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Carbon footprint of milk from sheep farming systems in Northern Spain including soil carbon sequestration in grasslands

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ABSTRACT

The link between climate change and livestock production has made carbon footprint based on life cycle assessment a world-wide indicator to assess and communicate the amount of greenhouse gases emitted per unit of product. Nevertheless, the majority of studies have not included soil carbon sequestration in the carbon footprint calculations. Especially in grasslands, soil carbon sequestration might be a potential sink to mitigate greenhouse gas emissions in the livestock sector. However, there is no commonly accepted methodology on how to include soil carbon sequestration in carbon footprint calculations. In this study, the carbon footprint of sheep milk was estimated from 12 farms in Northern Spain. Before taken into account contribution from soil carbon sequestration in the calculation, the carbon footprint values varied from 2.0 to 5.2 kg CO_2 eq. per kg Fat and Protein Corrected Milk (FPCM). Milk from semi-intensive systems with foreign breeds kept indoors had significantly lower carbon footprint than milk from semi-extensive systems with local breeds and grazing in mountain uplands during summer. However, no difference was found in the carbon footprint of sheep milk from different systems and breeds when soil carbon sequestration was included in the calculations. Four different approaches to estimate and include soil carbon sequestration in the carbon footprint calculations were tested. This study highlights the importance of including soil carbon sequestration in the carbon footprint calculations. Furthermore, it highlights the climate mitigation potential of the grazing systems.

1. Introduction

The livestock sector contributes with 12% of all human-induced greenhouse gas (GHG) emissions (Havlík et al., 2014) with the ruminant sector being responsible for 80% of these GHG emissions. Sheep world production accounts for around 254 million tonnes CO_2 eq. (Opio et al., 2013). Although the major proportion of milk production comes from cows, small ruminants contribute with 12% of total GHG emissions from methane (CH_4) from enteric fermentation and manure, and 19% of N_2O from manure management concerns small ruminants (Zervas and Tsiplakou, 2012).

Carbon footprinting is an increasingly important method of communicating the climate change impacts of food production to stakeholders (Zervas and Tsiplakou, 2012). Most of the studies of carbon footprint of milk are based on milk from dairy farms with cattle. There are only few studies published about carbon footprint of meat from small ruminant systems in Europe (Opio et al., 2013; Ripoll-Bosch et al., 2013; Weiss and Leip, 2012) and even less from small ruminant milk systems (Opio et al., 2013; Weiss and Leip, 2012) and these studies were based on modelling. These studies show that despite the similarities in emission profiles, carbon footprint of meat or milk from small ruminants is more than the double per kg product compared with that from dairy cattle.

Grazing systems are important resources in small ruminant feeding, especially in areas where natural grasslands are part of the landscape and endogenous resources. Furthermore, grasslands are also on the political agenda in relation to the greening measures in the European Common Agriculture Policy (CAP) post 2013 (Matthews, 2013). Ruminants are key elements in regions where grassland and mountainous areas are dominating (Hörtenhuber et al., 2010). In the Basque country, permanent grasslands are an important source of feed for sheep farms during the summer season. Farmers have been preserving these grasslands through traditional pasture practices and recently with programs to reseed

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the pastures with mixtures of grass and clovers. These grasslands can act as a carbon sink and soil carbon sequestration of approx. 1 t CO_2 ha^{-1} year^{-1} have been reported (Janssens and Freibauer, 2005).

The soil carbon sequestration is poorly reflected in current LCA's and is e.g. not part of the guidelines of PAS 2050 (PAS2050 2008). Most LCA studies have traditionally not included soil carbon sequestration in the carbon footprint calculation due to methodological limitations (Brandão et al., 2013), despite the fact that Smith et al. (2007) estimated soil carbon sequestration to contribute about 89% to the global mitigation potential from agriculture. However, some recent LCA studies have included soil carbon sequestration in the carbon footprint calculation for milk (Guerci et al., 2013; O'Brien et al., 2014) and in crop and feed production relative to different managements soil strategies (Knudsen et al., 2014; Mogensen et al., 2014). Indirectly soil carbon sequestration has been taken into account in Ripoll-Bosch et al. (2013), they use agri-environmental payments from CAP to allocate emissions to ecosystem services provided for grazing systems.

Different approaches to include soil carbon sequestration in LCA will be investigated in this study; the first one is the IPCC Guidelines (2006) using changes in carbon stocks according to inventories; and three models proposed on literature based on net carbon fluxes in agricultural soils (Vleesshouwers and Verhagen, 2002; Soussana et al., 2010; Petersen et al., 2013).

The main aim of this study is to estimate the carbon footprint of milk from sheep farming in Northern Spain using life cycle assessment and to include the soil carbon sequestration in the carbon footprint using four different approaches.

2. Materials and methods

2.1. Sheep production system in Northern Spain, the Basque country case

Sheep farming is one of the most common animal productions in The Basque country. Approximately 22% of the livestock farms are sheep farms with a high specialization on milk production (EUSTAT, 2011). Sheep milk production is one of the most traditional livestock systems in the territory with a strong link to use natural pasture uplands, as well as production of cheese with European Label of Quality, PDO "Idiazabal". In The Basque country, 87% of the sheep flocks are from a native breed, Latxa. This breed is well adapted to the ecosystems, but there is a tendency of a decreasing number of Latxa flocks due to lack of generational turnover and transitions to more industrialized foreign breeds instead (Ruiz et al., 2011).

In the present study, data from 12 sheep farms with milk production in Northern Spain have been investigated. Data is primary taken from SERGAL S. Coop (economic and technical management centre in the region of Álava). Management centres of the Basque country have developed for more than 25 years with programs of economic and technical management collaborating with associations of farmers in the region. Baseline for the study is year 2011. Data collection was based on surveys, and farm visits to get a detailed inventory for the on-farm activities whereas more generic data for other activities were taken from national or other official databases.

Key characteristics of the studied farms are given in Table 1. Average annual milk yield per sheep was between 109 and 169 L for native breeds (Latxa) in an extensive system with a very seasonal production (January–May), and more than 300 L for more intensive systems with the foreign breed (Assaf). One of the most important differences between farms is a high share of pasture in systems with native breeds, versus a high share of forage purchased for the more intensive systems. The on-farm areas used for the sheep are only grasslands. Traditional management of grazing include use of natural mountain grasslands during normally 3 months (though also depending on individual farmer manners) is very common in this region.

Based on the collected farm data; three different sheep farming systems were identified. These systems varied with regard to breed and degree of intensification:

- Group 1. Semi intensive system with foreign breed (SIF): Usually flock of assaf breed. Characteristics of this system are high-intensive reproductive management (5 lambing per ewe every 3 years); kept indoors without any pasture management; milking all the year.
- Group 2. Semi intensive systems and local breed (SIL): Flocks of latxa breed. Traditional reproductive management (1 lambing per ewe per year), mid-intensive management practices; low time grazing per year.
- Group 3. Semi extensive and local breed (SEL). Flocks of latxa breed. Traditional reproductive management (1 lambing per ewe per year), mid-extensive management practices and grazing in mountain uplands during summer season.

2.2. Method for calculating the carbon footprint

Carbon footprint values were calculated using the life cycle assessment (LCA) methodology. The guidelines used to calculate the global warming potential of milk sheep systems are according to the British Standard, PAS2050 (BSI, 2008). Carbon footprint is the net GHG emissions per production unit. The production unit is needed to define the Functional Unit (FU).

2.2.1. Functional unit and system boundaries

In this study, the FU is 1 L of fat and protein corrected milk (FPCM). Milk is corrected at 6.5% fat and 5.8% protein according to Pulina et al. (2005).

The system boundary was "from cradle to farm gate" and it included all the emissions on farm, as well as emissions associated with production of inputs to the farm (purchased inputs). Machinery, buildings and medicines were excluded. Fig. 1 illustrates the system boundaries of this study.

2.2.2. Calculation of emissions and allocation

According to the system boundary, all GHG emissions that take place on the farm are shown in Table 2 and the equations and emissions factors that have been used. Most of them correspond to IPCC guidelines (IPCC, 2006); data from national statistics to estimate average N excreted (Magrama, 2012) and other literature sources for local values (Merino et al., 2011).

Off farm emissions correspond mainly with the processing and transporting of all the inputs. To take into account all these off-farm emissions delimited in the system boundary, a combination of emissions factors and data from literature have been used (Table 3).

The emissions are expressed in CO_2 equivalents in a 100 year Global Warming Potential (GWP) of CH_4 and N_2O of 25 and 298, respectively, following IPCC guidelines (IPCC, 2007).

Total emissions have been allocated using allocation factors based on economic value for milk and co-products (lambs and wool) from their monetary value at farm level.

2.3. Including soil carbon sequestration in LCA

Soil carbon sequestration refers to changes in soil carbon stocks on-farm due to e.g. input of crop residues or manure. Differences in type of crop and management practices could significantly affect

Table 1
Technical description of the studied sheep farms in the Basque country.

Farm no.	SIF.1	SIF.2	SIF.3	SIL.4	SIL.5	SIL.6	SEL.7	SEL.8	SEL.9	SEL.10	SEL.11	SEL.12
Intensification	Intensive						Extensive					
Breed	Assaf			Latxa								
Grassland surface (ha)	17.68	90.20	85.90	32.03	120.37	75.56	85.90	214.31	17.68	29.10	85.90	32.03
Average annual temperature (°C)	11.7	10.5	12.1	11.1	10.5	10.7	10.5	12.1	10.2	10.9	11.1	10.2
UAA[a]	5	1	1	2.5	3	2	2	1	2	1	3	1
No of ewes for milk (average population)	835	504	546	253	268	265	288	213	365	108	190	278
Total LU[b]	123.1	74.8	81.1	49.8	55.4	56.1	54.0	42.2	70.3	24.1	42.0	63.8
% time Grazing/year(milk ewes)	0%	0%	28%	46%	46%	53%	48%	49%	48%	46%	51%	51%
Production cheese (if YES kg/NO)	NO	NO	NO	7612.5	0	6896	1460	NO	NO	NO	4083	5464
Other economic activity (no relative with sheeps)	Crops	NO	NO	NO	NO	NO	NO	COWS	Crops	NO	Honey	NO
Inputs												
Concentrates bought (kg/ewe/year)	465	358	303	321	239	178	163	164	270	431	285	272
Fodder bought (kg/ewe/year)	284	189	324	174	188	175	28	21	276	106	118	231
Oil (litres/year)	18,478	2814	7179	3000	3386	2616	9562	3961	7446	2831	4433	1269.18
Electricity (kwH/year)	37,431	9457	18,882	15,516	7059	2350	6321	6000	9092	5000	6833	7950
Mineral fertilizer (kg/ha/year)	479	112	119	318	20	123	0	73	0	0	95	80
Outputs												
Lambs sold/ewe	0.48	0.35	0.66	0.4	0.63	0.79	0.46	0.69	0.95	0.85	1.16	0.53
Milk, litres/reproductive sheep	399	350	328	171	213	154	143	109	132	161	149	115
kg concentrates/litre milk	1.61	1.15	1.05	1.61	1.4	2.06	1.42	1.37	1.13	1.32	2.17	2.05

[a] UAA: Utilized Agriculture Area.
[b] LU: Livestock unit. 1 sheep:0.15 LU 1 lamb: 0.1 LU.

soil carbon changes. These changes can be positive or negative, which means, that when net balance is negative, a loss of carbon takes place in form of CO_2, which also involves a change of C:N relation in the soil and emissions of N_2O.

For extensive ruminants systems, soil carbon sequestration in grassland pastures can be seen as a mitigation option (Soussana et al., 2010). Additionally, diets based on natural grass reduce the purchased of fodder and have other additional social and economic impacts in rural areas (preserving ecosystems, high value and low price of grass etc.).

So far, there is no common approach to account for soil carbon sequestration in LCA. Thus, a literature review of methods to account for soil carbon sequestration in LCA has been performed. Table 4 presents the four main approaches found, with the main characteristics of each of them. Two different points of view are considered in the literature to estimate the soil carbon changes: the first, using changes in carbon stocks according to inventories; the second using a balance of net carbon fluxes in the system livestock-crop-grassland. However, the time horizon used to allocate the emissions differs from 20 to 100 years (Table 4).

2.3.1. Soil carbon sequestration according to IPCC guidelines (IPCC, 2006)

This method estimates the annual changes in organic carbon stocks in mineral soils with the Tier 1 approach. Calculations are according to Equation (2.25) (Chapter 2.Vol 4) (IPCC, 2006). The

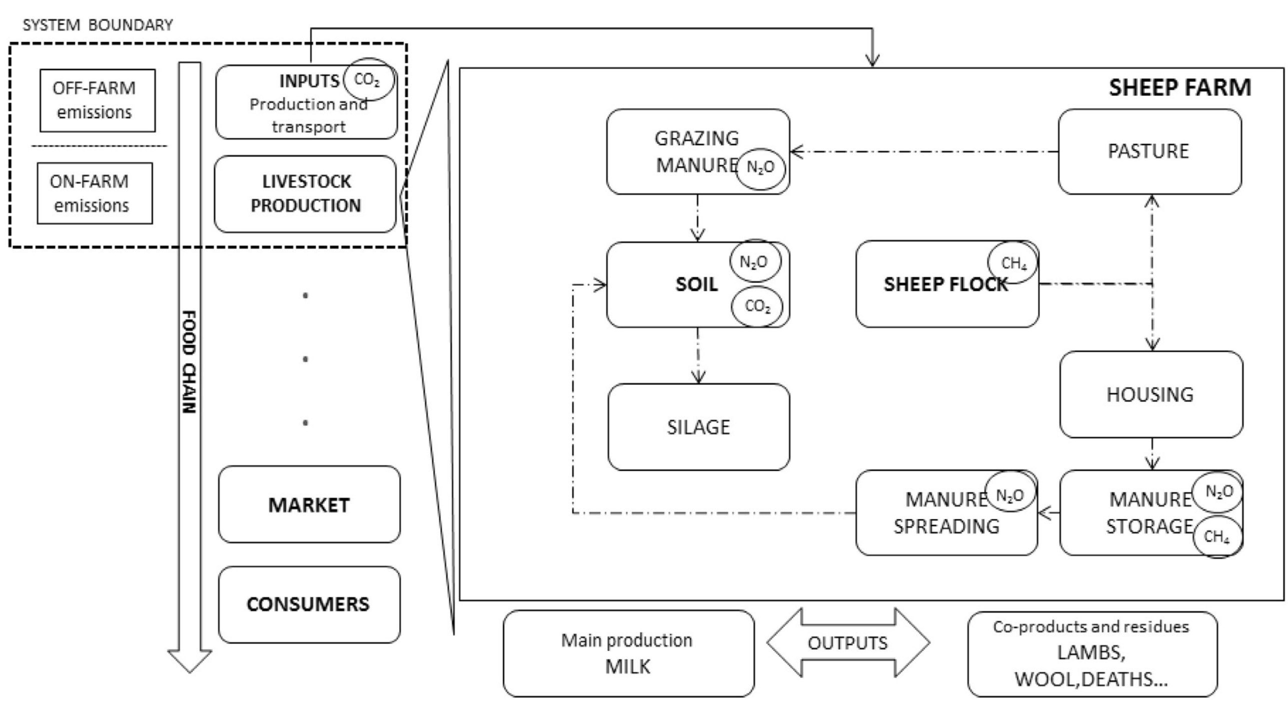

Fig. 1. System boundary. Scope of the study.

Table 2
Emission factor used in the baseline scenario of the dairy ewes for quantification of on-farms GHG emissions.

Emission and source	Pollutant	EF	Unit	Reference
Enteric fermentation	CH_4	8.2 kg CO_2eq/head year	kg CH_4/year	(Merino et al., 2011)
Manure management	CH_4	(0.19–0.37)[a] kg/headyear	kg CH_4/year	IPCC (2006)
Manure management direct	N_2O	1.1 kg N_2O–N/kg N Deep litter 0.005 kg N_2O–N/kg N Solid storage system	kg N_2O/year[b]	IPCC (2006)
Manure management – indirect	N_2O	1.1 kg N_2O–N/volatilized 0.0075 kg N_2O–N/leaching[c]	kg N_2O/year[b]	IPCC (2006)
N from inorganic fertilization	N_2O	0.001 kg N_2O–N (kg N input)$^{-1}$	kg N_2O/year[b]	IPCC (2006)
N from organic fertilizers (compost, manure)	N_2O	0.001 kg N_2O–N (kg N input)$^{-1}$	kg N_2O/year[b]	IPCC (2006)
N from urine and dung inputs to grazed soils	N_2O	0.001 kg N_2O–N (kg N input)$^{-1}$	kg N_2O/year[b]	IPCC (2006)
Indirect emissions management soils	N_2O	0.001 kg N_2O–N (kg % N volatilised/leaching)$^{-1}$	kg N_2O/year[b]	IPCC (2006)

[a] Table 10.15 Chapter 10. Vol 4 IPCC Guidelines (2006). With average temperature.
[b] N_2O–N*44/28 = N_20.
[c] 10% loss by leaching.

Table 3
Emission factors used in the dairy ewes farms for quantification of off-farm emissions.

Item	EF	Reference
Concentrates milk ewes	0.66 kg CO_2eq/kg concentrate	(Dia'terre® (2011), Gac et al., 2010)
Ammonium nitrate 30%	6.409 kg CO_2eq/kg N	(Dia'terre® (2011), Gac et al., 2010)
NPK fertilizer	5.27 kg CO_2eq/kg N 0.94 kg CO_2eq/kgP_2O_5 0.504 kg CO_2eq/kg K_2O	(Dia'terre® (2011), Gac et al., 2010)
PK fertilizer	0.566 kg CO_2eq/kg P_2O_5 0.444 kg CO_2eq/kg K_2O	(Dia'terre® (2011), Gac et al., 2010)
NK fertilizer	2.93 kg CO_2eq/kg N 0.444 kg CO_2eq/kg K_2O	(Dia'terre® (2011), Gac et al., 2010)
Herbicide	8.98 kg CO_2eq/kg active material	(Dia'terre® (2011), Gac et al., 2010)
Electricity	0.29 kg CO_2eq/kWh	(Iberdrola, 2011)
Diesel	2.664 kg CO_2eq/litre- Combustion 0.33 kg CO_2eq/litre- upstream	IPCC (2006)

Table 4
Key aspects of approaches studied in this work.

Approach	Temporal allocation of soil carbon sequestration emissions	Soil carbon sequestration	Scope
IPCC (2006). Chapter 2. (Vol IV)	20 years	Changes in soil carbon stocks	Equation 2.25 IPCC (2006). Variation of Soil Carbon Stocks from IPCC default values. Factors relative to management, inputs and land use.
(Soussana et al., 2010)	No specify	Net Carbon Fluxes	5 ± 30 g C/m^2 Carbon sequestration in grasslands according to inventories, 22 ± 56 g C/m^2 per year according to C flux balance. Net Carbon Storage
(Vleeshouwers and Verhagen, 2002)	No specify	Net Carbon Fluxes	Carbon fluxes from agricultural soils. Grasslands: 0.52 t C ha/year Arable crops −0.84 t C ha/year
(Petersen et al., 2013)	100 years	Net Carbon Fluxes	Soil Carbon Changes, LCA. Ex. In bioenergy and organic/convetional. (0–100 cm) (ΔCarbon/year). 10% of C added to the soil will be sequestered in a 100-year perspective.

time horizon to allocate the emissions is 20 years. When $\Delta C < 0$, there is a loss of C, and the C:N relation changes. Besides CO_2 emissions, N_20 emissions in soil will take place (Equation 11.1 (FSOM) from Chapter 11 Vol 4) (IPCC, 2006). When $\Delta C > 0$, there is a positive balance in favour of the soil. In this case, there will be a stock of carbon in the soil, which means that there is some C which is sequestrated in the soil.

Equation 2.25 (IPCC)

$$\Delta C \text{ kg C/ha year(IPPC) } \Delta C = \frac{soc_0 - SOC_{0-20}}{20}$$

where,

ΔC: Annual change in carbon stocks in mineral soils, kg C ha^{-1}.
SOC_0: Soil organic carbon stock in the last year of an inventory time period, kg C.
SOC $_{0-20}$: Soil organic carbon stock at the beginning of the inventory time period, kg C.
20 years: Time dependence of stock change factors to allocate changes in carbon stocks.

References for the study case:

Climate for Basque country (Climate zone IPCC. Warm, moist)	
SOC Ref (Table 2.3) HAC 88 for Basque country (Spain)	

Management factor for stock changes (FMG) have been considered to be 1.14 in all those farms where there is an improvement on the general practices relative to grassland management, for example: improving natural grassland. Due to characteristics of these production systems, pasture activities also, with organic fertilization from manure, have a substantial organic input for soil, and for that reason the factor for organic inputs (FI) has been assumed to be 1.11 in most of the farms, where pasture practices take place.

2.3.2. Soil carbon sequestration according to Vleeshouwers and Verhagen (2002)

This model creates business-as-usual scenarios to calculate change in carbon stocks using CESAR Model (Carbon Emission and

Table 5
Annual C Inputs in grasslands and total annual C sequestration calculated according to Petersen et al. (2013).

	SIF.1	SIF.2	SIF.3	SIL.4	SIL.5	SIL.6	SEL.7	SEL.8	SEL.9	SEL.10	SEL.11	SEL.12
C from crop residue												
Total crop yield (kg DM/ha)[a]	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
Above ground DM (kg DM/ha)[b]	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Below ground DM (kg DM/ha)	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Above ground C (kg C/ha) [c]	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350
Below ground C (kg C/ha) [c]	540	540	540	540	540	540	540	540	540	540	540	540
C from manure												
kg N excreted/year	5729	3424	3782	2327	2562	2590	2552	1971	3276	1099	1908	2926
kg N during grazing/year	0	0	0	1014	1198	1344	1222	915	1509	454	939	1385
kg C during grazing/ha[d]	0	0	0	424	133	614	217	143	94	344	146	579
kg C from applied manure/ha[e]	1454	170	198	184	51	194	152	55	37	164	51	410
Total												
kg C added from manure/ha[f]	1454	170	198	608	184	808	368	198	131	508	197	989
kg C from crop residues/ha	1890	1890	1890	1890	1890	1890	1890	1890	1890	1890	1890	1890
C sequestration												
kg C/ha	334	206	209	250	207	270	226	209	202	240	209	288
kg CO_2/ha	1226	756	765	915	760	989	828	766	741	879	765	1056
kg CO_2 avoid (Total)	22,497	72,310	69,721	30,818	97,107	66,055	69,730	168,741	16,361	8621	69,704	35 295

[a] 20% DM content in crops.
[b] 40% crop residue (Soussana et al., 2010)/total crop production.
[c] 45% of kg DM input.
[d] C:N sheep manure 13.4 (Escudero et al., 2012).
[e] We assumed 70% compost produced is added to soil.
[f] C added from manure = (C from grazing + C from manure applied to soil as organic fertilizer).

Sequestration by Agricultural land use). Land use and change in practices (manure, incorporate cereal straw of reduce tillage) are identified as important to get a positive carbon balance and sequestration. The authors analysed the interaction between soil, crop and climate. They also evaluated some mitigation options like application of farmyard manure, leaving behind cereal straw in the field and reduced tillage. Values used in this study is 0.52 t C ha/year for grasslands.

2.3.3. Soil carbon sequestration according to Soussana et al. (2010).

Soussana et al. (2010) concluded that carbon sequestration of European grasslands is 5 ± 30 g C/m^2 according to inventories and 22 ± 56 g C/m^2 per year according to C flux balance. Their work focuses on the potential of soil carbon sequestration for mitigation in the agricultural sector, and in particular on grasslands as sink. Nevertheless, CH_4 and N_20 emissions need to be reduced and soil carbon has to be preserved avoiding agricultural practices that reduce carbon sinks. Net carbon storage is calculated as the balance of carbon fluxes. Uncertainties related to grasslands management are high. In this study the average value from Soussana et al. (2010) of 22 g C/m^2 has been considered for calculations.

2.3.4. Soil carbon sequestration according to Petersen et al. (2013)

This approach also points to the importance of soil carbon sequestration like potential strategy to mitigate GHG emissions. Like in the method by Soussana et al. (2010), also Petersen et al. (2013) estimate carbon changes from net carbon fluxes. The main difference to other methods is the suggestion to use a 100 year perspectives to allocate the soil carbon changes, compared to the 20 year perspective that the IPCC guidelines have. Using a 100 years perspective or a 20 years perspective can change the results. 10% of C added to soil will be sequestered in a 100 years perspective (Petersen et al., 2013). In contrast to this 21% of C would be sequestered using a 20 years perspective which would double the contribution from soil carbon sequestration to the carbon footprint. Input of carbon to the soil, is the above and below ground crop residues (assuming a C content of 45% of dry matter). Table 5 shows all the main C inputs that enter the fields every year: C inputs from crop residue and manure. Amount of manure and N excreta per animal per year are based on data from National data (MAGRAMA, 2005). C:N relationship of sheep manure is 13.4, and in sheep compost the number is taken from Escudero et al. (2012).

2.4. Statistical analysis

Statistical analyses were performed using ANOVA in the R software system to test for possible significant differences between the three groups (SIF, SIL and SEL) using a p-value of 0.05 as threshold. If a general significant effect of group were found with the ANOVA Model, Tukey contrast was used to identify significant difference between groups again using $p \leq 0.05$ as threshold and identified by different letters.

3. Results and discussion

3.1. Carbon footprint of milk (without soil carbon sequestration)

Total emissions per kg FPCM are presented in Table 6 and the contribution per pollutant sources are also showed for the 12 individual farms. The values reflect that on average 34% of the emissions come from CH_4 from enteric fermentation and 34% from the use of feed purchased (concentrates and fodder). N_2O Emissions from soil are around 11% of total emission (8% from direct and 3% indirect) mainly due to N deposited at the pasture during grazing. Energy consumption of oil and electricity on the farms accounts for 9% of the total emissions. Fig. 2 represents the average values from all the sources and their contribution to the carbon footprint in %.

The carbon footprint of 1 kg FPCM from the sheep herds ranges from 2.0-to 5.2 kg CO_2eq/kg FPCM with an average value of 3.2 kg CO_2eq per kg of FPCM. Variation in carbon footprints per kg of milk between farms, indicates that the carbon footprint decreases with increased milk yield per sheep. The semi-extensive have seasonal variation in the milk production causing lower milk yields than the semi-intensive farms. The contribution per sources (Table 6) shows that feed purchased accounts for 37%–48% in the farms from Group I (SIF) and it is the biggest contributor to the total GHG emissions. On the other side, feeds purchased accounts for 18%–33% at farms

Table 6
Contribution to carbon footprint from different sources, presented both as kg CO_2/kg FPCM and as % of total carbon footprint in brackets.

Source of emission	SIF.1	SIF.2	SIF.3	SIL.4	SIL.5	SIL.6	SEL.7	SEL.8	SEL.9	SEL.10	SEL.11	SEL.12
Enteric fermentation CH_4 (kg CO_2eq/kg FPCM; [%])	0.49 [19]	0.71 [32]	0.62 [31]	1.17 [39]	1.37 [43]	1.17 [41]	1.51 [37]	1.61 [45]	1.15 [39]	1.10 [40]	1.72 [41]	1.85 [36]
Manure management CH_4 (kg CO_2eq/kg FPCM; [%])	0.01 [1]	0.02 [1]	0.02 [1]	0.03 [1]	0.04 [1]	0.03 [1]	0.04 [1]	0.05 [1]	0.03 [1]	0.03 [1]	0.05 [1]	0.05 [1]
Manure management N_20 (kg CO_2eq/kg FPCM; [%])	0.10 [4]	0.17 [7]	0.15 [7]	0.15 [5]	0.17 [5]	0.07 [2]	0.24 [6]	0.23 [6]	0.14 [5]	0.15 [5]	0.21 [5]	0.17 [3]
Direct emissions (N_2O) (kg CO_2eq/kg FPCM; [%])	0.27 [11]	0.13 [6]	0.08 [4]	0.17 [6]	0.23 [7]	0.20 [7]	0.44 [11]	0.29 [8]	0.28 [9]	0.17 [6]	0.26 [6]	0.69 [13]
Indirect emissions (N_2O) (kg CO_2eq/kg FPCM; [%])	0.09 [4]	0.05 [2]	0.03 [2]	0.07 [2]	0.09 [3]	0.08 [3]	0.18 [4]	0.12 [3]	0.10 [3]	0.07 [3]	0.11 [3]	0.27 [5]
Feed purchased (kg CO_2eq/kg FPCM; [%])	0.96 [37]	1.01 [45]	0.98 [49]	1.14 [38]	0.95 [30]	1.19 [41]	0.89 [22]	0.80 [22]	0.53 [18]	0.91 [33]	1.22 [29]	1.49 [29]
Mineral fertilizers (kg CO_2eq/kg FPCM; [%])	0.45 [17]	0.05 [2]	0.00 [0]	0.00 [0]	0.03 [1]	0.00 [0]	0.12 [3]	0.00 [0]	0.42 [14]	0.00 [0]	0.01 [0	0.38 [7]
Energy (oil + electricity) (kg CO_2eq/kg FPCM; [%])	0.20 [8]	0.08 [4]	0.15 [8]	0.24 [8]	0.22 [7]	0.13 [5]	0.60 [15]	0.51 [14]	0.30 [10]	0.33 [12]	0.47 [11]	0.13 [3]
Other inputs (kg CO_2eq/kg FPCM; [%])	0.04 [1]	0.00 [0]	0.00 [1]	0.04 [1]	0.09 [3]	0.00 [0]	0.01 [0]	0.00 [0]	0.01 [0]	0.00 [0]	0.00 [0]	0.00 [0]
Total emissions (kg CO_2eq/kg FPCM)	2.61	2.23	2.02	3.01	3.19	2.87	4.03	3.60	2.96	2.76	4.24	5.17

from Group III (SEL) and here it is the enteric fermentation being the major source of GHG emissions with values from 36% to 45%.

There are only few studies in the literature on carbon footprint of sheep milk. The first one, from a FAO report (Opio et al., 2013) gives 4.7 kg CO_2eq/kg FPCM in Western Europe using GLEIAM model and economic allocation (90% for milk). This study also gives higher values in general to grazing systems compared with mix grazing systems. A second study for the European Commission using the CAPRI Model (Weiss and Leip, 2012) gives a range from 2.6 to 4.1 kg CO_2eq/kg milk (7% fat) using protein (N) content in products as allocation rule. Bearing in mind that comparison with other LCA studies should be done with caution due to different assumptions (scope, delimitations, database etc.).

A sensitivity analysis was performed using different allocation rules (mass, economic and protein content) on data from this case study, which provided the price, amount and protein content of milk and animals. Results obtained are in the range of values on literature with similar conditions: 3.74 kg CO_2/kg FPCM with no allocation; 3.2 kg CO_2/kg FPCM with economic allocation; 3.2 kg CO_2/kg FPCM with mass allocation and 3.3 kg CO_2/kg FPCM with allocation based on protein content in milk. However, the average values found in this case study seems to be lower than the value given by FAO (2013) for Western Europe, this could be due to higher yields of foreign breeds in this case study. The average value for group 3 (SEL), the group with the lowest milk yields was 3.8 kg CO_2/kg FPCM.

3.2. Including soil carbon sequestration in the carbon footprint of milk

When the contribution from soil carbon sequestration is included in the LCA, the amount of CO_2 sequestered will depend on the chosen method. Fig. 3 presents the reduction (%) in the carbon footprint of sheep milk, when including contribution from soil carbon sequestration using the four different approaches. Using the IPCC method, gives the largest difference between farms in the contribution from soil C to the carbon footprint compared to using the other approaches (from −20% to −80% value of carbon footprint compared with the baseline carbon footprint). The methods by Soussana et al. (2010) and by Petersen et al. (2013) give quite similar carbon footprint values, when including soil carbon sequestration. The carbon footprint was reduced by 2%–43% of the carbon footprint baseline using the Soussana model, and by 3%–41% using the Petersen et al. (2013) model.

(Fig. 3. % Variation of different methods including soil carbon sequestration in the carbon footprint value).

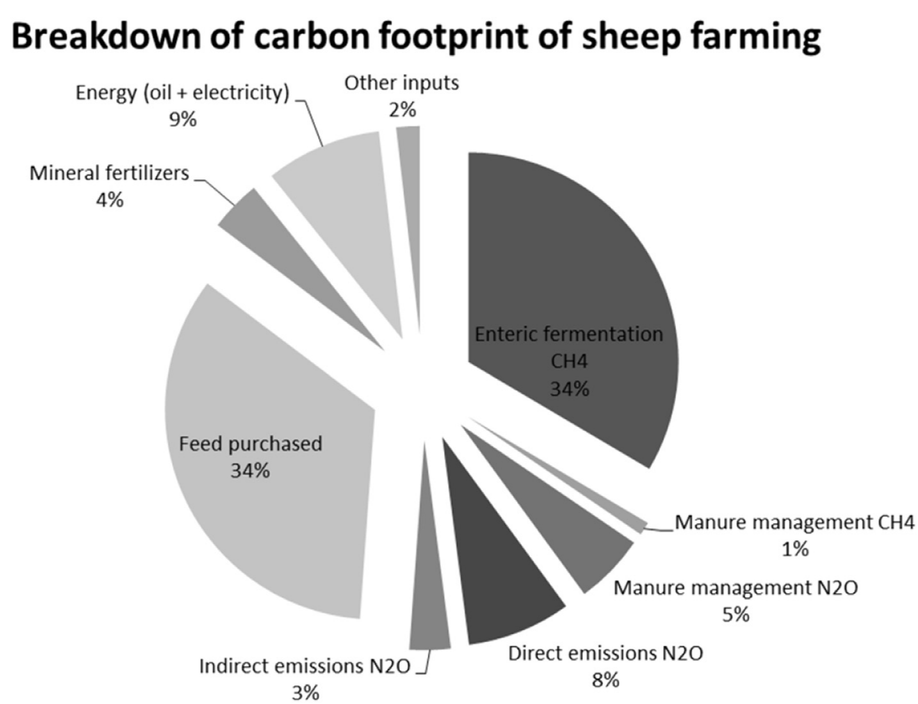

Fig. 2. GHG contribution per kg of FECM sheep milk from different sources, calculated as average across the 12 farms studied.

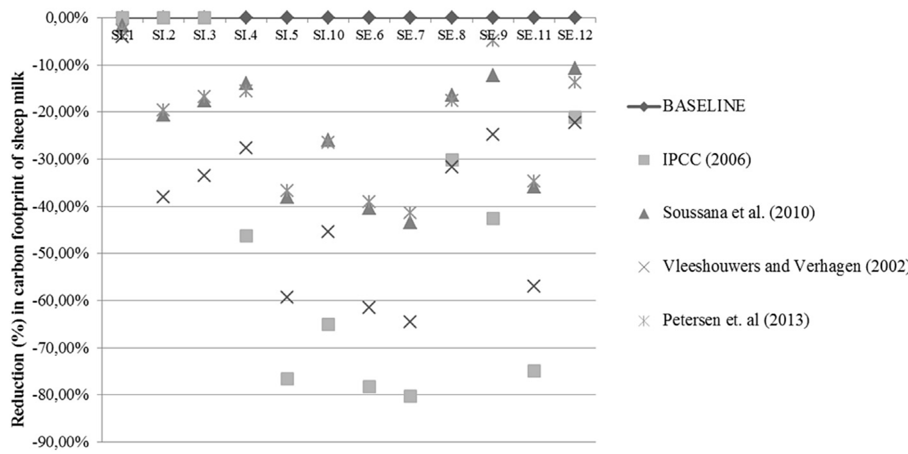

Fig. 3. Reduction (in %) of carbon footprint from including soil carbon sequestration using four different methods.

Thus, the carbon footprint value in the baseline calculation will decrease according to the amount of CO_2 sequestered. Table 7 shows average values of carbon footprint in kg CO_2eq/kg FPCM for milk from farms in Groups I, II and III for baseline before including contribution from soil C changes and after including soil carbon changes according to the 4 methodologies used in this paper.

Table 7 shows that the carbon footprint per kg FPCM in some cases can be even negative when contribution from soil carbon sequestration is included according to the approaches suggested by the IPCC (2006) or the Vleeshouwers and Verhagen (2002) approach.

The statistical analyses (ANOVA) showed that in the baseline case (without soil carbon sequestration) significant differences appear between the three groups. Milk from semi-intensive systems with foreign breeds kept indoors (SIF) had significantly lower carbon footprint than milk from semi-extensive systems with local breeds and grazing in mountain uplands during summer (SEL). The tukey contrast test showed significance differences ($\alpha = 0.03$) between SIF and SEL but not within the other comparisons. That means differences in carbon footprint within groups come from differences in production (milk yields) and not from differences in management practices (SIF-SIL; SIL-SEL). However, when soil carbon sequestration was included in the carbon footprint none of the groups were statistical different from the others. This highlights the importance of including soil carbon sequestration in life cycle assessments due to the climate mitigation potential of grazing systems, and the possibility of having lower carbon footprint in grazing systems when soil carbon sequestration is included, as O'Brien et al. (2014) point also in their study for dairy systems in Ireland.

3.2.1. *Methodology*

Due to the very simple approach using one default value per ha of grassland in the methods by Soussana et al. (2010) and by Vleesshouwers and Verhagen (2002); the approach by Petersen et al. (2013) seems to be more precise taking into account the actual production conditions in different fields with grassland. There are two reasons for this, 1) real data of C inputs of individual farms are used which also allows for possible monitoring on soil carbon sequestration year after year (mitigation options etc.), 2) Petersen et al. (2013) allocates soil carbon sequestration in 100 year time horizon which is more in line with LCA methods and the 100 years GWP characterization factor. The IPCC (2006) methodology presents more variable results between farms than the other methods. Other studies of LCA including soil carbon sequestration like (O'Brien et al., 2014) use average value of 1.19 t CO_2/ha (30 g C/m^2 sequestered) from Soussana et al. (2010) for Dairy Grazing Farms in Ireland.

Excluding these methodological differences, these results show that there is a potential for permanent soil carbon sequestration in these grazing systems as long as the same amount of carbon will be added to the grasslands every year. This should be included in the carbon footprint methodology and it is possible to add the effect of soil carbon sequestration in the carbon footprint (Petersen et al., 2013).

Fig 4 represents the emission sources per kg FPCM, including soil carbon sequestration using the method proposed by Petersen et al. (2013). Differences between the contributions of soil carbon sequestration between groups can be seen. Soil carbon sequestration is higher in farms of Group 3 (SEL) with an average C sequestration potential of 25% of the total emissions per kg FPCM at farm gate and Group 1, 13% C sequestration potential from carbon

Table 7
Carbon footprint (kg CO_2 eq) for 1 kg FPCM for different sheep farming system groups according to breed and degree of intensification. Carbon footprint is given both before and after including contribution from soil C changes calculated by 4 different methods (IPCC (2006), Soussana et al. (2010), Vleeshouwers and Verhagen (2002) and Petersen et al. (2013)).

Intensification	Group I	Group II	Group III	p-value
	Intensive	Intensive	Extensive	
Breed	Foreign	Local	Local	
Number of farms	3	3	6	
No soil carbon sequestration included	2.29a	3.02ab	3.81b	0.03
IPCC (2006)	2.43	−2.03	−3.41	0.30
(Soussana et al., 2010)	1.95	2.07	2.16	0.96
(Vleeshouwers and Verhagen. 2002)	1.46	0.77	−0.02	0.59
(Petersen et al., 2013)	1.95	2.06	2.18	0.94

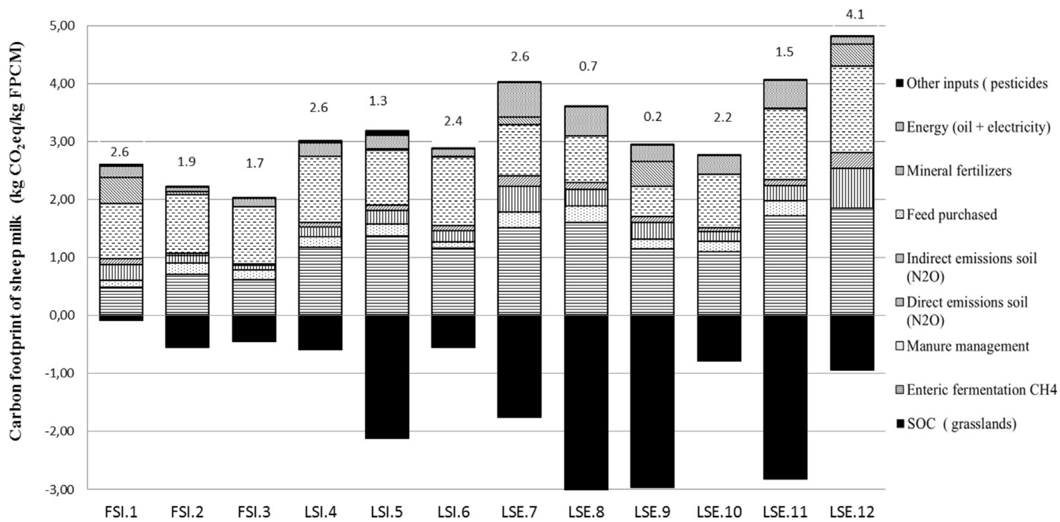

Fig. 4. Carbon footprint (kg CO_2eq per kg FPCM) for the 12 studied sheep farms in Northern Spain.

footprint baseline. Higher values of C sequestration potential are directly linked with grazing and type of management of grassland.

4. Conclusions

Average values for carbon footprint of sheep milk production systems in Northern Spain ranges from 2.0 to 5.2 kg CO_2eq/kg FPCM, when soil carbon sequestration is not taken into account. Results show that more intensive farms with higher amount of milk production per sheep have lower carbon footprint values than more traditional farms with less efficiency per animal (statistically significant). However, when soil carbon sequestration is included in the assessment, the carbon footprint values decrease much more in the lower productive farms due to highest C sequestration from grazing practices. Carbon footprint values per kg FECM are still higher, but there is no longer a statistically significant difference between groups.

So far, there is no commonly accepted methodology to include contribution from soil carbon sequestration in LCA. When different methods were compared, the approach by Petersen et al. (2013), based on actual data on C inputs and a 100 years' time perspective as for GWP, seems to give more precise and realistic results and allows for designing mitigation strategies with higher precision.

This study shows the importance of including soil carbon sequestration in LCA, especially in farming systems where grasslands are a substantial resource for animal feeding with high potentials of carbon sequestration. Nevertheless, there is a need to continue the development of strategies for a correct use and improvement of grasslands. Higher inputs from crop residues and manure increase the soil carbon sequestration. This study also indicates that grasslands used by extensive sheep farms plays an important role as carbon sinks.

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References

Brandão, M., Levasseur, A., Kirschbaum, M.F., Weidema, B., Cowie, A., Jørgensen, S., …, Chomkhamsri, K., 2013. Key issues and options in accounting for carbon sequestration and temporary storage in life cycle assessment and carbon footprinting. Int. J. Life Cycle Assess 18 (1), 230–240. http://dx.doi.org/10.1007/s11367-012-0451-6.

BSI., 2008. PAS 2050:2008. Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Good and Services. UK: British Standards Institution.

Dia'terre, 2011. Guide des valeurs.

Escudero, A., González-Arias, A., del Hierro, O., Pinto, M., Gartzia-Bengoetxea, N., 2012. Nitrogen dynamics in soil amended with manures composted in dynamic and static systems. J. Environ. Manag. 180, 66–72.

Gac, A., Cariolle, M., Deltour, L., Dollé, J.B., Espagnol, S., Flénet, F., Guingand, N., Lagadec, S., Le Gall, A., Lellahi, A., Malaval, Ponchant, C.,P., Tailleur, A., 2010. 2010. GES'TIM — Guide méthodologique pour l'estimation des impacts des activités agricoles surl'effet de serre.: Réalisé dans le cadre du projet «Gaz à Effet de Serre et Stockage de Carbone en exploitations agricoles» (CASDAR6147).

Guerci, M., Knudsen, M.T., Bava, L., Zucali, M., Schönbach, P., Kristensen, T., 2013. Parameters affecting the environmental impact of a range of dairy farming systems in Denmark, Germany and Italy. J. Clean. Prod. 54, 133–141.

Havlík, P., Valin, H., Herrero, M., Obersteiner, M.l, Schmid, E., Rufino, M.C., Mosnier, A., Thornton, P.K., Böttcher, H., Conant, R.T., Frank, S., Fritz, S., Fuss, S., Kraxner, F., Notenbaert, A., 2014. Climate change mitigation through livestock system transitions. Proc. Natl. Acad. Sci. 111 (10), 3709–3714. http://dx.doi.org/10.1073/pnas.1308044111.

Hörtenhuber, S., Lindenthal, T., Amon, B., Markut, T., Kirner, L., Zollitsch, W., 2010. Greenhouse gas emissions from selected Austrian dairy production systems-model calculations considering the effects of land use change. Reneweable Agric. Food Syst. 25 (4), 316–329. http://dx.doi.org/10.1017/S1742170510000025.

Iberdrola. 2011. http://www.iberdrola.es/inicio.

IPCC., 2006. IPCC guidelines for national greenhouse Gas inventories. In: Intergovernmental Panel of Climate Change (IPCC), National Greenhouse Gas Inventories Programme. Online at. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

IPCC., 2007. Intergovernmental Panel on Climate Change. IPCC Fourth Assessment Report (AR4) – Climate Change 2007.

Janssens, I.A., Freibauer, A., Schlamadinger, B., Ceulemans, R., Ciais, P., Dolman, A.J., Heimann, M., Nabuurs, G.-J., Smith, P., Valentini, R., Schulze, E.-D., 2005. The carbon budget of terrestrial ecosystems at country-scale a European case study. Biogeosciences 2, 15–26. http://dx.doi.org/10.5194/bg-2-15-2005.

Knudsen, M.T., Meyer-Aurich, A., Olesen, J.E., Chirinda, N., Hermansen, J.E., 2014. Carbon footprints of crops from organic and conventional arable crop rotations – using a life cycle assessment approach. J. Clean. Prod. 64 (0), 609–618. http://dx.doi.org/10.1016/j.jclepro.2013.07.009.

Magrama, 2012. Stadistical Yearbook. MAGRAMA, Ministerio de Agricultura, Alimentación y Medio Ambiente (In Spanish).

Matthews, A., 2013. Greening agricultural payments in the EU's common agricultural policy. Bio-based Appl. Econ. 2 (1), 1–27. http://dx.doi.org/10.13128/BAE-12179.

Merino, P., Ramírez-Fanlo, E., Arriaga, H., del Hierro, O., Artetxe, A., Viguria, M., 2011. Regional inventory of methane and nitrous oxide emission from ruminanr livestock in the Basque country. Animal Feed Sci. 166–167, 628–640.

Mogensen, L., Kristensen, T., Nguyen, T.L.T., Knudsen, M.T., Hermansen, J.E., 2014. Method for calculating carbon footprint of cattle feeds – including contribution from soil carbon changes and use of cattle manure. J. Clean. Prod. 73 (0), 40–51. http://dx.doi.org/10.1016/j.jclepro.2014.02.023.

Opio, C., Gerber, P., Mottet, A., Falcucci, A., Tempio, G., MacLeod, M., Vellinga, T., Henderson, B., Steinfeld, H., 2013. Greenhouse Gas Emissions from Ruminant Suppy Chains-A Global Life Cycle Assessment. Food and Agriculture Organization of the United Nations (FAO), Rome.

O'Brien, D., Capper, J.L., Garnsworthy, P.C., Grainger, C., Shalloo, L., 2014. A case study of the carbon footprint of milk from high-performing confinement and grass-based dairy farms. J. Dairy Sci. 97 (3), 1835–1851.

Petersen, B.M., Knudsen, M.T., Hermansen, J.E., Halberg, N., 2013. An approach to include soil carbon changes in life cycle assessments. J. Clean. Prod. 52 (0), 217–224. http://dx.doi.org/10.1016/j.jclepro.2013.03.007.

Pulina, G., Macciotta, N., Nudda, A., 2005. Milk composition and feeding in the Italian dairy sheep. Ital. J. Anim. Sci. 4 (Suppl. 1), 5–14.

Ripoll-Bosch, R., de Boer, I.J.M., Bernués, A., Vellinga, T.V., 2013. Accounting for multi-functionality of sheep farming in the carbon footprint of lamb: a comparison of three contrasting Mediterranean systems. Agric. Syst. 116 (0), 60–68. http://dx.doi.org/10.1016/j.agsy.2012.11.002.

Ruiz, B., Díez-Unquera, I., Beltrán de Heredia, J., Arranz, J., Mandaluniz, Ugarte, E., 2011. In: Berenues, A., Boutonne, J.P., Casaus, I., Chentouf, M., Gabiña, D., Joy, M., López- Francos, A., MORAND-Fehr, P., Pacheco, F. (Eds.), Is Cheese Making and Marketing by Farmers Determining Sustainability in Dairy Sheep?. CIHEAM/FAO/CITA-DGS, Zaragoza, p. 379 (Options Méditerranéennes, Série A: Séminaires Méditerranées, no.100).

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., …, Towprayoon, S., 2007. Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. Agric. Ecosyst. Environ. 118 (1–4), 6–28. http://dx.doi.org/10.1016/j.agee.2006.06.006.

Soussana, J.F., Tallet, T., Blanfort, V., 2010. Mitigating the greenhouse gas balance of ruminant production systems though carbon sequestration in grasslands. Animal 4 (3), 334–350.

Vleeshouwers, L.M., Verhagen, A., 2002. Carbon emission and sequestration by agricultural land use: a model study for Europe. Glob. Change Biol. 8 (6), 519–530. http://dx.doi.org/10.1046/j.1365-2486.2002.00485.x.

Weiss, F., Leip, A., 2012. Greenhouse gas emissions from the EU livestock sector: a life cycle assessment carried out with the CAPRI model. Agric. Ecosyst. Environ. 149 (0), 124–134. http://dx.doi.org/10.1016/j.agee.2011.12.015.

Zervas, G., Tsiplakou, E., 2012. An assessment of GHG emissions from small ruminants in comparison with GHG emissions from large ruminants and monogastric livestock. Atmos. Environ. 49 (0), 13–23. http://dx.doi.org/10.1016/j.atmosenv.2011.11.039.