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Transition among different production systems in a Sardinian dairy sheep farm: Environmental implications

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ABSTRACT

Sardinia (Italy) plays a relevant role on EU sheep milk production. In Sardinia, as well as in other Mediterranean regions, there is a range of different dairy sheep farming systems and an effective renovation process is needed to tackle the deep structural crisis of the sector. The eco-innovation of production processes and the valorisation of pasture-based livestock systems can be a key strategy to improve the farms competitiveness and to promote the environmental sustainability of the typical Mediterranean dairy sheep products. For these reasons, research studies based on holistic and site-specific approaches are needed to assess the environmental implications of Mediterranean sheep systems. The main objective of this study was to compare the environmental performances of two contrasting sheep milk production systems through a Life Cycle Assessment (LCA) approach. The LCA was carried out on a farm where changes in land use (from arable and irrigated crops to native and artificial pastures) occurred over a 10-year period, in conjunction with a reduction of total supply of mineral fertilizers. The analysis was performed using IPCC and ReCiPe methodologies, and a functional unit of 1 kg of Fat and Protein Corrected Milk (FPCM). The LCA analysis showed that the change from semi-intensive to semi-extensive production system had only a slight effect on the overall environmental performances of 1 kg FPCM, due to the dominant impact of enteric fermentation in both systems. The Carbon Footprint was on average 3.12 kg CO_2-eq per kg FPCM and the average score of the ReCiPe Endpoint was 461 mPt per kg FPCM. Methane enteric emissions and the use of imported soybean meal were identified as the main environmental hotspots.

1. Introduction

The dairy products scenario described by the last OECD-FAO (2015) baseline projection attributes to the sheep sector the most dynamic trend with an expected production increase of 23% during the period 2014–2024. Europe, with a contribution of about 35%, is the second continent in the world for sheep milk production, after Asia that contributes for about 44%. Considering the annual production of sheep milk per inhabitant in the mid-2000s, Europe is by far the world's biggest producer: 4.1 kg per inhabitant compared to an average worldwide production of 1.4 kg per inhabitant (FAOSTAT, 2014). The European sheep milk production is concentrated in Central and Southern regions (Czech and Slovak Republics, Hungary, Romania, Greece, France, Spain and Italy) where the dairy sheep farming plays a crucial role in cultural, economic and ecological terms, mainly in marginal rural areas. Structural data indicate that Sardinia (Italy) is among the leading regions for the sheep milk production: 3.2 million ewes and 14,000 dairy sheep farms (Anagrafe Nazionale Zootecnica, 2016) provide about 330,000 t $year^{-1}$ of milk, and 201.2 kg of milk per capita (ISTAT, 2012). In fact, 25% of total EU-27 sheep milk production came from Sardinia (Rural Development Programme of Sardinia – RDP, 2014–2020). These numbers explain why the dairy sheep breeding, driven by the export of Pecorino Romano PDO cheese, represents one of the main economic sectors of Sardinia. In Sardinia, as well as in other Mediterranean regions, there is a range of different dairy sheep farming systems, with differences in land use and input and intensification levels. These differences depend on a number of factors ranging from geographical location and specific market conditions to public incentive policies and local or global market trends (Biala et al., 2007). In the 80s, programs and actions for increasing farm productivity led to the development of intensified production systems in Sardinian lowlands, where the availability of irrigation water contributed to the spread of highly-yield forage crops like maize (for silage), lucerne and hybrid forage sorghum (Fois et al., 2001). Later, when the Sardinian dairy sheep farming sector suffered a deep structural crisis due to the collapse of Pecorino Romano PDO cheese price in the early 2000s, many

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farmers, looking for new strategies to reduce production costs, decided to overall extensify their production systems (i.e. low use of concentrate feeds, agrochemicals, agricultural machines, etc.) (Porqueddu, 2008). Now, the greening process of agriculture and livestock supply chain, supported by EU climate change policies and driven by the increasing demand of environmental-friendly agri-food products, puts additional emphasis on the importance of the environmental implications of production systems into marketing and production farming strategies. In this scenario, the Sardinian dairy sheep sector and the whole Mediterranean livestock supply chain can find new opportunities to improve their competitiveness through the eco-innovation of production processes and the valorisation of typical livestock products. Therefore, more research is needed in order to i) assess and improve the environmental performances of dairy sheep systems using a comprehensive approach (Vagnoni et al., 2015), and ii) enhance our understanding of the relationship between sheep farming and climate change (Marino et al., 2016; Wiedemann et al., 2015). FAO (2006a) showed several differences in greenhouse gases (GHG) emissions from small ruminant sector, according to the geographical regions, the agro-ecological zones and the grassland/mixed-based production systems. Regarding milk production, Africa and Asia were identified as the bigger GHG emitters per kg of milk, thus suggesting that the high productivity of most intensive farming systems adopted in the industrialized countries would increase the environmental performances (Opio et al., 2013). On the other hand, there is no clear scientific evidence that extensive systems, at least at farm scale, are preferable to more intensive ones from an environmental point of view. Several studies focused on complex processes that affect yield, resources consumption and emissions, showing that extensive farming systems determine lower environmental impacts than intensive systems, (Bailey et al., 2003; Casey and Holden, 2006; Haas et al., 2001; Nemecek et al., 2011; Vagnoni et al., 2015). Extensive agriculture may help in mitigating some negative environmental impacts caused by intensive livestock systems, such as consumption of fossil energy resources, demand for macroelements, global warming potential, loss of biodiversity, degradation of soil quality (Biala et al., 2007). On the other side, some studies showed that the introduction of various low-input techniques, i.e. manure fertilisation, mechanical weeding, no-till agriculture and so on, can have the opposite effect (Basset-Mens and Van Der Werf, 2005; Brentrup et al., 2004; Michael, 2011). This work was conducted with the main aim of contributing to fill in this knowledge gap. In particular, the specific objective of this study was to compare the environmental impacts of two contrasting sheep milk production systems used in the same farm during two different years through a Life Cycle Assessment (LCA) approach (de Boer, 2003; Hayashi et al., 2006).

2. Methods

2.1. Characteristics of the two production systems

The case study was a dairy sheep farm located in Osilo (40°45′11″ N and 8°38′43″ E, elevation 364 m a.s.l; Province of Sassari), North-western Sardinia. In terms of flock size and total Utilized Agricultural Area (UAA) (Table 1), the farm belongs to the most common sheep farming system in Sardinia. As reported by Idda et al. (2010), about 65% and 47% of Sardinian dairy sheep farms has a number of heads ranging from 100 to 500 and a total UAA in the range 30–100 ha, respectively. The climate is Mediterranean with an average annual rainfall amount of 550 mm, and monthly mean temperatures ranging from 10 to 26 °C. Data refer to two years, 2001 and 2011, when two different farming systems were implemented. Primary data, collected using a specific questionnaire, derived from farm records, several visits in situ and farmer interviews. In 2001, the farm was characterized by a forage system based on cereal crops (wheat and barley grain), annual forage crops (ryegrass/oat mixture, mainly) and irrigated maize for silage. From 2008–2011, a radical change occurred in the farm management

Table 1
Main characteristics of the two different production systems adopted to the same farm in 2001 and 2011.

	2001	2011
Heads (number of mature ewes)	340	320
Stocking rate (Livestock Unit ha^{-1})	0.46	0.46
Milk total annual production (kg)	104,234	82,214
Milk pro-capite annual production (kg ewe^{-1} $year^{-1}$)	307	257
Milk fat content (g 100 ml^{-1})	6.4	5.3
Milk protein content (g 100 ml^{-1})	5.6	5.2
Fat and Protein Corrected Milk (FPCM), pro-capite annual production (kg ewe^{-1} $year^{-1}$)	303	227
Net Energy Intake, NEI (Mcal ewe^{-1} $year^{-1}$)	812	657
Dry Matter (DM) intake (kg DM ewe^{-1} $year^{-1}$)	515	448
Pastures — grazing area (ha)	3	52
Arable land — cereals and annual forage crops (ha)	70	18
Total Utilized Agricultural Area (ha)	73	70
Concentrate feed annual consumption (t)	105	98
Mineral N-fertilizing (kg ha^{-1})	72	8
Mineral P_2O_5-fertilizing (kg ha^{-1})	110	29
Irrigated maize (ha)	7	0
Irrigated lucerne (ha)	0	2.7
Milk destination	Cheese industry	On-farm cheese manufacture
Power source	diesel generator	electricity

strategy, to face the very low sheep milk price payed by the Sardinian cheese industries that seriously threatened the farm profitability. Therefore, the whole farm milk production was destined to on-farm cheese manufacturing, instead of cheese industry. In particular, the farm produced "Pecorino di Osilo" cheese, which is included in the list of typical Italian agri-food products (18/07/2000 Ministerial Decree of the Italian Ministry for Agricultural, Food and Forestry). In addition, with the aim of reducing the production costs, the farm management moved to an extensification of forage production, with a larger use of natural and artificial pastures, valorising the role of native legume-grass mixtures and adopting low-input farming practices (minimum tillage, reduced use of fertilizers, etc.). Although there were considerable similarities between the two production systems (for example, number of heads, stocking rate, total UAA and concentrates consumption, see Table 1), the 2001 production system was mainly characterized by the irrigation of maize crop (7 ha), a large arable land area (73 ha) and a large use of mineral fertilizers (182 kg ha^{-1}). The feed efficiency ratio, calculated dividing the Net Energy Intake (NEI, Mcal ewe^{-1} $year^{-1}$) by the Dry Matter intake (kg DM ewe^{-1} $year^{-1}$), resulted in different values between the two years: 1.58 and 1.47 Mcal NEI kg DM^{-1} in 2001 and 2011, respectively. On the other hand, considering the individual production of milk corrected for fat and protein content (Fat and Protein Corrected Milk, FPCM), the dairy efficiency ratio was always higher in 2001 compared to 2011, when expressed in both Mcal of NEI and kg of DM ingested units (0.37 kg FPCM $Mcal^{-1}$ of NEI and 0.59 kg FPCM kg^{-1} of DM vs 0.34 kg FPCM $Mcal^{-1}$ of NEI and 0.50 kg FPCM kg^{-1} of DM^{-1}, respectively). Moreover, in 2011, 75% of the total UAA was destined to native and artificial pastures, on-farm maize production was abandoned and total mineral fertilizers supply was strongly reduced (about 80% less). At the same time, the farm no longer carried out the production of selected rams that, until 2001, represented an additional farm output. Starting from these features and focusing on farm forage production, the farming systems can be assumed as "semi-intensive" and "semi-extensive" in 2001 and 2011, respectively.

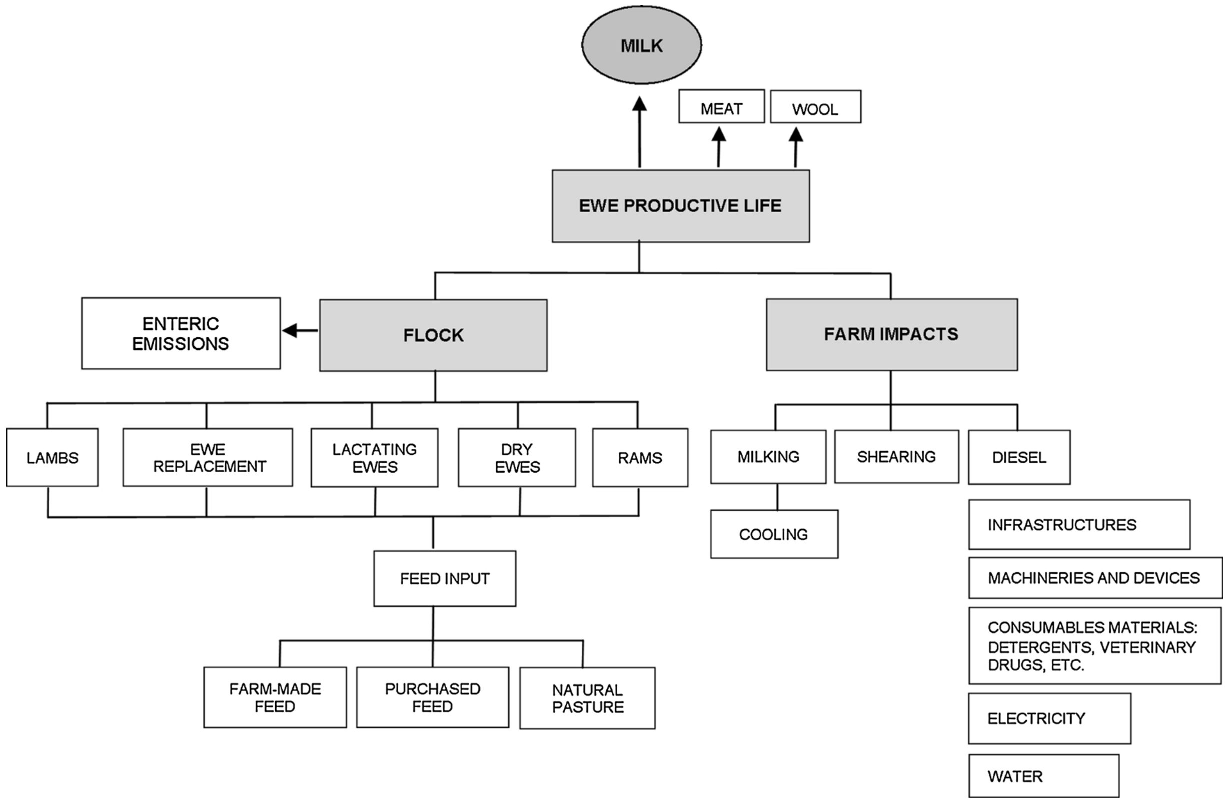

Fig. 1. Flow chart of sheep milk production (from Vagnoni et al., 2015).

2.2. LCA methodological issues

The LCA study followed the international standards ISO 14040–14044, adopting a "from cradle to gate" approach and using 1 kg of FPCM as functional unit. FPCM amounts expressed in kg were calculated using the equation by Pulina and Nudda (2002):

$$FPCM = RM\ (0.25 + 0.085FC + 0.035PC)$$

where RM, FC, and PC indicate raw milk amount (kg), fat content (%), and protein content (%) of the raw milk, respectively. The system boundaries included all inputs and outputs related to sheep milk production (Fig. 1). Since the dairy sheep farm produced not only milk but also meat, wool and rams (the latter only in 2001), an impact allocation of all inputs and outputs was performed by partitioning them between milk and the other co-products, on the basis of their economic value (Table 2). The economic allocation procedure was chosen considering the large economic value differences between milk and the other co-products. This allocation method applied to sheep milk production tends to be similar to mass-based methods and to estimate higher environmental impacts than protein-based and energy-based methods (Mondello et al., 2016). All data were organized into a Life Cycle Inventory (LCI), the phase of LCA that quantifies energy and raw material requirements, atmospheric and waterborne emissions, solid wastes and other releases for the entire life cycle of a product (SAIC, 2006). In summary, the analysis included the amount of fodder crops and pastures consumed by flocks, after cross-checking forage production and nutritional needs based on gender, age, weight, physiological stage and production level of animals. In the same way, other processes linked with the farm structure were analysed, i.e. milking parlor, barns, tractors and other agriculture machineries and devices, water and energy consumption, and consumable materials were taken into account. All modes of transportation and distances covered within the system were also assessed. In addition, enteric methane emissions were quantified using a detailed approach based on Vermorel et al. (2008) and considering the total metabolizable energy provided by each specific animal category diet. Emissions related to pesticide and fertilizer use were estimated with the IPCC method (IPCC, 2006). Since sheep spent their time almost exclusively in large open spaces, the impacts related to manure management included only the NO_2 emitted through animal excreta, estimated following again the IPCC (2006) approach. Carbon sequestration by crops and natural grassland was not taken into account for the lack of primary data. With the aim of accounting a wider range of impact categories, two evaluation methods were utilized: IPCC (2013), for the Carbon Footprint (CF) estimates, expressed in kg of CO_2-equivalents (CO_2-eq), and ReCiPe Endpoint (H) V1.12, which considers, besides the GHG emissions, others 17 categories of environmental impacts (Goedkoop et al., 2009). LCA calculations were performed using LCA software SimaPro 8.1.1 (Consultants PRé, 2016), which contains various LCA databases (Ecoinvent, Agri-footprint, etc.).

Table 2
Percentages of economic allocation of co-products from 2001 and 2011 dairy farm's production systems.

Products	2001	2011
Milk	76%	91%
Lamb meat	10%	7%
Ewe meat	0%	1%
Wool	1%	1%
Rams	13%	–

3. Results and discussion

3.1. LCI analysis

The LCI analysis of the total annual production of FPCM gives a first picture of the environmental implications and of the main differences between the two production systems (Table 3). The 2001 production

Table 3
Inventory of the impact categories for the total annual production of FPCM for the two production systems.

Impact category	Unit	2001	2011
Water	m^3	13,409.9	6,595.2
CO2	t	109.5	55.4
CO2 biogenic	t	5.2	3.6
Methane	kg	236.0	128.9
Methane biogenic	t	5.6	4.8
Dinitrogen monoxide	kg	101.0	74.9
Phosphorus, in water	kg	15.6	14.6
Phosphate	kg	91.2	70.2
Sulphur Dioxide	kg	367.2	226.7
Isoproturon	kg	2.6	2.0
Nitrogen oxides	kg	560.3	270.5
Particulates	kg	113.9	79.4
Coal	t	16.1	9.8
Occupation industrial area	m^2a	788.2	931.8
Occupation, arable, non-irrigated	ha	21.0	10.0
Occupation, arable, irrigated	ha	4.6	3.0
Occupation, grassland, natural	ha	9.9	28.9
Transformation from forest	m^2	80.8	126.8

Table 4
Percentage contribution of processes to the total value of “Transformation from forest” and “Occupation industrial area” impact categories related to Life Cycle Inventory of total FPCM annual production by 2001 and 2011 production system. The process category “Remaining processes” includes all the processes with a percentage contribution lower than 0.3%.

Impact category	Transformation from forest		Occupation industrial area	
Process/production system	2001	2011	2001	2011
Soybean meal	57	87	3	7
Protein pea	11	0	8	0
Cereals grain (barley, maize, wheat)	4	3	77	87
Machine operation, diesel	9	0	2	0
Transport (lorry and/or transoceanic freight ship)	6	4	2	2
Diammonium phosphate	3	0	2	0
Milking parlour	2	1	1	0
Urea	1	0	–	–
Tillage, ploughing	1	0	–	–
Electricity, medium voltage	0	1	–	–
Remaining processes	6	4	5	4

Table 5
Percentage contribution of processes to the total value of Occupation natural grassland impact category related to Life Cycle Inventory of total FPCM annual production by 2001 and 2011 production systems.

Impact category	Occupation natural grassland	
Process/production system	2001	2011
Natural grassland (hay and sheep grazing)	23	69
Straw (sheep bedding)	77	31

system showed higher values for all considered impact categories, except for “Land transformation from forest”, “Occupation of industrial area” and “Natural grassland use”. The difference in “Land transformation from forest” may be explained by the different percentage contribution attributed to “soybean meal” process: 87% and 57% in 2011 and 2001, respectively (Table 4). In particular, the 2011 animal diet was characterized by a larger use of soybean-based feed compared to 2001. Since we do not have specific data related to the environmental impacts of soybean meal production, in our LCI we used a process taken by Ecoinvent database. Ecoinvent assumed that soybean meal is composed mostly of soybean produced in Brazil, with a strong impact on forest transformation into agricultural land (Moreno Ruiz et al., 2013). Similarly, the diet composition affected both the “Occupation of industrial area” and “Natural grassland use” impact categories. In the first case, the total impact was principally related to “cereals grain feed” production. In the second one, the total impact was influenced by the effect of a high utilization of natural pastures for the animal grazing. As shown in Table 5, the contribution of the direct grazing to this impact category is around 50% in 2011, while is only 23% in 2001, when the contribution to “Natural grassland use” was mainly due to the straw production for animal bedding (77%). On the other hand, “Water”, “Nitrogen oxides” and “CO_2” were the impact categories that showed relevant differences (about twice) between 2001 and 2011. These results were consistent with the different overall input consumption of the two contrasting production systems.

3.2. Carbon footprint

The CF of 1 kg of FPCM was quite similar in 2001 and 2011, with values equal to 2.99 and 3.25 kg CO_2-eq, respectively (Fig. 2). This result seems to agree with some findings (Batalla et al., 2015; Gerber et al., 2013) indicating that more intensive systems had a lower environmental impact per kg of product than extensive ones. Fig. 2 shows a detailed contribution analysis and illustrate the main processes that contributed to the total CF of each production system. Enteric methane emissions accounted from 50% to 57% of the total GHG emissions for the semi-intensive and the semi-extensive system, respectively. This result was consistent with FAO (2006b) and several others studies (Berlin, 2002; González-García et al., 2013; Marino et al., 2016; Vagnoni et al., 2015), which clearly indicated enteric methane emissions as the main environmental hot spot in ruminant livestock sector. Thus, the reduction of methanogenesis from rumen fermentation represents a key factor for mitigation strategies in ruminants (Marino et al., 2016). For instance, an effective mitigating solution may be a diet based on tannin-rich feeds, since tannins are a potent tool to curb enteric fermentation in ruminants (Woodward et al., 2001; Carulla et al., 2005).

On the other hand, the two production systems showed different performances for the individual annual enteric methane emissions per kg of FPCM, which varied from 0.058 to 0.035 kg CH_4 kg^{-1} of FPCM in 2001 and 2011, respectively. This difference reflected the two contrasting management strategies adopted by the farm, since NEI supply influenced both milk productivity and ruminal fermentation of sheep. In 2001, the main scope of the farm was the maximization of productivity supported by a strong energetic feed supply, expressed by a high NEI value (812 Mcal ewe^{-1} $year^{-1}$). On the other hand, the input reduction was the farm priority in 2011, as shown by a reduction of NEI up to 24% compared to 2001 (657 Mcal ewe^{-1} $year^{-1}$).

The percentage contribution to total CF of overall feed production processes was equal (26%) for the two production systems. In both cases, the large influence of purchased feed was clear. In 2001, soybean meal and protein pea plus cereal grain contributed for 24%, while on-farm produced wheat grains for 2% (Fig. 2). In 2011, the 26% of total contribution was obtained considering soybean and protein pea (15%) and cereal grains (11%), again not self-produced (Fig. 2). In general, the percentage contributions of the other processes reflected the contrasting technological context and farm management strategy which characterized the two farming systems, such as power source (diesel generator in 2001 and public electricity in 2011), fertiliser use and agricultural machinery supply.

The CF of 1 kg of milk produced by several dairy sheep farms with different intensification level was recently assessed by Atzori et al. (2013), Batalla et al. (2015) and Vagnoni et al. (2015). Atzori et al. (2013) studied the differences in CO_2-eq emissions among different simulated scenarios of dairy sheep production systems in Sardinia. They reported 2.37 kg of CO_2-eq kg^{-1} of raw milk in farms with high production level, no pasture and 100% of feed produced on-farm, and

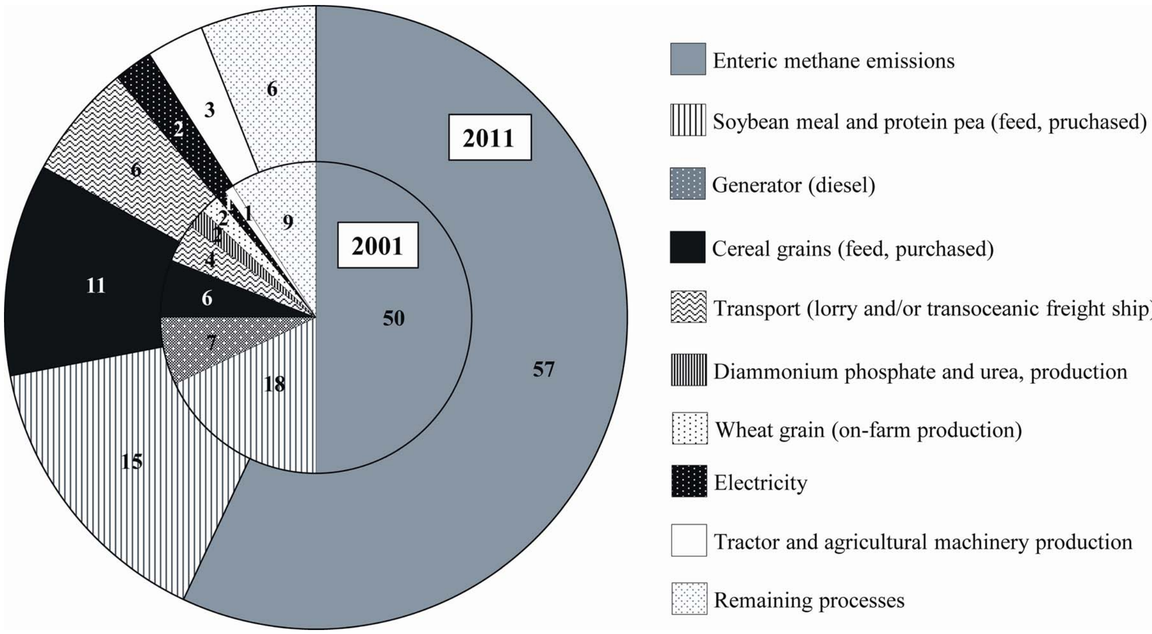

Fig. 2. Percentage contribution of inputs to GHG emissions for 1 kg of FPCM in 2001 and 2011 production systems. The process category "Remaining processes" includes all the processes with a percentage contribution lower than 0.4% for both production systems.

3.06 kg of CO_2-eq kg^{-1} of raw milk in farms with low production level, pasture and 100% of forages produced on-farm, without concentrates supply. Batalla et al. (2015) estimated the CF of sheep milk from 12 farms in Northern Spain. Considering only farms with Laxta breed, which are comparable with our study farms in terms of stocking rate and feed supply management, the CF ranged from 2.87 to 3.19 kg CO_2-eq kg^{-1} FPCM in three semi-intensive systems, and from 2.76 to 5.17 kg CO_2-eq kg^{-1} FPCM in six semi-extensive systems. It is important to highlight that the difference in CF between semi-intensive and semi-extensive production systems was statistically significant only when carbon sequestration was included in the assessment. Vagnoni et al. (2015) compared the environmental impacts of sheep milk production from different dairy farms in Sardinia (Italy). In this case, the CF was equal to 2.2 CO_2-eq kg^{-1} FPCM and to 2.3 CO_2-eq kg^{-1} FPCM in a semi-intensive and a semi-extensive system, respectively.

All these studies indicated that the main contributor to the CF was the methane enteric emissions, although with different average percentage contribution: 54% in the present work, 68% in Atzori et al. (2013), 34% in Batalla et al. (2015), 40% in Vagnoni et al. (2015). Also, all four studies found that the purchased feed represented the second average percentage contribution to total CF. In particular, the variability in methane enteric emissions may be mainly explained by the attribution of the different emission factors for the enteric methane emission estimate. Vagnoni et al. (2015) adopted the methane emission rates for Italian sheep livestock fixed by ISPRA (2011) in 8.0 kg CH_4 ewe^{-1} year^{-1}. This emission factor was based on the Tier 1 IPCC (2006) method, the most simplified approach in the IPCC scale, which considers three increasing levels of detail. A similar rate, equal to 8.2 kg CH_4 ewe^{-1} year^{-1}, was used by Batalla et al. (2015) according to values estimated by Merino et al. (2011) for methane emissions from ruminant livestock in the Basque Country. In this case, a Tier 2 approach was applied, considering the average gross energy intake (GE) according to ewes liveweight, and a IPCC (2006) default value for the conversion factor (proportion of GE in feed converted to CH_4). In our study, an average of 12.02 kg CH_4 ewe^{-1} year^{-1} was estimated for lactating sheep with a farm-specific approach, as described in the Methods section. This emission factor value agrees with the value used by Atzori et al. (2014) in their study on Italian inventories of small ruminant emissions, who estimated 13.6 kg CH_4 ewe^{-1} year^{-1} using a similar approach.

3.3. *ReCiPe Endpoint method*

The ReCiPe Endpoint method results confirmed the small differences found between the environmental performances of the two production systems, both in terms of total score (expressed in milli-eco-point, mPt) and percentage contribution of individual processes to total environmental impact (Fig. 3). The 2011 semi-extensive production system resulted the most impacting (479 mPt), with a score 7% higher than the 2001 semi-intensive (444 mPt). For both production systems, the most relevant impact category was represented by "Agricultural land occupation", which was responsible of 54% and 59% of the total estimated impact in 2001 and 2011, respectively. While the semi-intensive production system allocated the whole total UAA to arable crops, the semi-extensive allocated 75% of the total UAA to extensive grazed pastureland, characterized by native pastures and low-input artificial pastures. Therefore, the switching from arable land to extensive grazed pastureland resulted in the "Agricultural land occupation", affecting strongly the ReCiPe Endpoint results. The second impact category for both production systems was "Climate change — Human Health", with an average value of about 17%. Another relevant impact category was "Climate change − Ecosystems", which was responsible in average for about 11% of the overall impact. The remaining impact categories were responsible for less than 10% of the total score and, between them, "Fossil depletion" marked the main difference between the two production systems. In particular, "Fossil depletion" impact category resulted 48% higher in the 2001 than in the 2011, due to the highest fuel consumption both for diesel generator and agricultural machines use. "Fossil depletion" represented the main difference between the two production systems also in absolute terms, followed by "Particulate matter formation", which resulted 40% higher in 2001 than in 2011. Therefore, in our case study the substitution of irrigated maize and wheat with low input forage crops, such as oat/ryegrass forage crops and legume-based artificial pastures, determined contrasting environmental results. On the one hand, it slightly increased the overall environmental impact of the farm, due to the high agricultural land occupation whilst, on the other hand, it strongly reduced the contribution of two important impact categories, "Fossil depletion" and "Particulate matter formation". These findings are consistent with Soteriades et al. (2016), who stated that average eco-efficiency of dairy farms enhances when the percentage of maize for silage in the total

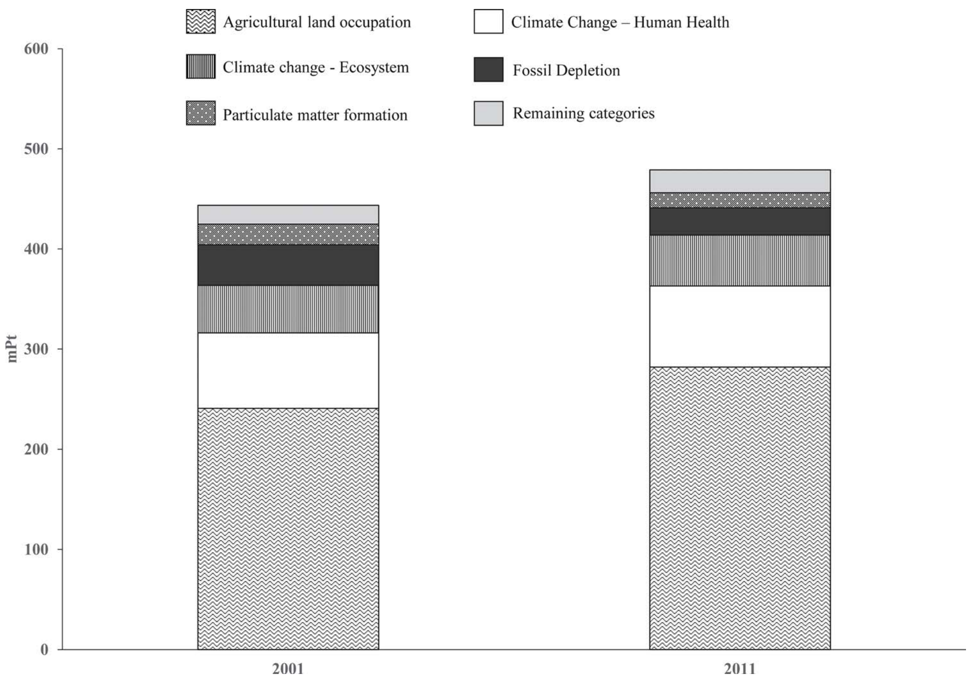

Fig. 3. Mean values obtained using the ReCiPe Endpoint impact assessment method for the functional unit 1 kg of FPCM for 2001 and 2011 production systems. Impact effects are expressed in milli-ecopoints (mPt). Impact categories with scores lower than 10mPt are included in the group "Remaining categories".

forage area is reduced. Moreover, according to Basset-Mens et al. (2009) and Rotz et al. (2010), low input grassland management, requiring less fertilization and field operations than arable land, has lower environmental impacts from eutrophication, acidification, greenhouse gas emissions and non-renewable energy use on grass-based farms.

Regarding the percentage contribution of each input to the total environmental impact of 1 kg of FPCM in 2001, when on-farm forage production was characterized by a more intensive management, ReCiPe Endpoint method highlighted the relevant role played by purchased protein-feed (soybean meal and pea), which represented 30% of the total impact (Table 6). On the other hand, in 2011, the percentage contributions were shared in several processes such as soybean meal (17%), cereal grains (15%), improved pastures (15%) and enteric methane emissions (14%).

The results from the ReCiPe Endpoint method assessment were very similar to those of Vagnoni et al. (2015). The total scores obtained in the two studies for each production system were very close. Also, in Vagnoni et al. (2015) the semi-intensive system was the most eco-efficient and "Agricultural land occupation" resulted by far the main impact category. In addition, both studies highlighted the same trend of values for both "Fossil depletion" and "Particulate matter formation" impact categories.

Table 6
Percentage contribution of processes to the total environmental impact of 2001 and 2011 production systems, using ReCiPe Endpoint evaluation method 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 both production systems.

Process/production system	2001	2011
Soybean meal and protein pea (feed purchased)	30	17
Wheat (on-farm production)	13	0
Enteric methane emissions	12	14
Improved pastures	8	15
Straw (sheep bedding)	5	8
Cereals grain (maize, barley and wheat purchased)	9	15
Generator (diesel)	5	0
Maize silage (on-farm production)	4	0
Natural grassland (hay and sheep grazing)	2	17
Diammonium phosphate, production	1	0
Transport (lorry and/or transoceanic freight ship)	2	4
Tractor and agricultural machinery, production	1	3
Electricity, medium voltage	0	2
Remaining processes	8	5

4. Conclusions

Our results indicated that the transition from a semi-intensive to a semi-extensive production system in a Sardinian dairy sheep farm had a negligible effect on the overall environmental performances of 1 kg FPCM. The Carbon Footprint was on average 3.12 kg CO_2-eq per kg FPCM and the average score of the ReCiPe Endpoint was 461 mPt per kg FPCM. For both production systems and evaluation methods, the methane enteric emissions and the use of imported soybean meal resulted the main environmental hot spots. The LCA approach demonstrated that the reduction of farm input level related to the forage supply system did not determined an environmental performance improvement because of the predominant effect of enteric fermentation compared to other impact factors. However, this work involved only one case study and did not account carbon sequestration by crops and pastures. Therefore, the findings obtained about the environmental implications of changes from semi-intensive to semi-extensive dairy sheep farming systems should be considered as preliminary conclusions and more detailed investigations are needed for improving our knowledge of the environmental implications of different sheep production systems.

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