Evaluating ecosystem services and disservices of livestock agroecosystems for targeted policy design and management

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Abstract

We present a critical analysis of the positive and negative impacts of pasture-based livestock systems on the environment. We use the case of sheep and mixed sheep-crops systems in Mediterranean Spain to illustrate our arguments and results. In the first part of the paper, we enumerate some limitations in the use of the ecosystem services concept when applied to agriculture in general and grassland ecosystems in particular. Next, we present an expert-knowledge assessment of the relationships between agricultural practices and a number of relevant ecosystem services identified in previous research. We introduce a Payment for Ecosystem Services (PES) system based on these relationships that can be applied at the farm level and can accommodate different policy targets. In the second part of the paper, we critically discuss the use of live cycle analysis in grassland-based livestock systems to evaluate ecosystem disservices, using as example the carbon footprint of lamb meat. We briefly discuss the limitations regarding the functional unit, the system boundary, the allocation approach, the availability of data, the consideration of carbon dynamics in soils, the land use management, and other sustainability factors.

Keywords: agricultural practices, expert-knowledge, payments for ecosystem services, carbon footprint, life cycle assessment

Introduction

The conceptual framework of ecosystem services (ES) is now well stablished in the scientific literature. However, there is still little evidence of its utility in environmental policy design, and it is uncertain that the ES framework will change decision-making and improve policy outcomes (Van Wensem *et al.*, 2017). When applied to agroecosystems, some limitations in the usability of the ES concept remain. First, the concept is not assimilated by society at large and farmers in particular, and there is lack of understanding of the different perspectives held by diverse stakeholders (Bernués *et al.*, 2016). Second, most non-provisioning ES constitute public goods, which are very difficult to measure and value, and therefore their incorporation in agri-environmental policies is difficult. As public goods do not have a market price, farmers have little or no economic incentive to produce them and public intervention is required to achieve a desirable level of provision according to societal demands (Cooper *et al.*, 2009). Third, analysing the multiple contributions of ES to human well-being requires diverse perspectives, combining biophysical, socio-cultural and economic tools to uncover different values (Rodríguez-Ortega *et al.*, 2014). Fourth, there are multiple trade-offs between ES at different spatial and temporal scales, typically between provisioning and non-provisioning ES that are widely described in the literature (e.g. Sabatier *et al.* (2014)). Synergies also exist (Bernués *et al.*, 2011) that could be promoted through adequate farming practices that can constitute action levers to maintain a diverse range of ES, benefiting different stakeholders (Rodríguez-Ortega *et al.*, 2014). However, the processes by which specific agricultural practices and management regimes affect ES (and other sustainability issues) need further investigation.

Compared to industrial agriculture, pasture-based livestock systems are associated with a wide range of ES. Nevertheless, they can also produce ecosystem disservices (EDS) or negative externalities. The positive or negative environmental outcomes will finally depend on the use of on-farm and off-farm resources, the degree of intensification, the species and the orientation of production, among others (Bernués *et al.*, 2011). The EDS most widely discussed nowadays is the emission of greenhouse gases (GHG) to the atmosphere. Many studies quantifying the carbon footprint of animal products advocate an intensification of animal production to mitigate the emission of GHG (Steinfeld and Gerber, 2010), moving away from beef and sheep/goat meat to pork and poultry; and from rustic, traditional animals to specialized, highly productive ones. The main rationale behind this proposal is the so-called 'efficiency gain'; i.e. more output with less input, and therefore less environmental impact per kg of product. Life cycle analysis (LCA) is the standard method to measure the carbon footprint of a product. However, its application to animal agriculture has a number of shortcomings.

In the first part of the paper, we present an expert-knowledge assessment of the multiple relationships between agricultural practices and a number of ES, and we introduce a Payment for Ecosystem Services (PES) system based on these relationships that can be applied at the farm level. In the second part of the paper we critically discuss the use of LCA analysis in grassland-based livestock systems using as example the carbon footprint of lamb meat. We will use the case of sheep and mixed sheep-crops systems in the Mediterranean to illustrate the results. Previous work on these systems has allowed to: (1) unravel the perceptions of farmers and nonfarmers about agricultural practices and related ES (Bernués *et al.*, 2016); (2) rank the main ES delivered by livestock agroecosystems according to socio-cultural preferences and elucidate their economic value (Bernués *et al.*, 2014); and (3) calculate the carbon footprint of lamb meat in contrasting farming systems (Ripoll-Bosch *et al.*, 2013).

Linking agricultural practices and ecosystem services for targeted policy design

In agri-environmental policy, it is crucial to recognize the delivery of ES by farmers and compensate them in economic terms, according to the demands of society, following the principle of 'public money for public goods'. Economic incentives can trigger the adaptation of farm management regimes or specific agricultural practices towards the delivery of ES. A system of Payments for Ecosystem Services (PES) can be defined as a voluntary transaction where one or more well-defined ES (or land uses that secure them) are bought by a buyer from a provider, if and only if the ES provider secures its provision (conditionality) (Wunder, 2005). According to this definition, payment mode can be oriented in two ways: by the ES outcome (target-oriented) or by the land management (practice-oriented) that secures the provision of the ES (see Reed *et al.* (2014) for advantages and disadvantages of both systems). Effectiveness of practice-oriented PES is questioned, as the link between land management and ES can be weak and might be based on assumptions that are not always backed up by scientific evidence. Therefore, designing a PES system requires elucidation of the biophysical effects of particular farming practices on the ES at the farm scale, where farmer decisions take place.

In this context, we developed a consistent and flexible PES framework for implementation of agri-environmental measures at the farm level. First, we quantified, based on expert-knowledge, the contribution of farming practices to the most relevant ES (as previously identified by Bernués *et al.,* 2014, 2016) in Mediterranean agroecosystems. Second, we applied this framework to policy scenarios targeting the actual demand of society, the conservation of biodiversity or the sequestration of carbon.

Contribution of farming practices to ecosystem services

We carried out an expert consultation with an on-line Delphi panel. The Delphi method consists of an iterative consultation process of many 'informed' individuals in different disciplines or specialties to contribute, with information or judgements, until a certain degree of judgement convergence is attained (Scolozzi *et al.*, 2012). We asked respondents to value the contribution of a number of farming practices (see below) on five ES in Mediterranean agroecosystems: the maintenance of agricultural landscapes, the conservation of biodiversity, the prevention of forest wildfires, the regulation of climate change through carbon sequestration, and the production of quality products linked to the territory (Bernués *et al.*, 2014).

From the list of 66 farming practices with potential to deliver public goods in Europe (Cooper *et al.*, 2009), we selected 36 that are currently implemented on real sheep and mixed sheep-crops farms in Mediterranean mountains and semiarid lowlands in Aragón, Spain (see Rodríguez-Ortega *et al.* (2017) for description of farming systems and monitoring). Respondents had to rate the (positive) contribution of each farming practice to the five ES separately according to a six-point Likert type scale (0: none, 1: very low, 2: low, 3: intermediate, 4: high, 5: very high contribution). We included the 'don't know' option.

The experts were chosen covering different types of knowledge and backgrounds: (1) researchers on agriculture-environment relationships (n=29) and (2) technicians/managers from the government and Non-Governmental Organizations related to agriculture and environmental conservation, as well as from agricultural associations, local agribusiness and cooperatives in the area of study (n=32). The survey implied two anonymous rounds of deliberation, with feedback information in the second round in search of the highest degree of consensus among experts.

Due to limitation of space, we graphically present the results obtained for two ES: biodiversity and prevention of forest fires (Figure 1). We performed a Kruskal-Wallis test to check for significant differences between experts in their evaluation of practices contribution to ES. Differences were very few (not presented here), so we present the two expert categories together. Figure 1 shows the ranking of importance of the top-ten farming practices for the selected ES. For example, for conservation of biodiversity the five most important farming practices were: reducing pesticides, maintaining semi-natural vegetation, applying adequate stocking rates, maintaining hedgerows, shrubs and trees, and maintaining grasslands. For prevention of forest fires, the five most important farming practices were: practicing silviculture, grazing remote or abandoned areas, grazing semi-natural areas, maintaining drove

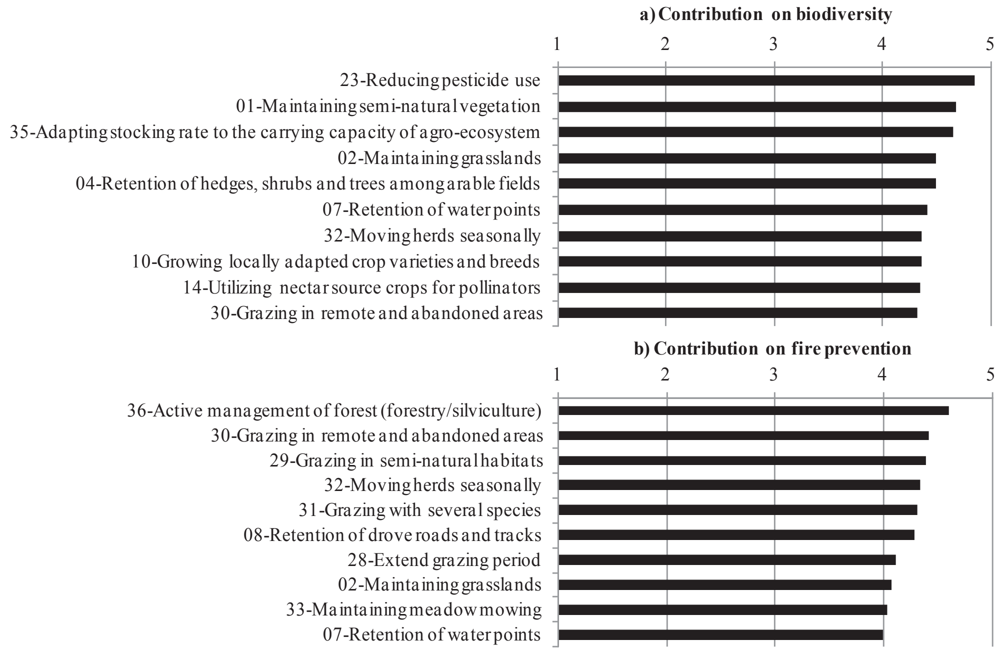

Figure 1. Contribution of top-ten farming practices to biodiversity and prevention of forest fires.

roads and paths, and extending grazing periods. Globally, the top five most important practices for the five ES considered together were: moving herds seasonally, maintaining grasslands, active management of forest (forestry/silviculture), grazing in semi-natural habitats and maintaining semi-natural vegetation. This highlights that despite single ES were highly influenced by multiple practices, synergies among these practices are common, delivering ES in bundles. In this sense, we observed that some ES such as conservation of agricultural landscape and biodiversity shared more synergies among farming practices, while other ES such as prevention of forest wildfires and production of quality products linked to the territory were influenced through more specific practices.

We grouped the 36 practices according to their nature in four categories: vegetation and other landscape elements, crops and species, use of inputs, and grazing and silviculture. We can observe the type of farming practices that are more important for the five ES under consideration (Figure 2). For preservation of the agricultural landscape, the most relevant practices referred to crops and species, followed by vegetation and other elements and grazing and silviculture. The same groups of practices also contributed the most to conservation of biodiversity. For the prevention of forest fires, the most important group of practices referred to grazing and silviculture. This group, together with crops and species contributed the most to carbon sequestration. Finally, the use of inputs had the greatest impact on the provision of quality products linked to the territory. Globally, the group with highest contribution to the delivery of ES was grazing and silviculture.

Application of a PES system to agri-environmental policy: an example

Figure 3 shows the designed framework of PES that link agricultural practices at farm level with the provision of ES as prioritized by society, the relationship among them being established according to the expert knowledge or empirical research. Policy makers can reward farmers according to the objective contribution of their practices on targeted ES, i.e. conservation priorities of a particular territory. The contribution of particular farming practices to each of the ES in Mediterranean agroecosystems is defined by the Delphi evaluation. Other variables can be customized (number of practices to include and relative importance of ES), making the framework generic and flexible. The PES system is implemented in Excel and it is fully operative.

The framework renders a different ranking of all farming practices according to their contribution to policy targets. We present the top-five (and last) agricultural practices in Table 1. For example, when policy targets correspond to the willingness-to-pay of society for ES provision in Spanish Mediterranean agroecosystems (i.e. landscape 8.2% of importance, biodiversity 18.4%, wildfires 53.2% and quality products 20.2%), as described in Bernués *et al.* (2014), the ranking of farming practices was as follows: 1st moving flocks seasonally between areas; 2nd grazing semi-natural habitats; 3rd active management of forest; 4th maintain herbaceous pastures; and 5th increase the grazing season. Globally, the groups of practices referring to grazing and silviculture (with a total contribution of 41.8%) and vegetation and

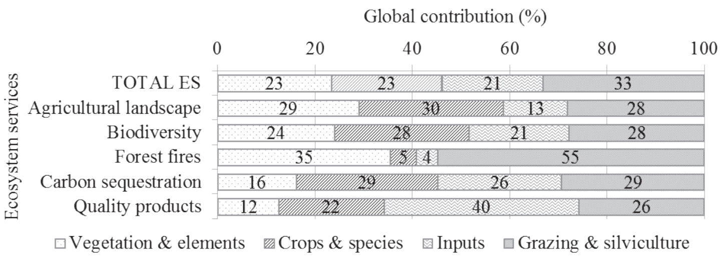

Figure 2. Contribution of groups of farming practices to ecosystem services (ES).

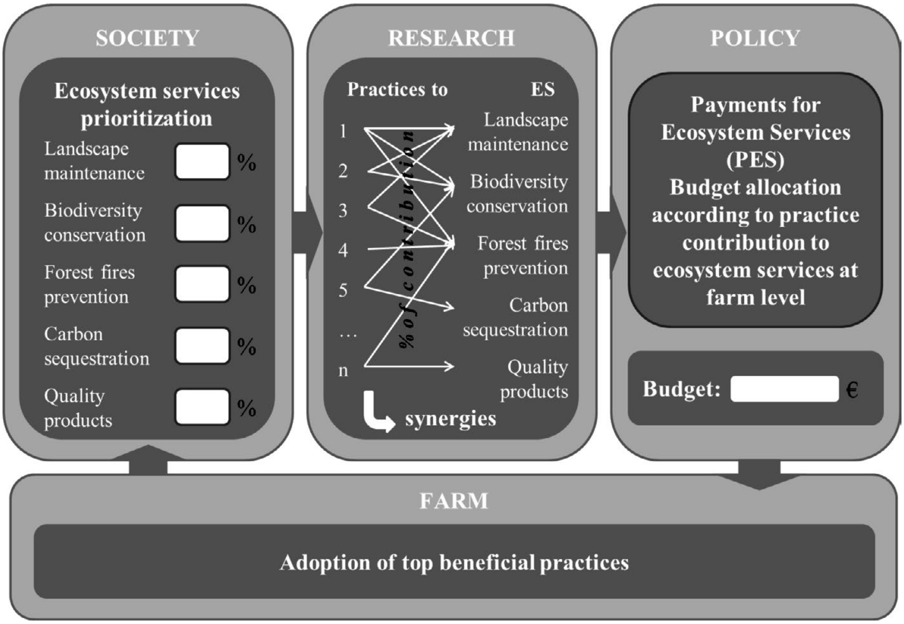

Figure 3. Framework of payments for ecosystem services.

Table 1. Ranking of top-five and last farming practices and contribution (%) to policy settings.

Rank	Willingness to pay for ES[1]		Biodiversity		Carbon sequestration	
	Practice	Cont.	Practice	Cont.	Practice	Cont.
1	Moving flocks seasonally	6.18	Reduce pesticide	3.56	Utilize manure correctly	4.92
2	Grazing semi-natural habitat	5.94	Maintaining semi-natural vegetation	3.48	Reduce ploughing	4.56
3	Management of forest	5.92	Adapt stocking rate	3.46	Maintaining semi-natural vegetation	4.44
4	Maintain grasslands	5.73	Maintain grasslands	3.33	Adapt stocking rate	4.32
5	Increase grazing season	5.49	Retention of hedges	3.33	Maintain grasslands	4.32
n	Reduce pesticide use	0.29	Reduce use concentrates	1.29	Maintain terraces	3.11

[1] Agricultural landscape 8.2% of importance, biodiversity 18.4%, wildfires 53.2% and quality products 20.2%. ES = ecosystem services.

other elements (28.2%) had the highest contribution due to their importance for wildfire prevention, which was highly prioritized by society.

If the focus of the policy was on biodiversity only, the ranking of farming practices was as follows: 1st reduce pesticide use; 2nd maintain semi-natural vegetation (trees and bushes); 3rd adapting stocking rate to the carrying capacity of agroecosystem; 4th maintaining grasslands; and 5th retention of hedges, shrubs and trees among arable fields. Globally, the groups of practices referring to grazing and silviculture (with a total contribution of 27.8%) and crops and species (27.7%) had the highest contribution.

If the focus of the policy was on carbon sequestration only, the ranking of farming practices was as follows: 1st utilizing manure correctly; 2nd reduce ploughing/tilling; 3rd maintain semi-natural vegetation (trees and bushes); 4th adapting stocking rate to the carrying capacity of agroecosystem; and 5th maintaining grasslands. Globally, the groups of practices referring to grazing and silviculture (with a total contribution of 29.3%) and crops and species (28.9%) had the highest contribution.

The framework renders a different prioritization of practices according to policy objectives. It also allows visualizing what practices are synergic, i.e. contribute to several objectives. The final user can decide how many practices to include in the agri-environmental scheme, and then allocate the available resources to farms implementing these practices. Nevertheless, the PES system would also require technical support to farmers and monitoring, in order to ensure the correct implementation of the agricultural practices. This monitoring could modulate the amount of money according to the efficacy of the management practice.

Shortcomings of LCA in grassland ecosystems: the carbon footprint of lamb meat

Life cycle assessment (LCA) has emerged as a widely accepted and standardized method to evaluate the environmental impacts during the entire life cycle of a product or service. LCA is a powerful method to provide a holistic assessment of the production processes, in terms of resource use and environmental impacts, as well as identification of hotspots (Cederberg and Mattsson, 2000; Thomassen and De Boer, 2005). However, LCA still presents significant challenges, particularly when applied to agriculture. The method presents limitations with: the comprehensive assessment of complex interconnected food chains, the production systems that have limited availability of data, and the multiple-output nature of many agricultural production systems (Gerber *et al.*, 2010). This is especially the case of grassland-based livestock farming systems (Ripoll-Bosch *et al.*, 2013), which in Europe are often located on High Value Nature (HVN) farmland and, aside from food supply, are acknowledged for providing multiple ecosystem services, such as enhancing biodiversity (Henle *et al.*, 2008), conserving cultural landscapes (Plieninger *et al.*, 2006) or preventing wildfires (Kramer *et al.*, 2003).

In an attempt to account for ecosystem services in LCA, we analysed three contrasting sheep farming systems in the Mediterranean (see Ripoll-Bosch *et al.,* 2013). Sheep farming systems in the Mediterranean are generally located in less favoured areas and considered to be pasture-based and extensive. However, a process of intensification has occurred across regions and production systems (De Rancourt *et al.*, 2006). As a result, sheep farming systems are very diverse in terms of use of inputs and land use intensity: from zero-grazing to very extensive pastoral systems. We hypothesized therefore that sheep farming systems would differ in performance (i.e. productivity), environmental impact (in this case, greenhouse gas – GHG – emissions) and in the delivery of ES or public goods (aside from meat production). We selected three farming systems: a pasture-based system (very extensive, located in the Pyrenees, Spain); a mixed sheep-cereal system (semi-intensive, the most widespread system in Spain); and a zero-grazing system (very intensive, located in the Ebro basin, Spain). The carbon footprint of lamb meat (when considered as the only output of the production system) decreased according to a degree of intensification: highest values for the pasture-based system and lowest for the zero-grazing system (Table 2). However, when allocating the carbon footprint to the different outcomes from the diverse systems (i.e. to the meat, but also the ES associated to the production system), the carbon footprint of lamb meat was reversed: lowest values for the pasture-based system and highest for zero-grazing system.

Table2. Greenhouse gas (GHG) emissions (CO_2-eq kg^{-1} of lamb meat) with or without consideration of ecosystem services (ES) and contribution (%) of CO_2, CH_4 and N_2O to total GHGs (Ripoll-Bosch *et al.,* 2013).

	Carbon footprint of lamb meat (kg CO_2-eq kg^{-1} lamb meat)		Contribution (%)		
	Without ES allocation	With ES allocation	CO_2	CH_4	N_2O
Pasture-based	51.7	27.7	7.9	61.6	30.5
Mixed	47.9	35.4	21.0	57.6	21.4
Zero-grazing	39.0	39.0	29.1	59.4	11.5

In that study we showed the tremendous effect of acknowledging multiple-output systems. System efficiency (in terms of GHG emissions) depended on the methodological choice of allocating emissions to a single output (i.e. lamb meat) or to the multiple outputs (i.e. lamb meat and ecosystem services). The approach we followed faces an important limitation, and should be understood as a proof of concept. The economic valuation to allocate GHG between lamb meat and ES was based on political decisions compensating for the loss of agricultural production rather than biophysical observations and scientific evidence. We considered the agri-environmental payments (of the Common Agricultural Policy) to farmers as a proxy of the cost for undertaking such conservation measures and, ultimately, the willingness of society to pay for the ES. There was no scientific consensus in how to incorporate ES in life cycle thinking then, and still this matter continues under development.

Despite the widespread usage and acceptance of LCA to assess the environmental impact of a product or service, the method still presents a number of challenges, especially when applied to grassland-based systems:

1. Direct comparisons between LCA studies are difficult because of potential differences in methodological choices (De Vries and de Boer, 2010). This suggests that further standardization is needed. Three main methodological issues deserve attention, as follows: (a) The functional unit. The expression of the environmental impact in relation to the product or service under study is still a matter of divergence between studies (e.g. GHG emissions per kg of product, per nutritional value, per hectare of land, or per person (Nguyen *et al.*, 2012). (b) The system boundary. The definition and delimitation of system under study will greatly influence the results. Different studies can differ, for instance, in including diverse stages of production (e.g. environmental impact up to farm gate, or to supermarket shelf), handling co-production (e.g. including, or not, the unavoidable meat production of dairy systems), or considering the carbon sequestration potential of grasslands (Soussana *et al.*, 2010). (c) The allocation method. In cases of multiple output systems, emissions can be distributed among the products in different ways (i.e. based on biophysical properties or economic valuation).
2. Land use in pasture-based systems may be difficult to measure, especially as an impact category. In many pastoral systems, animals graze in communal open areas, generally natural and semi-natural grasslands. The constant movement of animals looking for fresh forage prevents full usage or over usage (i.e. degradation) of grassland. This intermediate use of the resources allows communal-living with wild large herbivorous and hosts high biodiversity. In such cases, grassland that is not fully used may supposed to be well-managed grassland. However, the LCA framework considers land use (i.e. number of hectares used) as an impact category, implying that situations with more land used are worse. Under the LCA viewpoint the intermediate intensity usage of grasslands is not well captured.
3. Carbon (C) sequestration in grasslands has emerged as a research hotspot in recent years (Smith, 2014; Soussana *et al.*, 2010; Rodríguez-Ortega *et al.*, 2014). It is generally acknowledged that grasslands may have potential to sequester C (Lal, 2011). Hence, nowadays, many carbon footprint studies attribute a certain (default) value of C sequestered into the soils. Such methodological approach still faces important limitations: (a) There is still some controversy around the potential of grasslands to sequester C. While some authors seem enthusiastic (Soussana *et al.*, 2010), other are dubious about this potential (Smith, 2014). (b) Carbon sequestration in soils is dynamic, and C content in the soils tend to an equilibrium or saturation. This implies that grasslands cannot sequester C indefinitely in time and hence, the potential is limited (in amount and in time). The C sequestration potential will dependent on the type and maturity of the grassland, and on the management of the grassland. (c) The management of the grassland can influence C sequestration potential (sink), but more important is key to maintain the carbon sequestered into the soil (stock). A poor management of the soil cannot guarantee an actual removal of C from the atmosphere, and even less for a long period of time. (d) It is important to avoid confusion with the concepts carbon sequestration or sink and carbon stock or storage.

4. Data availability and quality is usually a constraint in low-input/pasture-based production systems (Ripoll-Bosch *et al.*, 2013). Productivity of natural and semi-natural grasslands, and the grasslands-livestock relationship is generally poorly documented. Grasslands are very diverse depending on their geographical location (e.g. latitude, altitude and/or ecosystem) and the degree of intensity of management, from natural and semi-natural rangelands (used extensively, where stocking rates and/or fire regimes are the main management variables) to intensively managed grasslands (e.g. with fertilization, irrigation, mechanization or management of species) (IPCC, 2006). In consequence, productivity of grasslands (in terms of biomass or net primary production) is very variable across locations and management, but also variable from year to year (i.e. variability in rainfall, temperature, etc.) and from season to season (i.e. seasonality within the year). Likewise, the quality of the grasslands (e.g. nutrient content, dry matter, digestibility, plant composition, etc.) varies across locations, management, years and seasons. This information, usually lacking or difficult to obtain (Lauenroth *et al.*, 2006), is crucial to properly estimate the intake and the diet composition (quality) of grazing animals, and ultimately, properly calculate the methane emissions from enteric fermentation (Moraes *et al.*, 2014).
5. The life cycle assessment or in a more generic way, the life cycle thinking, need to further recognize the multifunctionality of certain agricultural production systems, understood as services to society (Ripoll-Bosch *et al.*, 2013), and the multiple roles and functions of livestock production (Weiler *et al.*, 2014). The acknowledgement and valuation of the ecosystem services or public goods provided by grassland-based systems, especially when located in marginal areas or High Nature Value farmland, could be a key factor to increase the relevance and competitiveness of farms and farmers. Moreover, the extrinsic values of high quality products (e.g. protected designation of origin, PDO), which is highly appreciated by consumers (Bernués *et al.*, 2016) cannot be captured within the LCA methodology.

Conclusions

When analysing the relationships between pasture-based livestock and the environment, a controversial topic nowadays, conceptual and methodological challenges still remain open for discussion and further research. In this paper, we presented a novel PES system for pasture-based livestock farms that link agricultural practices and ES through expert knowledge. We showed its usability with different policy scenarios, one of which represented the societal expectations in terms of ES demand. Despite the limited success in translating the ES framework into policy design, partly due to the lack of knowledge regarding the concrete effect of practices on multiple ES at different scales, we believe that it is possible to articulate more targeted agri-environmental schemes with the existing information or with simple and quick appraisal methods to obtain it. We also argue that the LCA method to quantify the negative impact of pasture-based livestock farming systems on the environment, notably its contribution to climate change, needs to take into account the multifunctional character of these systems, and to take a more holistic approach that considers interlinked sustainability issues and broader scales.

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