Environmental footprint of milk production from Mediterranean sheep systems

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ABSTRACT

In the Euro-Mediterranean countries the sheep milk production is a significant sector that is currently going through a deep structural crisis. Since eco-sustainability of production systems and mitigation of climate change are European priorities, optimizing the environmental footprint of dairy sheep farms could become the access key of farmers for receiving financial support and achieve a more environmentally-sound agriculture. The main objectives of this paper were to compare the environmental impacts of sheep milk production from three different dairy farms in Sardinia (Italy), characterized by different input levels, and to identify the hotspots for improving the environmental performances of each farm, by using an LCA analysis. The LCA conducted using different functional units (1 kg of Fat Protein Corrected Milk and 1 ha of Utilized Agricultural Area) and different assessment methods (IPCC, ReCiPe, and Blue Virtual Water) led to a more objective evaluation of the environmental performances of farms.

Keywords: dairy sheep farming systems; environmental impacts; Life Cycle Assessment; agriculture multifunctionality; eco-sustainable livestock.

1. Introduction

The dairy sheep production is a significant sector for the European Mediterranean countries. Sardinia (Italy) is the most important EU region for sheep milk production, with more than 3.2 million ewes – about 3.5% of the EU total (EUROSTAT, 2012) – and a milk production of about 330.000 t year^{-1} (Osservatorio Regionale per l'Agricoltura, 2012), which represents more than 12% of the total European production (EUROSTAT, 2012). More than half of Sardinian sheep milk production is addressed to cheese industry for "Pecorino Romano PDO" (Protected Designation of Origin, European quality label) production (Furesi et al., 2013). "Pecorino Romano PDO" is one of the main Italian PDO product (ISMEA, 2012) and 95% of its production derives from Sardinian cheese factories (Idda et al., 2010). The dairy sheep farming system in Sardinia presents different degrees of intensification, depending basically on the geographical location of farms, which affect key-traits such as arable land availability, soil fertility and possibility for irrigation (Caballero et al., 2009; Porqueddu, 2008). In the last decades, Sardinian sheep production systems suffered a serious and continuous loss of competitiveness, due to several internal and external factors that caused a deep structural crisis in this traditional sector.

As production systems' eco-sustainability and climate change mitigation are on top of the European agenda, minimizing the ecological footprint of farms represents a key factor for farmers to obtaining public incentives and for enhancing the multifunctionality of agricultural systems. Therefore, the optimization of environmental performances could be a crucial factor to improve competitiveness of sheep farming, particularly in marginal areas. For this purpose it is essential to assess the environmental footprints of these livestock systems and to identify the weak points of the production chain where to take actions for reducing the farm's environmental impact (FAO, 2010). The environmental impacts (including greenhouse gases emissions) of animal production systems can be evaluated by using the Life Cycle Assessment (LCA) approach (De Boer, 2003). However, when applied to agriculture, the LCA analysis presents some challenges due to the intensive nature of required data, their limited availability and the multiple-output nature of production (FAO, 2010). Most of the research literature has been focused on intensive livestock systems of dairy cattle (Milani et al., 2011). To our knowledge, very little research studies have been conducted on life cycle assessment of sheep milk. A good example is given by Michael (2011), who made a detailed analysis of the resource use and emissions of sheep milk production in Australia, as part of a wider study on selected "new animal products" industries. On the other hand, several studies have been conducted to evaluate specific impacts of dairy sheep farming systems on soil, water, biodiversity, etc. (Molle et al., 2008; National Research Council, 2010; Peyraud and Delaby, 2006; Shepherd et al., 2007).

This study was conducted with the main aim of contributing to fill in these knowledge and data gaps and with the specific objectives of (i) comparing the environmental impacts of sheep milk production from three different dairy farms located in Sardinia and characterized by different input levels, and (ii) identifying the hotspots to improve the environmental performances of each farm, by using an LCA analysis.

2. Methods

2.1. Case studies

During 2011, data were collected from three different dairy farms located in the Province of Sassari, North-western Sardinia, Italy. The three studied farms fall into a homogenous agro-climatic area, with climate conditions typical of the central Mediterranean area, an average annual rainfall of approximately 550 mm, mean monthly temperatures varying from 10 to 26 °C, and elevation ranging from 60 to 350 m a.s.l. Rural landscape is characterized by dairy sheep farms with a mosaic of feed resources mainly represented by annual forage crops, cereal crops, improved and natural pastures.

The three farms differed mainly in stocking rate, size of grazing areas and concentrates consumption (Table 1), mostly covering the range of input levels for Sardinian sheep livestock (ARAS, 2013). We considered as low input farm (LI), the farm with the lowest stocking rate (1 ewe ha^{-1}), the largest grazing area (95 ha) and the lowest consumption of concentrates (1 t per year). On the opposite, the high input farm (HI) showed the highest stocking rate (5.5 ewes ha^{-1}), the smallest grazing area (12 ha) and an annual consumption of concentrates of about 200 t. Mid-input farm (MI) was characterized by intermediate levels of input. Farms had also different market strategy: LI and HI farms sold the milk to the cheese industry for “Pecorino Romano PDO” production, while MI uses its own milk for small-scale on farm cheese production, “Pecorino di Osilo”, which is included in the Italian list of typical agri-food products. Moreover, MI was the only farm that used the aseasonal lambing technique.

Table 1. Main characteristics of production system in low- (LI), mid- (MI), and high-input (HI) dairy farms. Data refer to 2011.

	Low-input (LI)	**Mid-input (MI)**	**High-input (HI)**
Utilized Agricultural Area (ha)	125	70	67
Heads (number)	120	320	370
Stocking rate (ewes ha^{-1})	1.0	4.6	5.5
Milk production (kg $year^{-1}$)	25,000	79,655	110,000
Milk pro-capita annual production (kg ewe^{-1} $year^{-1}$)	208	249	297
Pastures - grazing area (ha)	95	52	12
Arable land – cereals and annual forage crops (ha)	30*	18	55
Concentrate feed annual consumption (t) **	1	121	204
Mineral N-fertilizing (kg ha^{-1})	0	21	45
Mineral P_2O_5-fertilizing (kg ha^{-1})	0	72	32
Irrigation	no	yes	no
Milking system	manual	mechanical	mechanical

*10% of the arable land production is used for sheep feeding; the remaining part is sold as hay and grain.
** LI produces all concentrates on farm, MI imports all concentrate feed needed, and HI imports about 86% of total requirements.

2.2. Life Cycle Assessment methodology

The methodology used to carry out the LCA study is consistent with the international standards ISO 14040-14044 (2006 a, b). The analysis was conducted using two different *functional units* (FU): 1 kg of Fat and Protein Corrected Milk (FPCM) and 1 ha of Utilized Agricultural Area (UAA). The use of these two FU allows to define and to combine productive and economic results with depletion of natural resources. All inputs and outputs referred to 1 kg of FPCM were partitioned (*impact allocation*) between milk and the other co-products on the basis of the economic value of products (economic allocation), since the "main product" (milk) of all three farms had an economic value much higher than the other co-products (wool and meat) . When co-products were obtained from the same field (e.g., triticale-barley grain and stubble), mass-based allocation was applied, since the amounts of the individual co-products were interdependent in a physical relationship.

The life cycle was assessed "from cradle to gate", including in the *system boundaries* all the input and output related to sheep milk production. All modes of transportation and distances covered within the system were also taken into account. The model system was divided into two subsystems: a) Flock, and b) Farm Impact.

a) Flock - Processes linked with the productive life of livestock.

They include all the processes related to i) the use of agricultural soil and the cultivation operations required for the production of different forages; ii) the feed input, including the consumption of forage from pastures and feed concentrates; iii) livestock operations such as shearing (once a year) and milking (performed twice a day if mechanical, once a day if manual). Each of these processes has been applied to the different categories of sheep, depending on the breeding techniques adopted by each farm, having as primary reference points the quantity and quality of sheep diet. Therefore, LCA model includes ewes and rams, each subdivided into lambs, replacement animals and adults. The ewes were grouped by physiological and productive phase (maintenance, dry and lactation).

b) Farm Impact - Processes linked with the farm structure.

They include infrastructures (milking parlour, barns, etc.), agriculture machineries and devices (tractors, ploughs, milk cooler, pumps, etc.), water and energy consumption, and consumable materials like detergents, veterinary drugs, spare parts, etc.

About 70% of life cycle inventory data were collected through 12 visits *in situ*, interviews and a specific questionnaire (farm-specific data for year 2011). The remaining data (e.g., enteric methane emissions, supplement chemical composition, etc.) were collected from available literature and databases (mostly Ecoinvent v. 2.2 developed by Swiss Centre for Life Cycle Inventories).

With the aim of assessing in a more comprehensive way the environmental performances of the case studies, three different *evaluation methods* were used: 1) IPCC, Intergovernmental Panel on Climate Change (2006), which provides estimates on greenhouse gases emitted in the life cycle of products (Carbon Footprint), expressed in kilograms of CO_2-equivalents with 100-year time horizon; 2) ReCiPe that provides a more comprehensive assessment of life cycle environmental performances (Ecological Footprint), considering 17 different categories of environmental impact, which are calculated and harmonized obtaining a single eco-indicator (Ecopoint, Pt) (Goedkoop et al., 2009); 3) Blue Virtual Water that estimates the (virtual) water content incorporated (Water Footprint) into a product, as the volume of water, expressed in l-equivalents, consumed or polluted during the entire life cycle of the product (Hoekstra et al., 2011).

The life-cycle analysis was performed under the following *simplified assumptions*: the analysis included only the amount of forage (fodder crops and pastures) consumed by flocks, after cross-checking estimated and/or measured forage production and estimated nutritional needs based on gender, age, weight, physiological stage and production level of animals. National inventories of emissions by ISPRA (2011) for CH_4 and by IPCC (2006) for N_2O were used to quantify flocks' enteric emissions. Irrigation impacts of MI were estimated by Ecoinvent v. 2.2. Life cycle assessment calculation was made using LCA software SimaPro 7.3.3 (PRé Consultants, 2011), which contains various LCA databases.

A Monte Carlo analysis was also performed to quantify the effects of the data uncertainties on the final results and to weight the differences between the environmental performances of the three farms.

3. Results and discussion

3.1. Evaluation of the environmental performances

The main results of the environmental impact assessment are shown in Fig. 1 by farm (LI, MI, and HI), method (IPCC, ReCiPe and Blue Virtual Water), and functional unit (1 kg of FPCM and 1 ha of UAA).

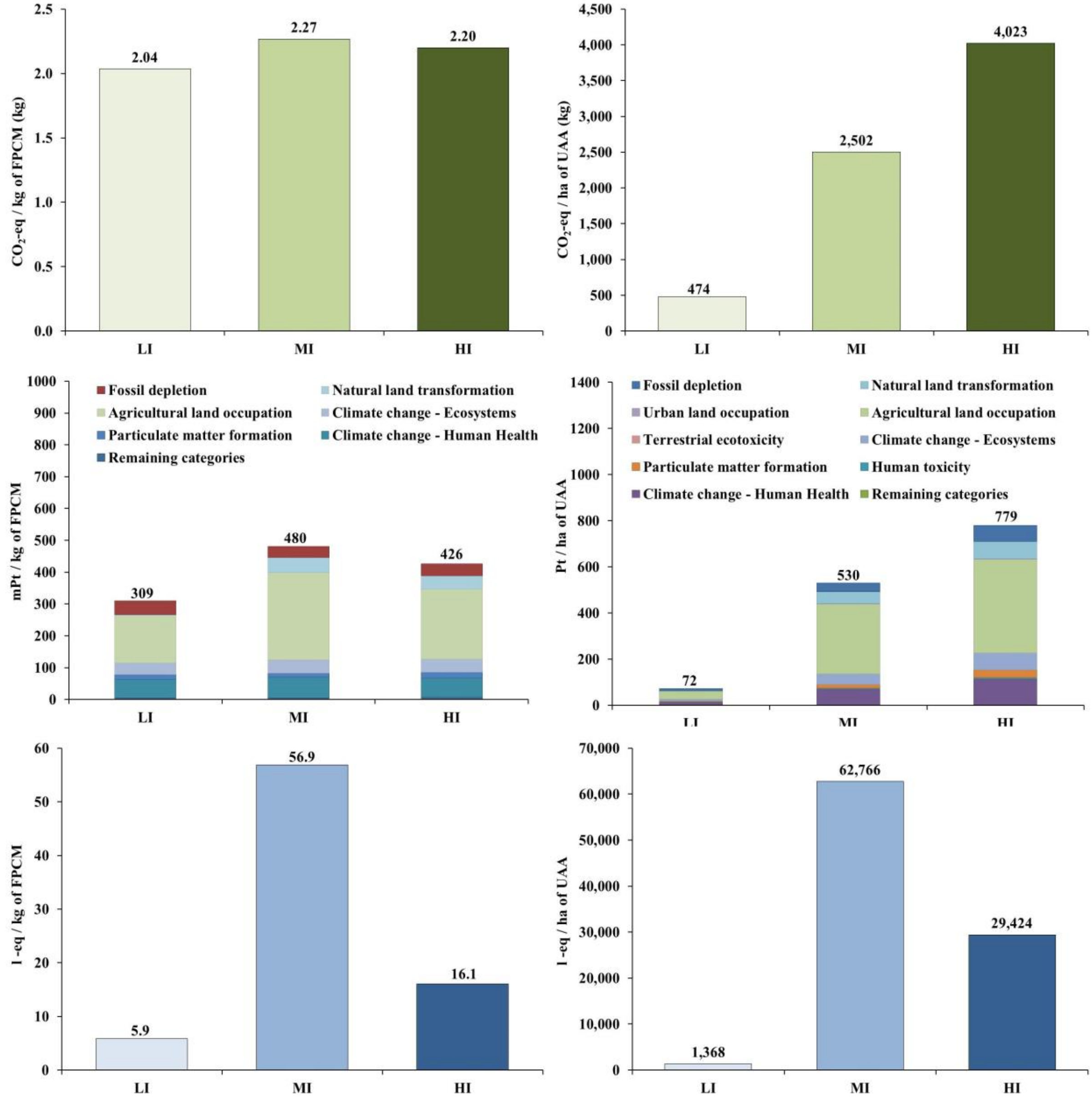

Figure 1. Main LCA results for three farms (LI, low input; MI mid input; HI, high input) using IPCC (plots at the top of the figure), ReCiPe (middle plots) and Blue Virtual Water (bottom plots) methods and two different functional units (1 kg of Fat Protein Corrected Milk, left plots, and 1 ha of Utilized Agricultural Area, right plots).

3.1.1. IPCC

The estimated life-cycle greenhouse gases (GHG) emissions of 1 kg of FPCM (plot on the left at the top of Figure 1) were slightly higher in MI. The GHG emissions per kg of FPCM from the observed production systems showed a slight variation ranging from approximately 2.0 (LI) to 2.3 (MI) kg of CO_2-eq. This result seems to contradict the findings reported in previous research studies (FAO, 2010; Hayashi et al., 2006; Michael, 2011). These authors showed that the degree of the environmental impact of farming systems referred to the quantity of product is negatively correlated with the intensity level in the inputs. The average Carbon Footprint of the three farms was equal to 2.17 kg CO_2-eq/kg FPCM and was about 61% lower than that estimated by Michael (2011) on a typical Australian dairy farm, where the Carbon Footprint was equal to 3.57 kg CO_2-eq/kg FPCM. However, the analysis of Michael (2011) was conducted on a more intensive dairy sheep farming system characterized by different sheep breed (East Friesian), and amounts of enteric methane emissions and stocking rate twice the amounts estimated in our case studies.

When the environmental impact assessment was performed using as functional unit 1 ha of UAA, the Carbon Footprint of the three studied farms showed relevant differences, indicating a strict positive relationship between the environmental impact of farms and the intensity level in the inputs (plot on the right at the top of Figure 1). The HI farm had the largest value (more than 4,000 kg of CO_2-eq), with LI and MI showing GHG emission amounts equal to about 12% and 62% of HI Carbon Footprint, respectively. Therefore, the highly extensive system of LI, with an UAA value almost twice compared to MI and HI and a stocking rate equal to 18% of HI (Table 1), was crucial in determining the environmental performance calculated per 1 ha of UAA.

3.1.2. ReCiPe

The results from the ReCiPe method assessment followed a trend similar to IPCC method for both FU (plots in the middle of Figure 1). To facilitate the interpretation of results, Fig. 1 shows only impact categories with scores higher than 10 milli-ecopoint (mPt) and 1 ecopoint (Pt) per 1 kg of FPCM (left side of the figure) and 1 ha of UAA (right side of the figure), respectively. When 1 kg of FPCM was used as functional unit, the farm with the lowest score was LI, with about 300 mPt per 1 kg of FPCM (approximately 36% and 27% less than MI and HI, respectively). When using 1 ha of UAA as functional unit, LI showed again the lowest value, with about 72 Pt per ha of UAA, which represents 14% and 10% of MI and HI impacts, respectively. It's interesting to note that the utilization of two FU led to different ranking of the three dairy farms and to a different weight of the impact categories on the life cycle assessment. Moreover, the use of 1 ha of UAA as FU determined a range of environmental impacts much higher than those assessed for 1 kg of FPCM. Agricultural land occupation was the impact category that showed the main contribution to the total environmental impact. The contribution analysis of the Agricultural Land Occupation impact category allowed to complete the description of the farming systems and to better understand the differences among the three farms in terms of input levels. The extensive land use represented more than 60% of the Agricultural Land Occupation in the LI, compared to 41% and 17% in MI and HI, respectively. On the other hand, the intensive land use was near 60% of Agricultural Land Occupation in HI, and around 35% for both MI and LI. In the latter case, the unexpected large percentage of intensive land occupation can be explained by the very limited arable land destined to forage production for sheep feeding. However, the contribution of the occupation of arable land on the total Agricultural Land Occupation was larger than 20% in MI and HI, and equal to about 1% in LI farm. Agricultural land occupation and, more generally, land use impact category are critical aspects of LCA analysis, in particular when the agricultural sector is investigated (Schmidinger and Stehfest, 2012). In this case, the impact category "land use", currently included in the most widely used LCA methods (like ReCiPe), quantifies mainly the potential impacts of land use on biodiversity, excluding other relevant land use impact categories, such as depletion of productive land area and changes in soil quality (Mattila, 2012).

3.1.3. Blue Virtual Water

Mid input farm (MI) was the only one that applied irrigation for crop production. The use of water for irrigation in MI determined, for both FU, a large Blue Virtual Water consumption compared to the other farms. The results of the Blue Virtual Water impact assessment method for 1 kg of FPCM indicate that the Water Footprint of MI was approximately 3.5 to 10 times larger than the Water Footprint observed in HI and LI, respectively (bottom plots of Figure 1). When the Water Footprint was calculated using 1 ha of UAA as functional unit, MI showed an impact value that is more than twice the HI value and about 46 times larger than the LI. In addition, the direct water consumption of MI for producing the annual total amount of FPCM was approximately 3,600 m^3, with about 65% being consumed for irrigation. The direct water consumption of HI amounted to 1,279 m^3, with an indirect consumption equal to 448 m^3. Conversely, the Blue Virtual Water consumption for LI derived mainly from indirect consumption, which represented, with 122 m^3, the 82% of the total consumption.

3.2. Contribution analysis

A detailed contribution analysis is reported in Table 2, which illustrates all processes that contributed with more than 1% to the total environmental impact of all farms for the three different evaluation methods adopted, using 1 kg of FPCM as functional unit. Similar results were also obtained for the functional unit 1 ha of UAA. In general, the analysis of the contributions of individual processes for the three farming systems showed a relevant role of enteric methane emissions, field operations (mainly tillage), electricity and production of agricultural machineries. In MI and HI, feed concentrates in the diet (in particular soy production) showed a relevant contribution, with percentages ranging from 16% for HI (IPCC method) to 30% for MI (ReCiPe method). The natural and improved pasture utilization resulted in relevant contribution only for the ReCiPe assessment method (31% in LI, 40% in MI and 34% in HI), essentially for the effect of the Agricultural Land Occupation impact category. The contribution of agrochemicals was generally low (always less than 3%), due to their very limited use in all the three farms. However, the incidence of contribution of each process varied with the evaluation method utilized. For example, the enteric methane emission is the most important impact (an overall average of 42% of total impacts) for the IPCC method, but when the estimate is performed using the ReCiPe method, the impact of the enteric methane emissions amounted on average to 11%, representing only the fifth highest-ranked impact. The complementary use of the three methods offered a multiple analysis perspective, resulting in a more comprehensive assessment of impacts. From a methodological point of view, there are many similarities between the different footprints, but each has its own peculiarities related to the uniqueness of the substances considered.

The analysis of contributions has been also useful for identifying more specific strengths and weaknesses of each dairy sheep farming system, in order to improve their environmental performances.

Enteric methane emissions represented the most important environmental impact factor for all the farms when IPCC method is used. This result is consistent with the actual knowledge about the role played by the enteric methane fermentation in ruminant livestock emissions, which are estimated to represent approximately 18% of the global anthropogenic GHG emissions (FAO, 2006). Few practical strategies can be followed for reducing enteric methane emissions of grazing animals (Hegarty et al., 2007), mainly by regulating the quantity and quality of feed consumed (Pelchen and Peters, 1998) or utilizing inhibitors of enteric fermentation (Martin et al., 2010; Nolan et al., 2010; Puchala et al., 2005; Tiemann et al., 2008; Wallace et al., 2006). However, further research studies are needed to carefully analyse the complexity of relations among breeding techniques and enteric gas emissions (e.g., methane and nitrous oxide).

Beside the crucial role of enteric methane emissions, the major contributions to the environmental impact of LI are due to land use on natural and improved pastures (i.e., field operations, ranging from 21% to 34%, for ReCiPe and Blue Virtual Water, respectively), electricity (from 8% to 16%, for ReCiPe and Blue Virtual Water, respectively), and agricultural vehicle's equipment (from 8% to 10%, again for ReCiPe and Blue Virtual Water, respectively). The power consumption of LI depended mainly on milk cooling and therefore an improvement of the environmental performance of this farm could be achieved choosing the proper size of the cooling tank and/or adopting a more efficient cooling system, possibly powered by renewable sources. In addition, LI showed a relevant contribution to the overall impact determined by tractor and other devices, such as pick-up and generator diesel (10%, 8%, and 26% for IPCC, ReCiPe and Blue Virtual Water methods, respectively). This contribution is at least double compared to the contribution observed in the other farms and it can be likely due to the use of over-dimensional and power-consuming equipment compared to the farm needs.

The contribution of field operations (tillage and sowing) to the total environmental impact of the productive cycle of 1 kg of FPCM was largely lower in MI (with values never exceeding 8%) than in the other farms, for all the adopted methods. This result could be probably due to the minimum tillage practice used by MI for sowing of pasture mixtures. However, the environmental performances of MI could be improved by reducing the purchase of feed concentrates and consequently increasing the amount of pasture and self-produced hay in the diet of flock. To achieve this result, an increase of the total surface sown with well adapted and high quality pasture mixtures may be suggested (Franca et al., 2008; Porqueddu and Maltoni, 2005). The overall high consumption of electricity suggests to introduce a farm strategy based on renewable source power supply. Finally, it may be appropriate to assess a proper sizing of the machinery stock, in relation to the needs of MI.

The contribution of concentrate feed was particularly large in MI, despite lower total annual consumption compared to HI (0.38 t ewe^{-1} versus 0.55 t ewe^{-1}). It's important to note that HI produced about 24% of its concentrate needs on-farm and had a larger annual milk yield per ewe compared to MI, which imported all concentrate. In HI, the improved pastures and annual forage crops represented the most relevant contribution to the overall environmental impact. Taking this result into account, a possible strategy to reduce the Carbon and Ecological Footprint of HI could consist in increasing the agricultural surface area utilized for permanent semi-natural pastures and finding proper pasture management strategies (i.e., deferred grazing during spring to allow self-reseeding). Moreover, improving power supply strategy could represent an effective way to enhance the HI environmental performance, as well as for the other farms.

Table 2. Percentage contribution of processes to the total environmental impact of low- (LI), mid- (MI) and high-input level (HI) farms, using three evaluation methods (ICPP, ReCiPe, and Blue Virtual Water) and 1 kg of FPCM as functional unit. The process category "Remaining processes" includes all the processes with a percentage contribution lower than 1% for all methods and farms.

	IPCC			**ReCiPe**			**Blue Virtual Water**		
Process	**LI**	**MI**	**HI**	**LI**	**MI**	**HI**	**LI**	**MI**	**HI**
Enteric methane emissions	45	46	34	14	10	8	0	0	0
Field operations (tillage and sowing)	27	8	16	21	4	8	34	1	7
Electricity, medium voltage	13	5	3	8	2	1	16	1	1
Natural pastures	1	2	0	31	24	9	0	0	0
Improved pastures	0	2	16	17	21	36	0	0	2
Concentrate feed	1	21	16	1	30	26	1	2	5
Lactating ewes (feed consumption and animal excretion)	1	1	1	0	0	0	0	0	0
Infrastructures (milking parlour, barn, etc.)	0	2	1	0	0	0	3	1	1
Irrigating (infrastructure and water consumption)	-	0	0	-	0	0	-	59	0
Tractor, production	4	2	2	3	1	1	9	0	1
Pick-up vehicle, production	1	0	0	1	0	0	2	0	0
Agricultural machinery, production	5	3	2	4	1	2	15	1	3
Transport (lorry and/or transoceanic freight ship)	0	5	4	0	1	1	0	0	1
Water consumption (milking and irrigating excluded)	0	0	0	0	0	0	18	32	70
Agrochemicals (urea, glyphosate, etc.)	-	0	3	-	0	2	-	0	1
Consumable materials (detergent, veterinary drugs, etc.)	0	0	0	0	0	0	1	0	1
Remaining processes	2	3	2	0	6	6	1	3	7

3.3. Monte Carlo analysis

Uncertainty results from the Monte Carlo simulations showed different implications depending on the functional unit and the evaluation method used (Table 3). Blue Virtual Water method showed significant differences between the three production system case studies, due to the large differences in water consumption (LI and HI water consumption were respectively 4% and 43% than MI) with relatively low uncertainty intervals (16%, 14%

and 4-5% for LI, MI and HI, respectively). No significant differences were found between the environmental performances of the three farms when using 1 kg of FPCM as functional unit and IPCC and ReCiPe evaluation methods. For both methods the uncertainty interval did not exceed 16% and the probability of a farm to have an Ecological or Carbon Footprint greater than or equal to the footprint of another farm did not exceed 22%, on average. As expected and regardless of the method used, the Monte Carlo analysis confirmed that the differences between the environmental impacts of the three farms calculated using 1 ha of UAA as functional unit were significant.

Table 3. Monte Carlo simulation output for each assessment method, functional unit and farm with low- (LI), mid- (MI), and high-input (HI) levels. Average values and uncertainty intervals for P≤0,05 (between brackets) are reported.

Farm /FU/ Method	LI		MI		HI	
	1 kg FPCM	1 ha UAA	1 kg FPCM	1 ha UAA	1 kg FPCM	1 ha UAA
IPCC (kg CO_2-eq)	2.0 ± 10%	474 ± 11%	2.3 ± 13%	2,502 ± 13%	2.2 ± 13%	4,023 ± 0%
ReCiPe (Pt)	0.3 ± 13%	72 ± 13%	0.5 ±16%	530 ± 16%	0.4 ± 15%	779 ± 15%
Blue Virtual Water (l-eq)	5.9 ± 16%	1,368 ± 16%	56.8 ±14%	62,766 ± 14 %	16.1 ± 4%	29,424 ± 5%

4. Conclusion

In this work, LCA approach was used for comparing dairy sheep production systems and for identifying the hotspots to improve their environmental performances. The LCA conducted with two different functional units (1 kg of Fat Protein Corrected Milk and 1 ha of Utilized Agricultural Area) and three different assessment methods (IPCC, ReCiPe, and Blue Virtual Water) led to a more objective evaluation of the environmental performances of three case studies, taking into account both the economic dimension and the environmental role of dairy farming systems.

The environmental performances of the studied farming systems were similar when using 1 kg of FPCM as functional unit, regardless of the assessment method used. On the other hand, the environmental impacts were significantly different when the assessment was based on the functional unit 1 ha of UAA. Moreover, the contribution of each process to the environmental performances of dairy sheep systems depended largely on the method used for the evaluation. However, this study shows the relevant role played by enteric methane emissions, tillage, electricity and machineries in the overall environmental performances. Feed concentrates in the diet (in particular soy production) showed a relevant contribution in MI and HI. The natural and improved pastures utilization resulted in relevant contribution only for the ReCiPe assessment method. The contribution of agrochemicals was generally low, due to their very limited use in all the farms.

Certainly, LCA represents a valid approach for developing an eco-design strategy at farm level aimed to exploit the multifunctionality of extensive Mediterranean livestock systems. Further studies and knowledge are needed to overtake the limits of the LCA methodology when applied to agriculture sector. In particular, a certain degree of weakness derives from the lack of both site-specific datasets on Mediterranean farming systems and appropriate methods to assess comprehensively the “land use” impact category.

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