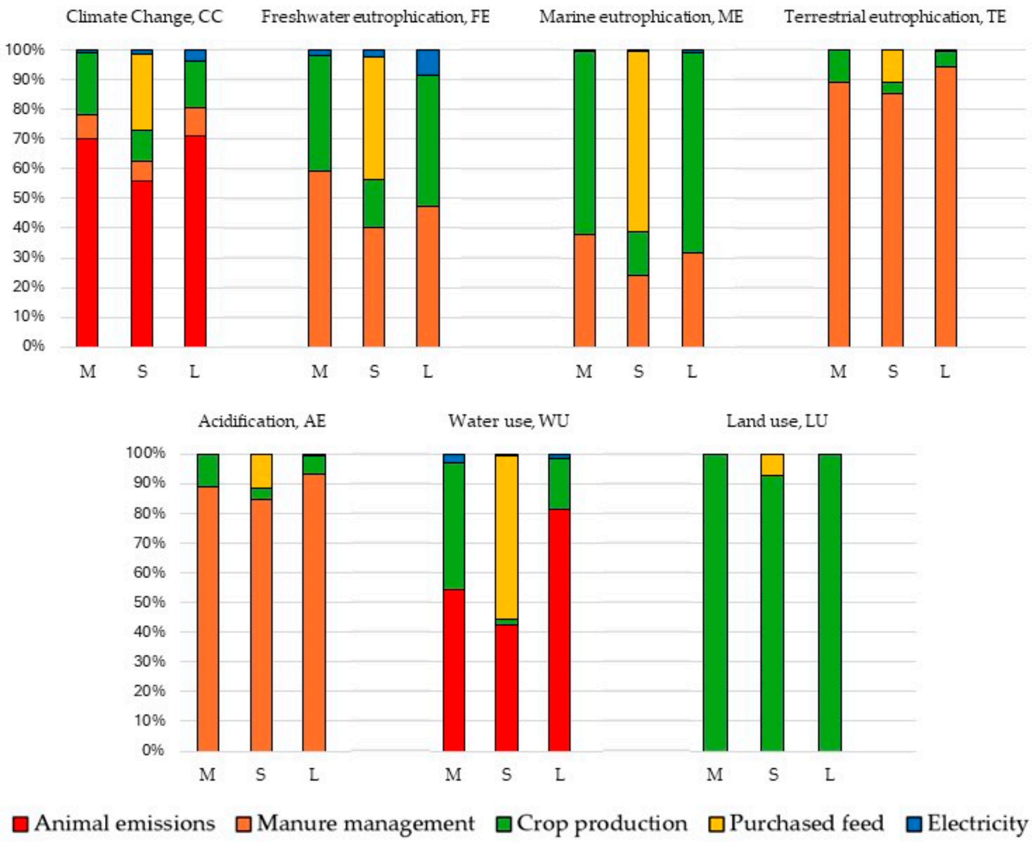

Figure 2. Percentage contribution to the impact categories of the main processes of the Massese (M), Sarda (S) and Lacaune (L) farms.

4. Discussion

The CC of the three farms analyzed agrees with other LCA studies on semi-extensive Mediterranean dairy sheep farms [32–35]. So far, the impact score of the Sarda farm (2.56 kg of $CO_{2\,eq}$ per kg of FPCM) obtained in the present study is lower than the other values observed regarding the same breed. In particular, Bosco et al. [36] assessed Sarda sheep in Tuscany and reported values of 5.7 and 3.2 kg $CO_{2\,eq}$ per kg of FPCM for conventional and innovative farming systems, respectively. Meanwhile, in Sardinia, a closer but dryer region, Atzori et al. [37] reported for Sarda farms values ranging from 3.05 to 6.02 kg of $CO_{2\,eq}$ per kg of FPCM and Vagnoni et al. [38] 3.25 kg $CO_{2\,eq}$ per kg of FPCM. The low CC scores obtained in this study can be attributed to the non-use of fertilizers or other synthetic chemicals on the analyzed farms, unlike in the above-mentioned litearature, except Sabia et al. [30]. Previous studies remarked on the application of syntethic fertilizers as a critical point in the production of crops, and especially feed, due to both their manufacturing and the fraction of N emitted to the air as nitrous oxides [39]. In addition, the N and P applied in the production of the feedstock can also be released in underground and surface water bodies [39]. In this study, only the Sarda farm used purchased feeds, while Massese and Lacaune are self-sufficient in feeding, i.e., all the dry matter intake of the sheep is on-farm-produced (Table 2), which can explain the higher WU of Sarda if compared to the other farms. Moreover, this result is corroborated by the assumption that the feed supply chain is the second contributor to CC, after CH_4 enteric emissions, as reported in other studies on the dairy sheep sector [36–38,40,41].

The environmental performance of the Sarda farm, especially for FE, ME and WU (Figure 2), is penalized because 18% of the annual feed consumed by the flock was purchased from outside the farm (Table 1). In fact, despite being the one with the highest FPCM production (Table 1), it still had greater impact scores than the Lacaune farm, which appeared to be the best for most of the impact categories studied. It is largely reported in the literature that milk yield is the main driver of the low emissions intensity in the dairy sector [42,43]. When looking at the primary data (Table 1), it is possible to derive some conclusions. Firstly, the Lacaune breed is the most productive, with 220 kg of milk per head per year against 180 kg of Sarda and 108 kg of Massese. These data agree with the literature on these breeds' productivity [5–7]. In addition to the high productivity, the fat and protein milk content is higher for the Lacaune breed (Table 1), which obviously influences the total FPCM production calculation (Equation (1)).

Regarding the energy consumed, the electricity consumption of the Lacaune farm is higher than the other two (Table 1). This can be explained by the greater use of the milking machine since the Lacaune breeding system is structured to produce milk all year while the other two farms follow seasonal cycles and some months have no or low milk production. Although the diesel consumption of the agricultural machinery generally increases with the cultivated hectares, the Sarda farm generated greater consumption despite having 15 ha less than the Massese and Lacaune farms (97.8 L yr^{-1} ha^{-1}; 76.3 L yr^{-1} ha^{-1}; and 67.3, L yr^{-1} ha^{-1}; Table 1). Indeed, the Sarda farmland has a 20% slope while the Massese and Lacaune farms are flat, and this may have induced the farmer to use different tools and tractors, or to undertake slower tillage operations.

The Massese farm showed the greatest impact scores for most of the categories studied (Figure 1). The Massese breed productive system enables the ewes to have three lambings in two years, thus leading to a higher lamb meat production than the other two farms (Table 1). Consequently, the percentage of the impacts allocated to the milk is lower (Table 2). Despite this, the Massese breed productivity is lower than that of the other two breeds (Table 1).

As regards the feed inputs, even though it is well-known that there is a positive linear relationship between BW and DMI [44], the feed intake of Lacaune is higher and that of Massese is more similar to the Sarda breed (Table 3). Lacaune and Massese are two breeds of about 60 kg of BW, while it is about 40 kg for Sarda; therefore, the high milk productivity of the Lacaune sheep (Table 1) is supported by a higher DM and gross energy intake (Table 3). However, the Lacaune and Sarda farms show the same feed efficiency; i.e., they produce more milk with less feed intake than Massese (Table 1).

Notably, the WU impact category is the only one in which the Massese farm has the lowest impact (Figure 1). The water consumption on the Massese farm was slightly higher than that of the other two companies (Table 1), but the WU score was the lowest (Table 5) since the AWARE CF was low (Table 4). Although all three farms are located in the same region, Tuscany, a high variability in the CFs was found. The CF highly depends on the geographic location, and the Massese farm was near an artificial lake. This suggests the importance of using CFs at the sub-watershed level instead of the national level. On the other hand, the highest WU score of the Sarda farm (Table 5) is due to the contribution of the purchased feed (Figure 2).

The LU impact was calculated using the soil quality index. This indicator assesses the impacts of land use activities on five soil properties: erosion resistance, mechanical filtration, groundwater regeneration and biotic production [45]. According to this method, due to the farmland dimension, the Massese farm has a higher LU than the Sardia and Lacaune farms (Table 1).

A limitation of this calculation method is that it does not evaluate some externalities of pasture-based systems that play a relevant role at a local scale, such as the ecosystem services (ESs) [45]. ESs are all direct and indirect benefits that people obtain from ecosystems [46], including agroecosystems and pasture-based production systems that are essential for providing a variety of ESs [47], such as the moderation of extreme events, maintenance of soil structure and fertility, landscape maintenance, cultural heritage conservation and biodiversity conservation [48].

The disappearance of local breeds and animal genetic resources has raised concerns about food security and livelihood, especially in light of the effects of climate change and the growing global population [49]. With 160 extinct breeds, sheep are second regarding the most extinct breeds after cattle worldwide [50]. Farmers' attention to sheep's production traits has resulted in an underestimation of the actual value of local breeds, including greater disease resistance and local condition adaptation [51,52], as well as low input requirements [50]. Moreover, foreign breeds, like Lacaune (i.e., breeds present for a relatively short time in a country different from the one in which it is developed), are generally genetically specialized to be highly productive in intensive production systems [53]. In contrast, native, locally adapted breeds like Massese and Sarda are considered more robust and reared in more extensive systems, providing more ecosystem services [53]. In this study, Lacaune is the breed that grazes the least, about 4 h a day, while Massese is the breed that grazes the most, about 7 h a day. From this perspective, it could be beneficial to improve the quality of this LCA study by integrating ecosystem services and biodiversity considerations to provide a comprehensive assessment and holistic understanding of the environmental impacts of these sheep breeds [54,55].

Moreover, expanding the study to include a larger number of farms could indeed provide valuable insights. With a broader sample size, it would be possible to better categorize different types of rearing systems and their respective impacts. This could lead to a more comprehensive understanding of the factors influencing farming practices and outcomes.

5. Conclusions

This is the first study that analyzes milk production's environmental impact considering the three most important sheep breeds in the Tuscan territory. The results show that the Lacaune farm has a lower environmental impact than the farms with the other two breeds due to its high productivity, even if the rearing occurs in a semi-extensive system and not in confinement. Notably, the low impact on the WU of the Massese farm is due to the lower CF in relation to the proximity to a local lake.

The contribution of purchased feed has hindered the performance of the Sarda farm, the only one not being self-sufficient. On-farm feed production appears to be a practice worth encouraging to reduce the environmental impacts of semi-extensive dairy sheep farms.

Replacing the two native breeds, Massese and Sarda, with the high-productivity Lacaune breed in the Tuscany region would not seem to cause a more significant impact from an environmental point of view. However, it would be interesting to evaluate the impact of these breeds from other points of view, such as the protection of biodiversity and the role of ecosystem services, with further studies.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su16124941/s1; Table S1: Analytical composition of the feed used on the Massese farm expressed as % on fresh matter, and flock intake expressed as kg dry matter per head per day; Table S2: Analytical composition of the feed used on the Sarda farm expressed as % on fresh matter, and flock intake expressed as kg dry matter per head per day; Table S3: Analytical composition of the feed used on the Lacaune farm expressed as % on fresh matter, and flock intake expressed as kg dry matter per head per day; Table S4: Life cycle inventory (LCI) metadata from Ecoinvent v3.9.1.

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