Agricultural Systems 116 (2013) 60–68

Contents lists available at SciVerse ScienceDirect

Agricultural Systems

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

Accounting for multi-functionality of sheep farming in the carbon footprint of lamb: A comparison of three contrasting Mediterranean systems

R. Ripoll-Bosch [a,*], I.J.M. de Boer [b], A. Bernués [a,d], T.V. Vellinga [c]

[a] Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA), Avda. Montañana 930, 50059 Zaragoza, Spain
[b] Animal Production Systems Group, Wageningen University, P.O. Box 338, 6700 AH Wageningen, The Netherlands
[c] Wageningen UR Livestock Research, P.O. Box 65, 8200 AB Lelystad, The Netherlands
[d] Department of Animal and Aquacultural Sciences, Norwegian University of Life Sciences (UMB), P.O. Box 5003, No-1432 Ås, Norway

ARTICLE INFO

Article history:
Received 1 December 2011
Received in revised form 29 October 2012
Accepted 20 November 2012
Available online 25 December 2012

Keywords:
Mediterranean sheep systems
Life cycle assessment
Cultural ecosystem services
Allocation

ABSTRACT

Intensifying animal production is generally advocated to mitigate greenhouse gases emissions associated with production of animal-source food. Sheep farming systems (SFSs) in Spain are generally considered to be pasture-based and extensive, but large differences in input utilization, land use and intensification level exist. Their environmental impacts, therefore, are expected to differ also. We used life cycle assessment (LCA) to evaluate greenhouse gases (GHGs) emissions of three contrasting meat-sheep farming systems in Spain, which differed in their degree of intensification (reproduction rate, land use and grazing management). The GHGs emissions of these systems varied from 19.5 to 25.9 kg CO_2-eq per kg of lamb live weight, or 39.0–51.7 kg CO_2-eq per kg of lamb meat, with highest values referring to the pasture-based livestock system. In addition to meat, however, these SFSs also provide other services to society (e.g. public goods such as biodiversity and landscape conservation). We valued these services for each SFSs based on agri-environmental subsidies of the EU and used farm economic values to allocate GHGs emissions of SFSs between meat and cultural ecosystem services. When accounting for multifunctionality, GHGs emission per kg of lamb live weight among the SFSs was reversed: with lowest values for the pasture-based system (13.9 kg CO_2-eq per kg of lamb live weight) and highest for zero-grazing system (19.5 kg CO_2-eq per kg of lamb live weight). A comparison of GHGs emissions among SFSs should account for the multifunctionality of pasture-based livestock systems.

1. Introduction

The FAO report "Livestock's long Shadow" implies that the livestock sector increasingly competes for scarce resources and causes a severe impact on air, water and soil (Steinfeld et al., 2006). Since its publication, public and scientific awareness about the impact of animal production on the environment has increased.

Intensifying animal production is generally advocated to mitigate certain environmental impacts, such as emission of greenhouse gases associated with production of animal-source food (Steinfeld and Gerber, 2010). In Mediterranean areas, however, most sheep farming systems (SFSs) are characterized as extensive or low-input: they are linked with natural and semi-natural areas, through grazing of shrubs, forest pastures and understorey (Bernués et al., 2005) or alpine grasslands. Sheep in these extensive systems have a low reproduction rate, but are able to add value-to a range of by-products from winter cereals production, such as crop residues remaining on-field after harvesting, stubbles, fallow (Barrantes et al., 2009) and failed crops. During the last decades, SFSs in Spain are intensifying rapidly, i.e. reproduction rates and in-door feeding have increased while the grazing season and grazing intensity has decreased (Caballero, 2003; Riedel et al., 2007). In parallel, the ovine sector is under restructuring process, i.e. in last 5 years, average flock size has increased (+38%) while the number of sheep farms and total number of heads has decreased (−35% and −11%, respectively) (MARM, 2009). Intensification of production in favorable areas and the gradual disappearance of traditional pasture-based sheep farming systems contribute to the processes of abandonment, afforestation and encroachment of unfavorable marginal areas (Bernués et al., 2005). The current trend of intensification, however, could be expected to mitigate the emission of greenhouse gases related to production of lamb (Steinfeld and Gerber, 2010).

Besides its primary function of producing lamb meat, most SFSs in Spain provide other functions to society, such sustainable management of renewable natural resources (OECD, 2001), preservation and enhancement of biodiversity (Plieninger et al., 2006; Henle et al., 2008), conservation of cultural landscapes (Plieninger

* Corresponding author. Tel.: +34 976713437; fax: +34 976716335.
E-mail addresses: rripoll@aragon.es (R. Ripoll-Bosch), Imke.deBoer@wur.nl (I.J.M. de Boer), abernues@aragon.es (A. Bernués), theun.vellinga@wur.nl (T.V. Vellinga).

0308-521X/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.agsy.2012.11.002

et al., 2006) and contribute to the socio-economic viability of many rural areas (OECD, 2001), especially in marginal or less favored areas (De Rancourt et al., 2006). These other functions of SFSs, considered as cultural ecosystems services (Millennium Ecosystem Assessment, 2005), are generally ignored when comparing emissions of greenhouse gases among systems differing in intensity, which might favor intensive systems. The emission of greenhouse gases of diverse animal production systems can be evaluated using life cycle assessment (LCA) (De Boer, 2003). LCA is a widely accepted and standardized method to evaluate environmental impact during the entire life cycle of a product (ISO, 2006). A carbon footprint is a single-issue LCA, focusing on emissions of greenhouse gases of a product only. The *product* in an LCA not only refers to material products, such as meat or wool, but also to services, such as landscape conservation (Baumann and Tillman, 2004). From the perspective of a carbon footprint, extensive livestock systems relate to low production efficiency, which then delivers high GHGs emissions per functional unit. This highlights the potential conflict between carbon efficiencies and other environmental objectives (Edwards-Jones et al., 2009). Conducting LCA still presents significant challenges, particularly when applied to agriculture. The method places limitations on the comprehensive assessment of complex, interconnected food chain, limited data availability, and multiple-output nature of production (FAO, 2010). Multiple-outputs are not only referring to material products, but also to services or benefits delivered by some farming systems to society, considered as non-commodity outputs (OECD, 2001) or non-marketable public goods (Tscharntke et al., 2005). Farm multiple-output nature is especially true for pasture-based SFSs (Bernués et al., 2011).

Our aim was to explore if accounting for multifunctionality of sheep farming affected the carbon footprint of lamb meat. We quantified the carbon footprint of lamb in three contrasting SFSs in the north-eastern part of Spain, i.e. a pasture-based system, a mixed sheep–cereal system and an industrial (zero-grazing) system, accounting both for the production of meat and for the cultural ecosystem services provided.

2. Material and methods

2.1. Definition of sheep farming systems (SFSs) in study area

We chose a study area in north-eastern Spain, at the catchment basin of the Ebro River, because of its heterogeneous mix of agro-ecological and climatic characteristics that gives rise to a wide variety of sheep farming systems (Barrantes et al., 2009). The north is dominated by the Pyrenees (altitude up to 3400 m above the sea level), the south by the Iberian Range (altitude up to 2000 m above the sea level), whereas in the middle lies the Ebro Basin (altitude around 200 m above the sea level). For each of these three regions, we defined a representative SFS based on intensification level in meat production, using as proxy the type of reproductive management (no. of lambings per ewe per year), land use and grazing management (Ripoll-Bosch et al., 2012). We aimed at gaining an in-depth understanding of the critical factors that affect GHGs emissions in different SFSs, so we opted to use a scenario-based methodology (Basset-Mens and Van der Werf, 2005). The following three contrasting SFSs, typical in the study area (Table 1), were parameterized and their carbon footprint for lamb production was compared.

1. The **pasture-based** system was located in alpine mountains of the Central Pyrenees; a less favored area threatened by land abandonment (Riedel et al., 2007). The reproductive management was low-intensive or traditional, with one lambing per ewe per year. The herd grazed freely, except during lactation when animals were kept in semi-stall conditions. Forage meadows for grazing or hay making were located at the valley bottoms, in scarce arable land. Availability of grazing resources was extremely seasonal, such as summer alpine grasslands, spring and autumn grasslands, shrub and forest pastures and forage crops. The herd was supplemented (conserved forage crops) occasionally in winter, when grazing resources were scarce.
2. The **mixed** sheep–cereal system was located at the mid-altitude Iberian range. It represents a wide spread sheep farming system in Spain and other Mediterranean countries (Caballero, 2001). The reproductive management was mid-intensive, with three lambings per ewe every 2 years. The herd grazed daily with a shepherd, and was kept indoors at night and during lactation. Considerable arable land was used, mainly for winter cereals in non-irrigated lands. Annual fallows and summer stubbles of winter cereals were typical resources available for grazing; as well as common semi-arid grassland and shrub pastures, such as xerophilous grasslands, rosemary shrub-lands and little Mediterranean broom shrub-lands. Cereal grains and/or concentrates derived from winter cereals were usually used as feed.
3. The industrial system or **zero-grazing** was located at low altitude semi-arid conditions in the Ebro Basin; associated to the more easy-to-work, plain arable lands (De Rancourt et al., 2006) and close to agro-industry and by-products supply. The reproductive management was high-intensive, with five lambings per ewe every 3 years. The herd was kept indoors all year round and fed with total mixed ration. Major extension of arable land for winter cereals, forage crops and maize cultivation was in irrigated lands. Conserved forage crops and by-products from the agro-industry were frequently used in rations

2.2. Carbon footprint assessment

2.2.1. Definition of system boundary

We computed a "cradle-to-farm-gate" carbon footprint of lamb, which implies that emissions of greenhouse gases were assessed for all processes involved up to when lambs leave the farm (see Fig. 1). Post-farm gate processes were assumed equal for each SFS, and, therefore, excluded from the analysis. Production processes of medicines, machinery and buildings were excluded from the analysis (Cederberg and Mattsson, 2000; De Boer, 2003). This carbon footprint assessment followed the attributional approach, which implies estimating the environmental impact of an existing situation, under current production and market conditions (Thomassen et al., 2008).

2.2.2. Functional unit (FU)

An LCA relates the environmental impact to a functional unit (FU), which is the main function of a production system expressed in quantitative terms. Environmental impacts on a global scale, such as emissions of GHGs, are generally related to a product-based FU (Haas et al., 2000). The functional unit, therefore, was one kg of lamb live weight, leaving the farm-gate. To be able to compare our results with values from the literature, we also computed the carbon footprint per kg of lamb meat, assuming an average live weight at farm-gate of 22 kg and an average dressing percentage of 50% (i.e. average value for Spanish conditions) (Carrasco et al., 2009).

2.2.3. Model description

A model was used to capture the most important interactions in complex SFSs, to compute data required to determine for GHGs

Table 1
Details about the region, farm structure, herd structure and inputs.

Location	Pasture-based	Mixed	Zero-grazing
	Pyrenees	Plateaus, pre-Pyrenees and Iberian range	Ebro basin
Region			
Mean annual temperature	9.7 °C	13.6 °C	15.0 °C
Mean annual precipitation	1051 mm	535 mm	318 mm
Vegetation	Alpine pastures, mid-valley grasslands, shrub-land and open forest pastures	Common semi-arid grassland and shrub pastures, such as xerophilous grasslands	Shrub-lands characterized by halophilus and gypsophilus vegetation
Less favoured area[a]	The main reason, for being mountainous	The main reason, because of depopulation	Partly; the main reason being depopulation
Farm structure			
Total on-farm land use (ha)	110	190	9[b]
Arable crop land (ha)	–	80	9
Arable forage land (ha)	–	10	–
Pastures and meadows (ha)	10	–	–
Woodland and shrub (ha)	100	100	–
Communal off-farm land (ha)	750	500	–
Woodland and shrub (ha)	250	500	–
Alpine pastures (ha)	600	–	–
Herd details			
Breed	Churra Tensina	Rasa Aragonesa	Salz
Average number of ewes	350	550	1200
Reproductive management	1 Lambing:1 year	3 Lambing:2 years	5 Lambing:3 years
Number of lambs sold per year	296	631	2759
Lambing frequency	0.90	1.10	1.45
Litter size	1.22	1.30	1.92
Average lamb live weight of lamb sold (kg)	22	22	22
Grazing time (% time spent annually)	90	25	0
INPUTS			
Energy use			
Diesel used (l)	565	3150	9850
Electricity (kW/h)	–	–	738
Fertilizers (kg/year)			
Nitrogen	–	920	2700
Phosphorous	–	788	2250
Organic nitrogen	360	–	–
Pesticides			
Pesticide (kg/ha)	–	–	1

[a] Less favoured areas are farming areas presenting handicaps for production and/or environment (Council regulation (EC) No. 1257/1999).
[b] Irrigated arable land.

emissions, and to quantify actual GHGs emissions. The model is based on the LCA model used by FAO (2010) to calculate global GHGs emissions of livestock production systems, and was adapted to sheep husbandry and particularities of the SFSs studied. Four interrelated modules were distinguished. Module I described the herd structure and its technical performance, based on the fertility rate, replacement rate, mortality rates, growth rates and animal specific production parameters. The herd size was assumed constant.

Module II calculated the emissions related to feed production, based on the input of the animal's diet composition. Cultivation and processing emissions of all feed resources, such as fresh and conserved grass, forages, (co-)products, crop residues and compound feeds, are included. Diet composition is input to this module. Emission factors regarding crop production was obtained from life cycle inventory (LCI) data from Wageningen University (De Boer, pers. communication) and from EcoInvent (EcoInvent, 2009).

Module III determined the feed intake of the herd, based on the herd structure of module I, their energy requirements based on the Tier 2 approach of IPCC (2006), and diet composition and feed characteristics of module II (e.g. dry matter content, digestibility and nitrogen content). Feed characteristics were mainly obtained from Spanish Foundation for Animal Nutrition Development (*Fundación Española para el Desarrollo de la Nutrición Animal*, FEDNA, 2010), feedstuff database) and characteristics of natural resources grazed were obtained from Spanish Society for the Study of Pastures (*Sociedad Española para el Estudio de los Pastos*, SEEP, 2010). The quantity of nitrogen (N) excreted via manure was derived from the difference between N intake via feed and N retained by the animal for production purposes. Nitrous oxide emissions from manure were estimated given the N content in manure and type of storage used, including direct deposition from grazing. The time spent grazing is input to this module. Methane emissions of manure storage have been derived by calculating volatile solids and the type of storage, including deposition in pastures. All emissions related to feeding (methane from enteric fermentation), to fertilization of feed crops, to manure excretion during grazing, and to storage of manure (methane and nitrous oxide) are calculated, based on IPCC (2006).

Finally, module IV calculated the total GHGs emissions of the system integrating the other modules. Emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are summed into CO_2 equivalents (CO_2-eq) based on the following factors: 1 for 1 kg of CO_2, 25 for 1 kg of CH_4 and 298 for 1 kg of N_2O, assuming a 100-years time horizon (IPCC, 2007).

2.2.4. Data inventory

Data on farm structure and general management (e.g. farm size, herd size, land use, animal feeding, grazing calendar and management, cropping activities and main inputs), were obtained from representative farms of a group of 42 farms surveyed in 2008.

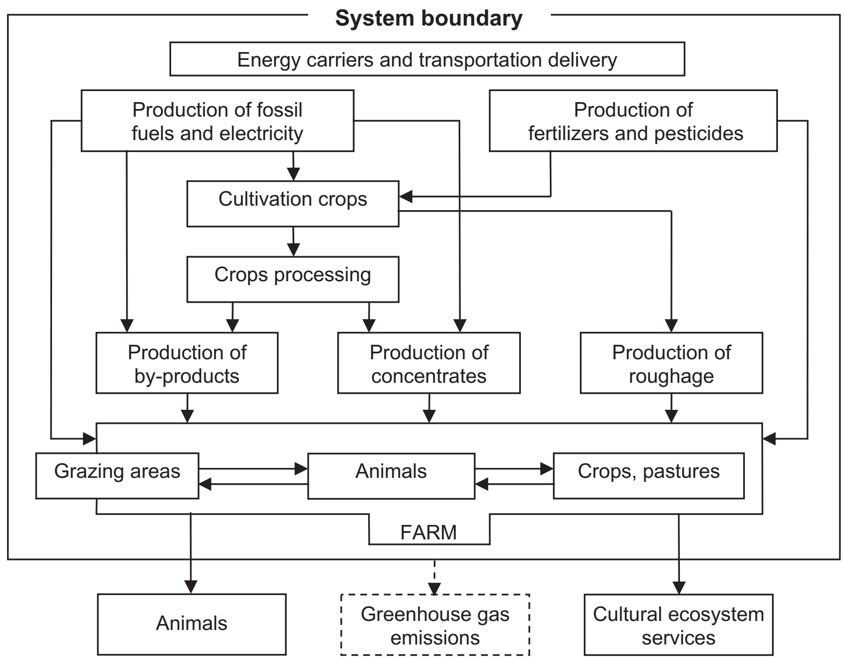

Fig. 1. Schematic representation of system boundary (i.e. stages of the life cycle included in our carbon footprint assessment), the outputs considered (animals and cultural ecosystem services) and the impact assessed (broken line).

Additional technical data (e.g. lambing rate, lamb mortality, animal prolificacy, slaughtering lamb weight, crop yields) were based on site-specific technical reports and publications. No information on soil type was available, and, therefore, all soils were assumed to be mineral soils.

The annual diet of the sheep was defined as a share (in percentage) of different feed ingredients from both on- and off-farm, for adult animals and for lambs (Table 2). The total contribution of grazing to the diet resulted from deducting energy supplied by feeds from total energy requirements of the herd. Different resources grazed were included in the diet depending on the time spent in corresponding land types.

Direct deposition of manure and urine on pasture crops by the herd was determined by the average time spent outdoors (i.e. 90% for pasture-based, 25% for mixed and 0% for zero-grazing systems).

To determine emissions related to production and transport of feed ingredients, we derived the composition of concentrates (from feed industry) and the country of origin of its ingredients [from feed industry, from FAOSTAT (2010) and national statistics (MARM, 2009), see Table 3]. Subsequently, we defined the production process of each feed ingredient based on real farm data, including yield, fertilization, and machinery required for field operations, phytosanitary treatments, irrigation, processing, drying and transportation. Some feed ingredients were co-products from crop cultivation (i.e. straw) or food production (i.e. citrus pulp, apple pulp and soybean expeller). In this case, GHGs emissions from crop cultivation were allocated to main and co-products based on relative economic values, a procedure also known as economic allocation (Cederberg and Stadig, 2003). To determine GHGs emissions of apple or citrus pulp, information about Italian citrus production (Beccali et al., 2009) was used as no information was found for Spanish conditions. We accounted for GHGs emission from land use change associated with soybean production only, assuming stable farm plans in different SFSs. These emissions were assumed 7.69 kg CO_2-eq per kg soybean expeller from Brazil and 0.93 kg CO_2-eq per kg soybean expeller from Argentina (FAO, 2010). Detailed information regarding feed production, transport and feed quality is available in electronic Supplementary material.

Energy requirements for blending to produce concentrates were considered (186 MJ per ton dry matter (DM) from electricity and 188 MJ from gas). GHGs emissions associated with on-farm use of machinery for the total mixed ration production (339 MJ per ton DM from fuel) or energy requirement for cleaning sheds (46 MJ/ewe/year from fuel) were estimated based on real farm data.

2.3. Valuation of cultural ecosystem services and allocation of emissions

Besides lamb meat, the SFSs analyzed in this study provide a number of other functions or services to society, such as conservation of biodiversity or the cultural landscape, also referred to as cultural ecosystem services. In this study, we considered these ecosystem services co-products of our SFSs, or in other words, we assumed our SFSs can be multi-functional. In a multiple-output situation, the environmental impact under consideration has to be allocated to the various outputs (Ekvall and Finnveden, 2001). The GHGs emission of the SFS under consideration was allocated to lamb products and cultural ecosystem services based on their relative economic value (i.e. economic allocation) (Cederberg and Stadig, 2003; Guinée et al., 2004).

To perform an economic allocation between the multiple outputs of production, all products must be economically valued. The economic value from lamb production was calculated by multiplying the number of lambs sold with the average price of lamb at farm gate (i.e. 57€/lamb). Economic benefits of wool and meat from culled ewes and rams were excluded, because these outputs represented only 1.2–1.5% of total farm income.

The economic value of cultural ecosystem services was based on Common Agricultural Policy (CAP) agri-environmental payments to farmers. According to Guinée et al. (2004), for missing markets with public provision, prices can be constructed based on costs. The Pillar 2 of the CAP establishes agri-environment measures that

Table 2
Feeding ration in dry matter (%) and origin[a] (on/off).

Animal	Feed type	Pasture-based	Mixed	Zero grazing[b]
Adult	Pastures and meadows (hay)	7% (on)		
	Alfalfa (grazing)		12% (on)	
	Alfalfa (hay)		7.5% (on)	
	Alfalfa (pellets)	7% (off)		18% (off)
	Pastures and meadows (grazing)	17% (on)		–
	Transitional woodland/shrub (grazing)	43% (on)		
	Schlerophyllous vegetation (grazing)		54% (on)	
	Alpine pastures (grazing)	26% (off)		
	Concentrates	–	13% (off)	–
	Grains (barley)	–	6% (on)	–
	Pulps (citrus and apple)	–	–	21% (off)
	Maize silage	–	–	16% (on)
	Rye grass silage			12% (on)
	Straw		7.5% (on)	29% (off)
	Soya hulls	–	–	4% (off)
Lamb	Milk	18%	12%	8%
	Concentrates	74% (off)	80% (off)	84% (off)
	Straw	8% (off)	8% (on)	8% (off)

[a] Feed produced on-farm (on) or off-farm (off).
[b] Use of total mixed ration to feed the herd. Average of different diets served.

Table 3
Concentrates composition (%) used for feeding sheep and lambs and origin of raw products.

Ingredients	Inclusion (%)	Origin
Concentrates for sheep		
Alfalfa (pellets)	32	Spain (100%)
Barley	21	Spain (100%)
Maize	21	Spain (35%); USA (49%); France (16%)
Soybean hulls	21	Brazil (85%); USA (15%)
Soybean meal	5	Argentina (90%); Brazil (10%)
Concentrates for lambs		
Barley	37	Spain (100%)
Maize	30	Spain (35%); USA (49%); France (16%)
Soybean meal	26	Argentina (90%); Brazil (10%)
Wheat	8	Spain (100%)

compensate farmers for their loss of income and costs when undertaking voluntary environmental protection commitments (EEA, 2009). In Spain, agri-environmental measures include payments that generically promote the "extensification" of sheep production, the conservation of the environment and habitats for endangered spices, or compensate for producing in harsh conditions in less favored areas (combination of social and environmental objectives in this case; EEA, 2004). To value the ecosystem services, we considered these measures as a proxy of the cost for undertaking such conservation measures, or the willingness of society to pay for cultural ecosystem services delivered by SFSs.

Since the farm practices are described and farm types geographically located, specific agri-environmental payments could be applied to them (Table 4) following the specifications of the Rural Development Program of Aragon, Spain (*Programa de Desarollo Rural de Aragon)* (PDR, 2009) and subsequent regulations. Only agri-environmental payments related to the sheep farming activity were considered, since the main study tries to assess the cultural ecosystem services provided by SFSs. For the zero-grazing system, no agri-environmental measures applied.

3. Results

The total emission of GHGs per farm per year varied considerably among SFSs, i.e. 184 t CO_2-eq for the pasture-based system, 353 t CO_2-eq for the mixed system and 1201 t CO_2-eq for the zero-grazing system (Table 5). Differences in GHGs emission per farm were caused mainly by differences in herd size (350 ewes for pasture-based; 550 ewes for mixed and 1200 ewes for the zero-grazing system).

Farm income from lamb meat production reached 17.7 k€ for the pasture-based; 36.8 k€ for the mixed and 150.5 k€ for the zero-grazing system. Farm income from agri-environmental subsidies were 15.3 k€ for the pasture-based; 13 k€ for the mixed and 0€ for the zero-grazing system. Hence, when considering both productions, the percentage of the total GHGs emission per farm to be allocated to lamb production was 54% for pasture-based, 74% for mixed and 100% for the zero-grazing system.

Table 5 shows the GHGs emissions per kg of lamb live weight for the three contrasting sheep production systems (in CO_2-eq per kg of lamb live weight) in two situations: (1) all GHGs emissions are allocated to lamb production and (2) GHGs emissions are allocated to both lamb production and cultural ecosystem services. The contribution of each GHGs (CO_2, CH_4 and N_2O) to the total emission is also presented. When GHGs emissions are allocated to lamb production only, GHGs emission per kg of lamb live weight was highest for pasture-based (25.9 kg CO_2-eq), intermediate for mixed (24.0 kg CO_2-eq) and lowest for zero-grazing system (19.5 kg CO_2-eq). Global warming potential (GWP) per kg of lamb followed an opposite trend to intensification process: the higher the intensification of production the lower the CO_2-eq per kg of product. When GHGs emission are allocated to lamb production and cultural ecosystem services, the figure per kg of lamb live weight was lowest for pasture-based system (13.9 kg CO_2-eq), highest for zero-grazing system (19.5 kg CO_2-eq), and intermediate for the mixed system (17.7 kg CO_2-eq). Hence, intensification increased GHGs emissions per kg of lamb.

The contribution of each gas to total GHGs emissions differed among SFSs. Emission of CH_4 contributed around 58–62% to the total emissions (Table 5). The largest share of the GHGs emissions from sheep production in Spain, therefore, is due to emission of CH_4 from enteric fermentation and manure management. The contribution of CO_2 and N_2O emissions differed among systems. Emission of CO_2 varied from 8% for the pasture-based system to 29% in the zero-grazing system, increasing according to the intensification level; whereas emission of N_2O varied from 31% in the pasture-based system to 12% in zero-grazing system, decreasing according to the intensification level.

Table 4
Agri-environmental measures (Common Agricultural Policy of the European Union) suitable for each sheep farming system described.

Land use	Units	Subsidy ID	Objective	Euro/ha	Euros
Pasture-based					
Pastures and Meadows	10 ha	4.3	Maintenance of meadows in mountains for hay and extensive livestock production	109	1090
Transitional woodland/shrub	250 ha	4.2	Maintenance of grazing (extensive production)	36	1872
Natural grassland	600 ha	4.2 (comp.)	Maintenance of grazing in natural grasslands (extensive production)	43	2236
Compensatory indemnify[c]	–	2.1.1	Difficulty of producing in less favored areas (mountainous)	94	3000
Endangered breeds grazing	52.5 LU	4.4	Extensive production with endangered breeds	121	6316
Autochthonous breeds	52.5 LU	RD 1724/2007	Extensive production with autochthonous breeds using natural resources	130	6000
Total subsidies[a]			2.1.1 + 4.4 + RD 1724/2007		15,316
Mixed					
Barley	40 ha	4.1	Maintenance of grazing in stubbles (extensive production)	41	1640
Fallow land	40 ha	1.1[b]	Maintenance of fallow land. To be used for grazing purposes and for flora and fauna protection	60	–
Schlerophyllous vegetation	500 ha	4.2	Maintenance of grazing in natural resources (extensive production)	36	2322
Compensatory indemnify[c]	–	2.1.2	Difficulty of producing in less favored areas (non-mountainous)	57	3000
Autochthonous breeds	82.5 LU	RD 1724/2007	Extensive production with autochthonous breeds using natural resources	100	6000
Total subsidies[a]			4.1 + 4.2 + 2.1.2 + RD 1724/2007		12,962

[a] Total subsidies result as the sum of different applicable agri-environmental measures. When incompatibility among measures arise (measures 4.1 and 4.2 are incompatible with 4.4), then the highest sum was considered.
[b] Measure applicable only in *Natura 2000 Networking Programme* areas. Not considered in this case, due to its specificity.
[c] Compensatory payments (subsidies 2.1.1 and 2.1.2) are a combination of social and environmental objectives and are part of the second pillar of the Common Agricultural Policy of the European Union (EEA, 2004).

Table 5
GHGs emissions (CO_2-eq/kg) with or without ES allocation for lamb live weight or lamb meat and contribution (%) of CO_2, CH_4 and N_2O to total GHGs.

	Without ES allocation		With ES allocation		Contribution		
	kg lamb live weight (CO_2-eq/kg)	kg lamb meat (CO_2-eq/kg)	kg lamb live weight (CO_2-eq/kg)	kg lamb meat (CO_2-eq/kg)	CO_2 (%)	CH_4 (%)	N_2O (%)
Pasture-based	25.9	51.7	13.9	27.7	7.9	61.6	30.5
Mixed	24.0	47.9	17.7	35.4	21.0	57.6	21.4
Zero-grazing	19.5	38.9	19.5	39.0	29.1	59.4	11.5

ES: ecosystem services.

4. Discussion

Under the conditions established in our research and considering meat production only, the pasture-based system emits more GHGs per FU, than the mixed and zero-grazing system. This may be due to the overall lower quality of pasture-based diets (FAO, 2010) and overhead maintenance requirements of the herd, but especially from low reproduction results in the pasture-based system. Relating emissions to production of meat (FU = 1 kg meat) results in relatively high impacts in pasture-based systems because of their intrinsic lower productivity. Animal production in less favored areas is associated to lower breeding efficiency (number of offspring per breeding unit per annum) and daily weight gains, which affect animal productivity (Gill et al., 2010).

The main GHG in lamb meat production is CH_4. In ruminants, CH_4 production depends on animal type and size, and on feed intake and its digestibility. Emission of CH_4 decreases as feed digestibility increases (Beauchemin et al., 2008). Since intensive systems generally rely more on highly digestible concentrates, we expected a decrease in CH_4 emissions with an increase of intensification level (Gerber et al., 2011). However, in our study the fraction of CH_4 emissions in the total GHGs emissions remained steady across systems as diets showed similar digestibility rates across systems, since the zero-grazing systems used by-products instead of concentrates.

Emissions of CO_2 and N_2O depend on the type of system. Emission of CO_2 is related to combustion of fossil fuels and, therefore, increased according to the degree of intensification, as zero-grazing systems have a higher consumption associated to cultivation and transport. Inversely, emissions of N_2O decreased according to the degree of intensification, since deposition of manure directly on pasture is related to high N_2O emissions. A reduction of the fraction nitrous oxide and an increase in the fraction of carbon dioxide due to intensification is also seen by Gerber et al. (2011).

Direct comparisons between LCA studies are difficult due to potentially large methodological differences such as the allocation method, the functional unit chosen or the system boundaries adopted (De Vries and De Boer, 2010; Edwards-Jones et al., 2009). Few studies on lamb meat production have been performed (Williams et al., 2006; Edwards-Jones et al., 2009; Ledgard et al., 2010), and results differ largely. Besides methodological differences, variability in results also reflects differences in sheep productive systems, in geographical locations and in market conditions. Williams et al. (2006) attributed, for example, 17.5 CO_2-eq per kg of conventional lamb meat and 10.1 CO_2-eq per kg organic lamb meat produced in the UK. Compared to our study (i.e. 38.9–51.7 CO_2-eq per kg lamb meat, Table 5), the low values of Williams et al. (2006) can be explained by higher per-hectare production of pasture, a relatively better feed quality (higher digestibility), and higher slaughtering weights (26–36 kg in UK vs. 22 kg in Spain).

Considering a similar system boundary, Edwards-Jones et al. (2009) reported GHGs values from two case-study farms of 8.1 and 143.5 kg CO_2-eq per kg of lamb live weight in the UK (compared to 19.5–25.9 CO_2-eq per kg of lamb live weight in our study, Table 5). The high CO_2-eq values per kg of lamb weight resulted from the fact that one of the farms was located on organic soils. In New Zealand, Ledgard et al. (2011) found CO_2-eq per kg of lamb live weight between 8 and 10 (compared to 19.5–25.9 CO_2-eq per kg of lamb live weight in our study, Table 5). These low CO2-eq values resulted from greater wool production per ewe and the fact that wool is economically more important in New Zealand compared with European countries.

The GHGs emissions of other livestock products were reviewed by De Vries and De Boer (2010). Differences in environmental impact of pork, chicken and beef production were explained mainly by three factors: differences in feed efficiency, differences in enteric CH_4 emission between monogastric animals and ruminants, and differences in reproduction rates. One kg of beef resulted in the highest emissions, within 14–32 kg CO_2-eq per kg. Beef is produced in a wide range of production systems and the highest value represents a pure suckler-system. Lamb meat production could be compared to this system as they are more similar. However, lamb meat results in slightly higher emissions (from 39 up to 52 kg CO_2-eq). Lower quality of the diet and the related growth rate of the animals could explain the higher emission intensities.

Higher emissions associated with meat from ruminant livestock than monogastrics are described in some studies (Williams et al., 2006; De Vries and De Boer, 2010). However, it is worth considering the type of animal feed, as most diets for monogastrics are human-edible, whilst diets of pasture-based ruminant production are not (Gill et al., 2010; Wilkinson, 2011). Sheep have the ability to valorize "natural and renewable resources" that do not compete with human nutrition and cannot be used for alternative purposes into human-edible products. Although monogastrics are more efficient in terms of total food resource use, accounting for the proportions of human-edible and inedible feeds would render a more realistic estimate of efficiency to compare between systems (Wilkinson, 2011).

Despite the well-known negative environmental impacts, some agricultural systems have also positive effects (OECD, 2011; Tscharntke et al., 2005). Pasture-based livestock farming systems produce positive externalities or public goods, defined as regulating and cultural ecosystem services (Millennium Ecosystem Assessment, 2005) or generically environmental services, since they can play a major role in landscape conservation (Plieninger et al., 2006; Casasús et al., 2007), biodiversity enhancement (Henle et al., 2008; Benton et al., 2003) or wildfire prevention in Mediterranean regions (Kramer et al., 2003), among others. In Europe, intensification of agricultural systems in favored areas and abandonment of High Nature Value (HNV) farmland (EEA, 2005) are reported as the two main causes of changes observed in agricultural landscapes and conflicts between agriculture and biodiversity conservation (EEA, 2010; Henle et al., 2008; Piorr, 2003). However, these public services do not have a market price (Swinton et al., 2007), are difficult to disaggregate, are highly interrelated in complex dynamic ways (Bennett et al., 2009), and therefore are difficult to measure. As a result, they are often ignored in environmental evaluation or animal agriculture. LCA and other evaluation methodologies show shortcomings when trying to integrate land use and biodiversity dimensions mainly due to the inherent spatial and temporal heterogeneity (Neumann et al., 2011).

Costanza et al. (1997) stated that if cultural ecosystem services were actually paid for, in terms of their contribution to the global economy, the global price system would be very different from what it is today and the price of commodities would be higher. Payment for cultural ecosystem services have attracted increasing interest as a mechanism to translate external, non-market values of the environment into real financial incentives to provide ecosystem services (Farley and Costanza, 2010; Engel et al., 2008; Wunder et al., 2008; Pagiola et al., 2007). Agri-environmental policies are examples of payments for ecosystem services that pay farmers to deliver positive public goods (Baylis et al., 2008) based on the requirement to compensate the possible loss of income resulting from undertaking such measures (EU, 2005).

In our study, the cultural ecosystem services delivered by each SFS were valued based on the CAP agri-environmental scheme. Afterwards, an economic allocation was performed to distinguish GHGs emissions between meat and cultural ecosystem services. When correcting emissions for multifunctionality, GHGs emissions per kg of lamb meat increased according to the degree of intensification, i.e. lowest for pasture-based, intermediate for mixed and highest for zero-grazing systems.

The approach we have followed has a number of limitations. First, pasture-based animal production systems are complex, with numerous and interrelated factors affecting their sustainability (Bernués et al., 2011; Ripoll-Bosch et al., 2012). Assessing the environmental impact of these systems following a holistic framework, therefore, is challenging. The aim of this study was to perform a single-impact analysis (carbon footprint) considering the multifunctional nature of certain systems of production, rather than to assess the environmental impact of sheep production. For this purpose, we considered the cultural ecosystem services provided as co-products. This relies on the fact that some sheep farming systems in Spain, beyond their primary function of producing animal products, also provide other services or public goods, such as landscape conservation, cultural heritage, preservation of biodiversity, or fire prevention. Management practices in sheep farming systems providing these services differ from those focusing on production of animal products only. Consistently, in LCA, the concept *product* refers to material products but also to services or public goods (Baumann and Tillman, 2004). This implies that the provision of cultural ecosystem services do not only have an economic cost (EU subsidies), but also a cost in terms of GHGs emissions.

Second, systems heterogeneity makes characterization particularly difficult and sensitive, and as a result, the parameterization of the system (e.g. the inventory flows) and the methodological choices will determine the final result of an LCA. Besides, in contrast to industrialized production systems, data availability and quality is normally a constraint in low-input/pasture-based production systems and, therefore, LCA results will partly depend on assumptions.

Third, economic allocation in our study is based on political decisions and the loss of agricultural production (EU, 2005) rather than on empiric observations for valuing cultural ecosystem services. By following this approach, variability among regions and countries could mostly rely on arbitrary-political decisions rather than the production process itself.

Finally, this approach cannot distinguish between the different cultural ecosystem services as they are often interconnected and operate at various spatial and temporal scales. Consequently, it is not able to elucidate the impact of changing agricultural practices on the cultural ecosystem services delivered and their trade-offs.

5. Conclusions

Sheep farming systems are diverse and complex and the evaluation of their environmental impacts from a life cycle perspective is not straight forward. For GHGs, when allocated to lamb meat production only, the emissions per kg of product decreased according to the intensification level. However, pasture-based livestock systems also provide other functions to society (e.g. biodiversity and landscape conservation), and when accounting for these functions, GHGs emissions per kg of product increased according to the degree of intensification. The strong links between pasture-based livestock production and the provision of diverse ecosystems services, especially in mountain and other marginal areas, need to be considered and integrated into a standard evaluation framework for environmental impacts of agricultural production, such as LCA.

Acknowledgements

Research funded by projects INIA-RTA2006-00170, INIA-PET2007-06-C03-01 and RTA2011-00133 of the Spanish Ministry of Science and Innovation, Government of Aragón and FEDER. The first author acknowledges the pre-doctoral financial support of INIA.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agsy.2012.11.002.

References

Barrantes, O., Ferrer, C., Reiné, R., Broca., A., 2009. Categorization of grazing systems to aid the development of land use policy in Aragon, Spain. Grass Forage Sci. 64 (1), 26–41.
Basset-Mens, C., Van Der Werf, H.M.G., 2005. Scenario-based environmental assessment of farming systems: the case of pig production in France. Agric. Ecosyst. Environ. 105 (1–2), 127–144.
Baumann, H., Tillman, A., 2004. The Hitch Hiker's Guide to LCA: An Orientation in Life Cycle Assessment Methodology and Application. Studentlitteratur, Lund, Sweden.
Baylis, K., Peplow, S., Rausser, G., Simon, L., 2008. Agri-environmental policies in the EU and United States: a comparison. Ecol. Econ. 65 (4), 753–764.
Beauchemin, K.A., Kreuzer, M., O'Mara, F., McAllister, T.A., 2008. Nutritional management for enteric methane abatement: a review. Aust. J. Exp. Agric. 48, 21–27.
Beccali, M., Cellura, M., Iudicello, M., Mistretta, M., 2009. Resource consumption and environmental impacts of the agrofood sector: life cycle assessment of Italian citrus-based products. Environ. Manage. 43 (4), 707–724.
Bennett, E.M., Peterson, G.D., Gordon, L.J., 2009. Understanding relationships among multiple ecosystem services. Ecol. Lett. 12 (12), 1394–1404.
Benton, T.G., Vickery, J.A., Wilson, J.D., 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol. Evol. 18 (4), 182–188.
Bernués, A., Riedel, J.L., Asensio, M.A., Blanco, M., Sanz, A., Revilla, R., Casasús, I., 2005. An integrated approach to studying the role of grazing livestock systems in the conservation of rangelands in a protected natural park (Sierra de Guara, Spain). Livest. Prod. Sci. 96, 75–85.
Bernués, A., Ruiz, R., Olaizola, A., Villalba, D., Casasús, I., 2011. Sustainability of pasture-based livestock farming systems in the European Mediterranean context: synergies and trade-offs. Livest. Sci. 139, 44–57.
Caballero, R., 2001. Typology of cereal–sheep farming systems in Castile-la-Mancha (south-central Spain). Agric. Syst. 68 (3), 215–232.
Caballero, R., 2003. A set of guidance for the management of grazing units in the cereal–sheep system of Castile-la-Mancha (south-central Spain). J. Sustain. Agric. 21 (3), 11–28.
Carrasco, S., Ripoll, G., Sanz, A., Álvarez-Rodríguez, J., Panea, B., Revilla, R., Joy, M., 2009. Effect of feeding system on growth and carcass characteristics of Churra Tensina light lambs. Livest. Sci. 121 (1), 56–63.
Casasús, I., Bernués, A., Sanz, A., Villalba, D., Riedel, J.L., Revilla, R., 2007. Vegetation dynamics in Mediterranean forest pastures as affected by beef cattle grazing. Agric. Ecosyst. Environ. 121 (4), 365–370.
Cederberg, C., Mattsson, B., 2000. Life cycle assessment of milk production - a comparison of conventional and organic farming. J. Clean. Prod. 8 (1), 49–60.
Cederberg, C., Stadig, M., 2003. System expansion and allocation in life cycle assessment of milk and beef production. Int. J. Life Cycle Assess. 8 (6), 350–356.
Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Peruelo, J., Raskin, R.G., Sutton, P., Van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.
De Boer, I.J.M., 2003. Environmental impact assessment of conventional and organic milk production. Livest. Prod. Sci. 80 (1–2), 69–77.
De Rancourt, M., Fois, N., Lavín, M.P., Tchakérian, E., Vallerand, F., 2006. Mediterranean sheep and goats production: an uncertain future. Small Ruminant Res. 62 (3), 167–179.
De Vries, M., De Boer, I.J.M., 2010. Comparing environmental impacts for livestock products: a review of life cycle assessments. Livest. Sci. 128 (1–3), 1–11.
EcoInvent, 2009. Swiss Centre for Life Cycle Inventories. Version 2.1. <http://www.ecoinvent.org>.
Edwards-Jones, G., Plassmann, K., Harris, I.M., 2009. Carbon footprinting of lamb and beef production systems: insights from an empirical analysis of farms in Wales, UK. J. Agric. Sci. 147 (6), 707–719.
EEA, 2004. High Nature Value Farmland: Characteristics, Trends and Policy Challenges. EEA Technical Report 1/2004. European Environment Agency, Copenhagen, p. 31.
EEA, 2005. The European Environment – State and Outlook 2005. European Environment Agency, Copenhagen, p. 580.
EEA, 2009. Distribution and Targeting of the CAP Budget from a Biodiversity Perspective. EEA Technical Report 12/2009. European Environment Agency, Copenhagen, pp. 90.
EEA, 2010. The European Environment – State and Outlook 2010: Synthesis. European Environment Agency, Copenhagen, p. 222.
Ekvall, T., Finnveden, G., 2001. Allocation in ISO 14041 – a critical review. J. Clean. Prod. 9 (3), 197–208.
Engel, S., Pagiola, S., Wunder, S., 2008. Designing payments for environmental services in theory and practice: an overview of the issues. Ecol. Econ. 65 (4), 663–674.
EU, 2005. Council Regulation (EC) 1698/2005 on Support for Rural Development by the European Agricultural Fund for Rural Development (EAFRD).
FAO, 2010. Greenhouse Gas Emissions from the Dairy Sector – A Life Cycle Assessment. Food and Agriculture Organization of the United Nations, Rome, Italy, p. 94.
FAOSTAT, 2010. Food and Agriculture Organization Statistical Database.
Farley, J., Costanza, R., 2010. Payments for ecosystem services: from local to global. Ecol. Econ. 69 (11), 2060–2068.
FEDNA, 2010. Fundación Española para el Desarrollo de la Nutrición Animal. <http://www1.etsia.upm.es/fedna/introtabla.htm> (Last accessed 10.05.11).
Gerber, P., Vellinga, T.V., Opio, C., Steinfeld, H., 2011. Productivity gains and greenhouse gas emissions intensity in dairy systems. Livest. Sci. 139, 100–108.
Gill, M., Smith, P., Wilkinson, J.M., 2010. Mitigating climate change: the role of domestic livestock. Animal 4 (3), 323–333.
Guinée, J.B., Heijungs, R., Huppes, G., 2004. Economic allocation: examples and derived decision tree. Int. J. Life Cycle Assess. 9 (1), 23–33.
Haas, G., Wetterich, F., Geier, U., 2000. Life cycle assessment framework in agriculture on the farm level. Int. J. Life Cycle Assess. 5 (6), 345–348.
Henle, K., Alard, D., Clitherow, J., Cobb, P., Firbank, L., Kull, T., McCracken, D., Moritz, R.F.A., Niemelä, J., Rebane, M., Wascher, D., Watt, A., Young, J., 2008. Identifying and managing the conflicts between agriculture and biodiversity conservation in Europe – a review. Agric. Ecosyst. Environ. 124, 60–71.
IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. National Greenhouse Gas Inventories Programme, IGES, Japan.
IPCC, 2007. Technical summary. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, pp. 19–91.
ISO, 2006. Environmental Management – Life Cycle Assessment: Requirements and Guidelines. International Organization for Standardization (ISO), Geneva.
Kramer, K., Groen, T.A., Van Wieren, S.E., 2003. The interacting effects of ungulates and fire on forest dynamics: an analysis using the model FORSPACE. For. Ecol. Manage. 181 (1–2), 205–222.
Ledgard, S.F., Lieffering, M., McDevitt, J., Boyes, M., Kemp, R., 2010. A greenhouse Gas Footprint Study for Exported New Zealand Lamb. Agresearch, New Zealand, p. 24.
Ledgard, S.F., Lorinque, E., Gac, A., Boyes, M., Le Gall, A. 2011. LCA of sheep meat produced in different farm systems in France and New Zealand. In: Proceedings of the 2nd New Zealand Life Cycle Assessment Conference. LCA: A business compass for sustainable development. http://www.lcaconference.org.nz/sites/default/files/sites/default/files/Proceedings/25%20LCM%20Conf%20NZ%20France%20lamb%202pager%20v2.pdf> (accessed 26.07.12).
MARM, 2009. Anuario de estadística 2008. Ministerio de Medio Ambiente y Medio Rural y Marino. Madrid, España, p. 1150.
Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-Being. Island Press, Washington, DC.
Neumann, K., Verburg, P.H., Elbersen, B., Stehfest, E., Woltjer, G.B., 2011. Multi-scale scenarios of spatial–temporal dynamics in the European livestock sector. Agric. Ecosyst. Environ. 140, 88–101.
OECD, 2001. Multifunctionality: Towards an Analytical Framework. Organisation for Economic Co-operation and Development, Paris, France.
Pagiola, S., Ramírez, E., Gobbi, J., de Haan, C., Ibrahim, M., Murgueitio, E., Ruiz, J.P., 2007. Paying for the environmental services of silvopastoral practices in Nicaragua. Ecol. Econ. 64 (2), 374–385.
PDR, 2009. Programa de desarrollo rural de Aragón 2007–2013, España, Comunidad Autónoma de Aragón, p. 404.
Piorr, H., 2003. Environmental policy, agri-environmental indicators and landscape indicators. Agric. Ecosyst. Environ. 98 (1–3), 17–33.
Plieninger, T., Höchtl, F., Spek, T., 2006. Traditional land-use and nature conservation in European rural landscapes. Environ. Sci. Policy 9 (4), 317–321.
Riedel, J.L., Casasús, I., Bernués, A., 2007. Sheep farming intensification and utilization of natural resources in a Mediterranean pastoral agro-ecosystem. Livest. Sci. 111 (1–2), 153–163.
Ripoll-Bosch, R., Díez-Unquera, B., Ruiz, R., Villalba, D., Molina, E., Joy, M., Olaizola, A., Bernués, A., 2012. An integrated sustainability assessment of Mediterranean sheep farms with different degrees of intensification. Agric. Syst. 105, 46–56.
SEEP, 2010. Sociedad Española para el Estudio de los Pastos. Database "Spanish Pastures (SEEP)". <http://www.uco.es/sia/en/paginas.php?pagina=bancos> (last accessed 10.05.11).

Steinfeld, H., Gerber, P., 2010. Livestock production and the global environment: consume less or produce better? PNAS 107 (43), 18237–18238.
Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., Haan, C.d., 2006. Livestock's Long Shadow: Environmental Issues and Options. Food and Agriculture Organization of the United Nations. Rome, Italy, p. 390.
Swinton, S.M., Lupi, F., Robertson, G.P., Hamilton, S.K., 2007. Ecosystem services and agriculture: cultivating agricultural ecosystems for diverse benefits. Ecol. Econ. 64 (2), 245–252.
Thomassen, M.A., van Calker, K.J., Smits, M.C.J., Iepema, G.L., de Boer, I.J.M., 2008. Life cycle assessment of conventional and organic milk production in the Netherlands. Agric. Syst. 96 (1–3), 95–107.
Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C., 2005. Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. Ecol. Lett. 8 (8), 857–874.
Wilkinson, J.M., 2011. Re-defining efficiency of feed use by livestock. Animal 5 (7), 1014–1022.
Williams, A.G., Audsley, E., Sandars, D.L., 2006. Determining the Environmental Burdens and Resource Use in the Production of Agricultural and Horticultural Commodities. Main Report. Defra Research Project IS0205. Bedford, UK, p. 97.
Wunder, S., Engel, S., Pagiola, S., 2008. Taking stock: a comparative analysis of payments for environmental services programs in developed and developing countries. Ecol. Econ. 65 (4), 834–852.