Small Ruminant Research 185 (2020) 106085

Contents lists available at ScienceDirect

Small Ruminant Research

journal homepage: www.elsevier.com/locate/smallrumres

Dairy sheep carbon footprint and ReCiPe end-point study

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ARTICLE INFO

Keywords:
Global warming potential
Greenhouse gas emissions
Sheep farming
Human health
Damage biodiversity
Damage resource availability

ABSTRACT

Sheep milk production is an important livestock sector for the European Mediterranean countries including the regions of southern Italy. The main objective of this study was to investigate the carbon footprint and the related damages generated by dairy sheep farming by using a simplified LCA approach based on the ReCiPe End-point method. We used 1 kg of Fat and Protein Corrected Milk (FPCM) as functional unit (FU). The average flock size was about 400 animals and the average farm size was about 66 ha. In addition to milk all farms produced meat and wool. Therefore, we performed an economic allocation by dividing all inputs and outputs among milk and the other two co-products (meat and wool), based on farm financial statements. The CF impact determined by 1 kg of FPCM was 3.78 kg CO_2.eq. The highest CF impact was mainly due to the enteric fermentation, producing biogenic CH_4 as the prevalent chemical compound, followed by the production of meadow hay. Based on the ReCiPe End-point method the impact of 1 kg of FPCM from dairy sheep farming was 7.35 E-06 Disability Adjusted Life Years, whereas the Damage to Ecosystem Diversity was 3.29 E-07 Species*year and the value of the Damage to Resource Availability 0.025 $. In conclusion, the environmental management and sustainability of sheep farms should be constantly controlled with the aim of minimizing their impacts without compromising the competitiveness of this productive sector.

1. Introduction

Livestock production is a main global source of greenhouse gas emissions and it is also associated with other environmental issues, such as ammonia emissions and regional nutrient imbalances (Gerber et al., 2013). Although sheep farming contribution to global milk production is low, this sector plays a central role in small economies, such as those located in marginal rural areas, where this productive activity may sustain the local communities at social and economic levels (FAO and GDP, 2018). The increasing atmospheric concentration of greenhouse gas (GHG) plays a dominant role in global warming and climate change (IPCC, 2006a). The impact of the small ruminant area to GHG emission is equal to 596 million tones CO_2-eq. (FAO, 2019). Methane (CH_4) and nitrous oxide (N_2O) represent the most important GHG emissions ascribed by the International Panel of Climate Changes (IPCC) to agriculture. Life Cycle Assessment (LCA) is one of the most common approach for estimating the environmental impacts that a functional unit of product causes during the entire life cycle. Several studies on the impacts of livestock enterprises were based on the application of LCA. These studies involved the dairy cattle (e.g. Thomassen et al., 2008; Braghieri et al., 2015; Mostert et al., 2018), beef cattle (e.g. Bragaglio et al., 2018; Alan Rotz et al., 2019), dairy buffaloes (e.g. Pirlo et al., 2014; Sabia et al., 2018a), dairy goats (Pardo et al., 2016; Gutiérrez-Peña et al., 2019) and sheep for wool and meat production (Biswas et al., 2010). Carbon footprint (CF) is entirely referred to Global Warming Potential (GWP) and it is commonly used to communicate to the stakeholders the contribution of the dairy productions to climate change (Opio et al., 2013). Most of the studies on the CF of milk and dairy products were conducted on cattle. In Basilicata region a high number of sheep (about 291,000) is bred (ISTAT, 2017). In the same region, there are two cheeses with Protected Designation of Origin labels: "Canestrato di Moliterno" and "Pecorino di Filiano" produced by using sheep milk. A priority of the European Commission political plan is the environmental sustainability of the agricultural production systems, including climate change mitigation. The reduction of the environmental impacts is fundamental to access public funds, increase

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https://doi.org/10.1016/j.smallrumres.2020.106085
Received 3 October 2019; Received in revised form 24 February 2020; Accepted 24 February 2020
Available online 25 February 2020

competitiveness and maintain the multi-functionality of the dairy sheep enterprises, particularly when farms are situated in marginal upland areas (Gaskell et al., 2008; Romano et al., 2010). Therefore, it is important to evaluate the environmental performances of these livestock systems, categorize the weak points of the production chain and suggest actions to be taken for reducing the overall environmental impact of farms. However, there are few studies in the field of dairy sheep production systems (Michael, 2011; Batalla et al., 2015; Vagnoni et al., 2015, 2017; Vagnoni and Franca, 2018), and none of them used the ReCiPe End-Point methodology. This is a life cycle impact assessment developed by Goedkoop et al. (2008) that provides harmonized characterization factors at midpoint and endpoint levels. At endpoint level, 17 endpoint impact classes are identified and then pooled into 3 endpoint damage categories labelled as 'human health' damages, 'ecosystems', and 'resources'. The results concerning these damage categories are combined into a single score which is easier to be interpreted and communicated to consumers and citizens. This approach was only occasionally used to evaluate the damages generated to human health, ecosystems and natural resources by the agricultural sectors (Fantke et al., 2012; Park et al., 2016; Chatzisymeon et al., 2017; Du et al., 2019; Liang et al., 2019), and never applied to livestock production systems. Therefore, we aimed to investigate the carbon footprint and the related damages generated by dairy sheep farming by using a simplified LCA approach based on the ReCiPe End-point method.

2. Materials and methods

By using the LCA approach, CF values were calculated. The CF was assessed by using the software package SimaPro 8.01 PhD. In particular, we used the ReCiPe method Midpoint/Endpoint (H) V1.10/ Europe Recipe H/A module of this package (Sabia et al., 2018b). CF is the net GWP emission per production unit. Damage assessment was carried out by ReCiPe Endpoint method using the three following indicators. The "human health" index damage category, which is also used by the World Health Organization and the World Bank, is expressed in years and derives from the combination of the estimated reduction of life expectancy in years and the estimated number of years lived with a disability; the latter is defined as Disability Adjusted Life Years (DALYs). The damage category 'ecosystems' is expressed in number of species * year and represents the loss of species over a specified period of time and in a given geographical area. The damage category 'resources' is expressed in US $ and represents the expenditures needed for the extraction of the resources consumed in a given period of time at a steady annual production rate and at 3 % discount rate (Goedkoop et al., 2008). Production units are required to define the Functional Unit (FU).

2.1. Functional unit and system boundaries

Following the indications given by the Food and Agriculture Organization (FAO, 2010) and International Dairy Federation (IDF, 2010) for the evaluation of the CF of the dairy industry, in this study we used 1 kg of Fat and Protein Corrected Milk (FPCM) as FU. Fat and protein corrected milk amounts were calculated using the equation by Pulina et al. (2005) with a reference milk fat and protein content of 8.0 % and 5.3 %, respectively:

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

where RM, FC, and PC indicate raw milk amount (kg), fat content (%), and protein content (%) of the raw milk, respectively. In addition to milk, wool from sheep and meat from lambs were considered as outputs and assessed through an economical allocation (Table 1). The economic allocation was conducted on the basis of the farm financial statements provided by farmers. These documents showed that, due to the low market price of wool and meat, milk represented about 90 % of the farm profit. The system boundaries of our study are reported in Fig. 1 where all of the GHG emissions associated with the production of ewe milk up to the farm gate were included and all of the farm activities were taken into account.

Table 1
Economic allocation of co-products from four sheep dairy farms.

	Farm 1	Farm 2	Farm 3	Farm 4	Averages
Milk (%)	92	87	94	91	91
Meat (%)	7	10	4	7	7
Wool (%)	1	3	2	2	2

2.2. Inventory analysis

Data were collected in 2014–2015 from four dairy sheep family farms located in the Province of Potenza (40°16'23" N; 15°50'37" E), Basilicata Region, Italy along the valley of Agri river. Primary data (Table 2) were obtained directly from the farmers through questionnaires. In all farms a Merinos derived breed was used to produce milk, meat and wool. These farms were representative of the geographical area and characterized by low energy inputs, no concentrated feeds purchased from outside the farms and use solely mature manure as fertilizer for the production of meadow hay. In particular, the Merinos derived sheep breed currently accounts for about half of the sheep population in the Province of Potenza (ARA Basilicata, 2018), in particular in the area studied, sheep farms have an average area of 35 ha, 50–500 animals and 70 kg/ewe/y as mean milk yield (ISTAT, 2017). The farming system is based on diurnal grazing on natural pastures and housing during the night. The animals receive a feeding supplementation in the barn and are milked twice a day. The major characteristics of the farms used in the present study in terms of size, feeding regimen, diesel fuel and energy consumptions are shown in Table 2. In particular, the mean number of lactating animals per farm was 406, while the mean annual total milk production was 24.75 t/milk/year. The average size of the farms was about 66 ha with a minimum of 15 ha and a maximum of 160 ha. The hay production was 59.1 t/y, all the hay produced was harvested with two cuts per year, the average production per hectare is about 5.5 t/ha, while the permanent pasture had an average productivity of 103.2 t/y and its was used exclusively through grazing activity. The average of the productions of barley seed was about 3.1 t/ha while the production of oat seed was 3.5 t/ha. The estimation of pasture productivity in the Mediterranean area of southern Italy was based on studies conducted by Martiniello et al. (2007) and Sabia et al. (2014). The grazing period was about 300 days per year.

2.3. Life cycle assessment methodology

The emissions of the four sheep farms were estimated on the basis of enteric fermentations, releasing of urine and faeces on pasture during grazing, management of manure (involving handling, storage and use as fertilizer in agriculture), and combustion of fuel. The emission of carbon dioxide (CO_2) due to energy use was estimated by considering both the direct combustion of diesel fuel in liters and the indirect consumption of electricity in kWh throughout farm operations. Enteric methane (CH_4) emissions were estimated on the basis of the national emission factor of 8 kg CO_2-eq/head/year (ISPRA, 2011). The amounts of fuel purchased for animal feeding and general agricultural practices were compiled to estimate fuel consumption. In the present study a standard diesel density value of 0.85 kg per liter was applied, while a 3.13 eq. emission factor was used to compute the CO_2 produced by the combustion of 1 kg of diesel fuel (ENAMA, 2005). As to electricity consumption, we used the emission factor suggested by Cóndor (2011) for the Italian agricultural sector (i.e. 0.47 eq.). The CH_4 emitted by the manure left on pasture by grazing animals and by the manure stored in

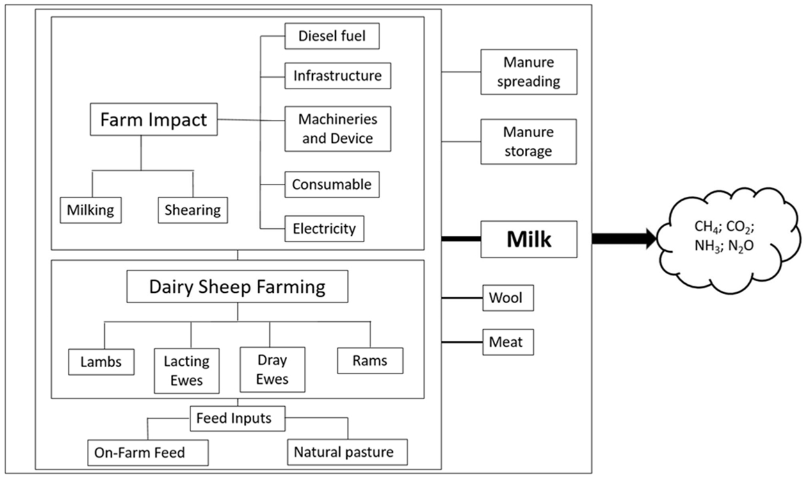

Fig. 1. System boundaries of the dairy sheep farming systems.

Table 2
Main characteristics of four dairy sheep farms.

	Farm 1	Farm 2	Farm 3	Farm 4	Averages
Size (ha)	15	40	50	160	66.3
Head (n)	130	95	550	850	406
Milk production (kg year^{-1})	10.000	4.000	50.000	35.000	24.750
Milk yield/ewe/y (kg)	76.9	42.1	90.9	41.2	62.8
Meadow hay (t year^{-1})	21	3	62.5	150	59.1
Permanent Pasture (t year^{-1})	47	60	18	288	103.2
Oats flour (t year^{-1})	3	3.5	30	60	24.1
Barley flour (t year^{-1})	2	2	0	0	1
Diesel fuel (t year^{-1})	6	12	10	14	10.5
Electricity (kWh year^{-1})	2000	3298	2101	2547	2487

the farm was calculated following the method Tier 2 IPCC (2006a). The direct emissions of N_2O were computed from fecal deposition of grazing sheep on pasture and manure storage on the basis of nitrogen (N) excretion, which, on turn, was estimated by using the equation 10.25 (Tier 2 method) and the default values of the N excretion (total amount per year) for mature dairy sheep category. The estimation of the quantity of nitrous oxide produced by manure during storage and management was based on the total excretion of N by using the emission factor of 0.02 kg of N–N_2O/kg of excreted N. This emission factor was indicated by Cóndor et al. (2008) as country-specific for Italy. Nitrogen direct deposition in the soil was computed using 0.0125 kg N–N_2O/kg N as emission factor (Cóndor et al., 2008), while N_2O indirect emissions were estimated following the method suggested by IPCC (2006b), which is based on leaching and run-off of NO_3^- and re-deposition of volatized gases to waters and soils. In particular, an emission factor of 0.01 kg N_2O/kg N and an emission factor of 0.025 N–N_2O/kg N were used for the estimation of the indirect deposition from the atmosphere and for N leaching and run-off, respectively. Both emission factors were indicated by Cóndor et al. (2008) as country-specific for Italy.

3. Result and discussion

3.1. Carbon footprint

The average carbon footprint determined by 1 kg of FPCM was 3.78 kg CO_2-eq. This result is in line with those recently reported by Vagnoni and Franca (2018). In the region of Sardinia, the most important Italian dairy sheep breeding area, Vagnoni and Franca (2018) reported that in the year 2011 the CF was 3.25 kg CO_2-eq, about 14 % less than that observed in our study, while Vagnoni et al. (2015), in that same region reported a CF of 2.0–2.3 kg CO_2-eq in two different farming systems, both corresponding to levels about 40 % lower than that observed in the present study. These different results may be attributed to the breed and the farming system. In particular, in Sardinia the Sardinian sheep is predominantly farmed, which is more productive than the Merinos derived breeds considered in the present study. In addition, in our study the farming systems were semi-extensive, with low energy inputs and no concentrates and silages. Obviously, when the production level is higher, a corresponding lower CF is observed. Batalla et al. (2015) observed that in one semi-extensive Spanish sheep farm, CF was 5.17 kg CO_2-eq per kg FPCM, while Weiss and Leip (2012) in a European Commission study observed a CF ranging from 2.6 to 4.1 kg CO_2-eq. In a study conducted in Australia in semi-intensive farms, Michael (2011) observed a CF of 3.57 kg CO_2-eq, whereas Opio et al. (2013) in a study commissioned by FAO, observed that in mixed farming systems global greenhouse gas emission for small ruminant milk production was 6.6 kg CO_2-eq/kg FPCM. These different studies conducted in different geographical areas show that the CF of dairy sheep systems presents a high degree of variability depending on the sheep breeds and farming techniques. The main processes contributing to CF are shown in Table 3. The enteric emission from sheep was the process with the highest impact (77.9 %), followed by the production of meadow hay (6.8 %). Vagnoni et al. (2015) in a system with low energy inputs observed a percentage impact due to enteric emissions of 45 % and 14 %, using IPCC and ReCipe method approaches, respectively. Conversely, Batalla et al. (2015) observed enteric emissions ranging between 36 % and 45 %, Vagnoni and Franca (2018) found percentages ranging between 50 and 57 % of the total emissions, whereas using a Tier 3 approach Atzori et al. (2013) observed that the enteric emissions could be up to 68 % of the total emissions. These results clearly show that enteric emissions are the major contributor in terms of CF in dairy sheep farms, although a high variability is observed across studies. This high variability can be partly attributed to the different national emission factors, but also at the different farming systems, including different breeds and

Table 3
Main processes contributing to carbon footprint[a,b].

	Farm 1	Farm 2	Farm 3	Farm 4	Averages
Enteric emission (%)	78.1	76.5	83.4	73.5	77.9
Meadow hay (%)	7.5	9.8	1.3	8.7	6.8
Oat seeds (%)	6.2	6.7	2.6	2.1	4.4
Manure emission (%)	2.1	2.1	2.3	2	2.1
Traction (%)	2.5	2.7	1.0	0.9	1.8

[a] Barley flour is not reported because the emissions were so low that they could be considered negligible.
[b] Cut-off set at.0.1 %.

feeding regimens. Marino et al. (2016) suggested several feeding strategies to minimize the emissions of enteric methane, such as an increase of the voluntary feed intake. In general, in extensive or semi-extensive farming systems most of the emissions originate from the animals due to the low levels of inputs used in these farms (e.g. no feeds were purchased from outside the farm) combined with the low production levels. In sheep as in other ruminants CH_4 is emitted as a direct result of fiber degradation. In particular, in the rumen a number of fermentative processes occur resulting in the production of important nutrients such as volatile fatty acids and proteins of bacterial origin deriving from the fermentation of vegetal fibers (Pirlo et al., 2014; Caputo et al., 2015; Sabia et al., 2018b). Therefore, the mitigation of the emissions generated in the rumen plays a strategic role. For instance, Sabia et al. (2015a, b) showed that the inclusion of more digestible forages in small ruminant diets may reduce CO_2-eq emissions, whereas the use of a mycorrhizal inoculum paired with a lower use of fertilizers may reduce GHG emissions (Uzun et al., 2018). In our study, farm 3 showed the highest impact due to enteric emissions (83.4 %) and the lowest impact due to meadow hay production (1.3 %). Conversely, farm 4 showed the lowest impact from enteric emissions (73.5 %) and the highest impact from meadow hay production (8.7 %). These results can be explained on the basis of the main characteristic of the farms as reported in Table 2. In particular, farm 3 relied more on the use of permanent pastures as compared with farm 4, which may have beneficial effects on carbon sequestration and CF mitigation (Batalla et al., 2015). However, a higher reliance on grazing can lead to a reduction in milk production efficiency and, consequently, to an increase in the environmental impact per functional unit. The main pollutant emissions in air contributing to CF are shown in Table 4. Biogenic CH_4 was the main chemical compound (80 %) emitted in the air, followed by CO_2 and N_2O, (11.5 % and 7.8 %, respectively). These results perfectly match those concerning the main source of GHG as shown in Table 3 and showing that the main process contributing to carbon footprint was enteric emission, since biogenic CH_4 is the product of rumen fermentation. Conversely, CO_2 and N_2O are mainly produced during fossil fuel combustion, hence more related to traction and feed production.

3.2. ReCiPe end-point study

The results from the ReCiPe End-point for 1 kg of FPCM are reported in Table 5. In terms of human health, the impact of 1 kg of FPCM from dairy sheep farming was 7.35 E-06 Disability Adjusted Life Years (DALY). Liang et al. (2019), in a study conducted in northern China, observed that the damage to human health generated by the winter wheat production was 2.94 E-03 DALY t^{-1}, whereas for summer maize it was 1.96 E-03 DALY t^{-1}. Therefore, the production of 1 kg of winter wheat and 1 kg of summer corn determined an impact which accounts for about 40 and 26 % of the production of 1 kg of sheep FPCM, respectively. In a Brazilian study, Du et al. (2019) observed that the production of manually harvested sugarcane generated an impact in terms of damage to human health of 2.06 E-04 DALY, whereas the estimated damage caused by mechanically harvested sugarcane was 1.02 E-04 DALY. The main compound responsible of the damage to human health was biogenic CH_4, followed by NH_3 in air (Table 6). Ren et al. (2017) observed that the presence of methane in the air can increase by 8% the formation of ozone in urban areas during the summer period, while in general the emission of biogenic volatile compounds may have marked detrimental effects on human cardiovascular and respiratory systems (Madaniyazi et al., 2016). Motoshita et al. (2018), in a study conducted in Germany on water scarcity arising from freshwater overconsumption, showed that a 4.90×10^{-6} DALY/m^3 damage was generated, while in Switzerland the damage was 3.18×10^{-6} DALY/m^3. The Damage to Ecosystem Diversity generated by 1 kg of FPCM from dairy sheep farming was 3.29 E-07 Species*year, (Table 5). The main process responsible for this damage was Land Occupation from pasture and meadow hay production followed by arable land occupation, wich accounted for 69.5 and 18 % of the total Damage to Ecosystem Diversity, respectively (Table 6). Opinions on land occupation are controversial. For instance, Kaenchan et al. (2018) claimed that land use can have negative effects on the ecosystem including humans, whereas other authors (Henle et al., 2008; Riedener et al., 2013) stated that the preservation of extensive agricultural systems including species-rich meadows is crucial for the maintenance of the biodiversity in semi-natural management conditions. In addition, pasture-based systems may provide other services, such as preservation of traditional land use (Plieninger et al., 2006), support to the socio-economic sustainability of several rural and marginal areas (de Rancourt et al., 2006), improvement of animal welfare and product quality as perceived by consumers (Sitz et al., 2005). Du et al. (2019) observed that the production of manually harvested sugarcane generated a damage to the species of 3.11 E-07, whereas the estimated Damage to Ecosystem Diversity caused by mechanically harvested sugarcane was 2.38 E-07. Steinmann et al. (2017) observed that this damage can be the result of the combination of land and energy footprints. In addition, Aguilera et al. (2013) observed that agronomic practices may undermine both soil and water quality while also negatively affecting the natural biodiversity through, for example, N deposition in ecosystems. In order to promote a balance between damages and restoration (i.e. compensation), the monetization of the environmental impact is necessary to combine all estimations of the ecological damages into one single value (Chen and Wu, 2018). In a recent study conducted at European level on the impact on biodiversity of total foods consumption using the ReCiPe end-point approach, Crenna et al. (2019) observed that the damage produced in terms of species*year was equal to 3.34-E05 per capita consumption. Table 5 shows that the value of the Damage to Resource Availability for 1 kg of FPCM was 0.025 $. Du et al. (2019) showed that in economic terms Damage to Resource Availability was lower for sugarcane manual cutting than for mechanical cutting. Although Huijbregts et al. (2010) stated that the use of natural fossil resources is less impactful in agriculture as compared with other production sectors, while biogenic methane and land use are generally more impactful, in this study the main Damages to Resource Availability were attributed to crude oil (46.5 %), followed by energy from natural gas (25.5 %) and hard coal (9%).

Table 4
Main pollutant emissions in air contributing to carbon footprint[a].

	Farm 1	Farm 2	Farm 3	Farm 4	Averages
Methane biogenic (%)	80.2	78.6	85.7	75.5	80.0
Carbon dioxide (%)	10.2	10.0	10.2	15.7	11.5
Dinitrogen monoxide (%)	9.0	10.8	3.6	7.9	7.8

[a] Cut-off set at.0.1 %.

4. Conclusion

Our study represents the first example of assessment of the impact of an animal-based product (i.e. the production of 1 kg of sheep FPCM) in terms of non-renewable energy resources used in the production process, damage to human health and damage to the ecosystem. Therefore, our results can be used to compare the impact of ovine milk with that of other agricultural and animal-based products. In addition, indications can be extrapolated for mitigation studies through a careful analysis of the damages. The average carbon footprint of the dairy sheep production system associated with 1 kg of FPCM was 3.78 kg CO_2-eq. In line with previous studies, the enteric emission from sheep, particularly methane, was the most impactful category in terms of CF, followed by the production of meadow hay. In conclusion, the environmental management and sustainability of dairy sheep farms should be constantly controlled with the aim of minimizing their impacts without compromising the competitiveness of this productive sector. The

Table 5
ReCiPe End-point Carbon footprint per 1 kg of FPCM[a].

	Unit	Farm 1	Farm 2	Farm 3	Farm 4	Averages
Damage to Human Health	(DALYs)[b]	4.25 E-06	1.14 E-5	7.59 E-6	6.17 E-06	7.35 E-06
Damage to Ecosystem Diversity	(Species*year)[c]	8.62 E-08	5.46 E-07	3.93 E-07	2.70 E-07	3.29 E-07
Damage to Resource Availability	($)[d]	0.01	0.03	0.03	0.03	0.025

[a] Fat and Protein Corrected Milk.
[b] Unit of DAILY includes years of life lost and years of life disabled.
[c] Unit of species*year is the weighted damage in terms of loss of species over a specified period of time and in a given geographical area.
[d] Unit of $ represents the marginal changes in expenditures needed for the extraction of the resources consumed in a given period of time at a steady annual production rate and at 3 % discount rate (Goedkoop et al., 2008).

Table 6
Main components and processes involved for damage assessment through the ReCiPe end-point method[a].

	Damage to Human Health (%)				Damage to Ecosystem Diversity (%)			Damage to Resource Availability (%)		
	CH_4 biogenic	NH_3	CO_2	N_2O	Occupation pasture and meadow hay	Occupation arable land	CH_4 biogenic	Crude oil	Energy from natural gas	Hard coal
Farm 1	56	26	7	6	39	40	16	51	25	6
Farm 2	54	28	7	7	73	18	6	46	26	7
Farm 3	67	18	8	3	84	8	7	49	21	10
Farm 4	53	25	11	6	82	6	7	40	30	13
Averages	**57.5**	**24.3**	**8.3**	**5.5**	**69.5**	**18.0**	**9.0**	**46.5**	**25.5**	**9.0**

[a] Cut-off systems was.0.1 %.

reduction of the ecological impact may promote the social and economic sustainability of the entire dairy sheep sector, particularly those located in upland less productive areas.

Funding

The research was funded by the "PSR-Basilicata 2007–2013 misura 214 azione 5".

Declaration of Competing Interest

None.

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