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An integrated sustainability assessment of mediterranean sheep farms with different degrees of intensification

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ABSTRACT

In the European Mediterranean basin, pasture-based sheep farming systems are mostly located in marginal/High Nature Value areas. These production systems are multifunctional, and their economic, environmental and social roles are equally important and recognised by policy makers and by society. However, the number of animals and holdings is decreasing, and there is great uncertainty regarding the reproducibility of these farming systems, which depends on many internal and external farm factors and their interactions. The aim of this paper was to perform a comprehensive assessment of sustainability in different sheep farming systems in north eastern Spain using the MESMIS framework. We followed a case-study approach to perform an in-depth investigation of 4 sheep meat and dairy farms with different intensities of reproduction management. Critical points of sustainability, including weaknesses and opportunities, were obtained using a participatory process with stakeholders (farmers and technical advisers) that resulted in the selection of 37 sustainability indicators that were classified according to the systemic attributes defined by MESMIS (productivity, stability, self-reliance, adaptability, equity) and according to the classical sustainability pillars (social, economic and environmental). Some underlying patterns could be observed when analysing sustainability pillars, attributes and indicators. A positive relationship between productivity and intensification level in meat farms was observed; however, economic sustainability was determined not only by on-farm but also by off-farm activities. The economic efficiency of farming (without considering subsidies) was mainly explained by the capture of added value in the dairy systems and the combination of high animal productivity as well as high forage and feed self-sufficiency in the meat systems. Social issues were also central to explaining sustainability at the farm level, including the prospects of generational turnover and the manner in which farmers perceive and rate their activity. A clear trade-off between economic and environmental indicators was observed, i.e., the higher the economic sustainability, the lower the environmental sustainability. Each farm scored differently for diverse attributes, pillars and individual indicators. The scores differed according to size, structure, resource availability and managerial skills, which implies that it would be difficult to apply a holistic sustainability analysis to farming systems instead of individual farms. A number of methodological questions arose during the evaluation process relative to the stakeholders perception of these indicators, their relevance and meaning, the reference values for comparison, or their validity to assess sustainability across spatial and temporal scales. These questions are discussed in the paper.

1. Introduction

Pasture-based animal production in Mediterranean Europe is mostly distributed in mountain areas and other less favoured areas that are considered High Nature Value (HNV) farmland (EEA, 2004). Among the diverse livestock farming systems, small ruminants normally occupy the most marginal areas, with harsh climatic conditions (extreme temperatures and low rainfall) that provide grazing resources characterised by high seasonality,

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generally low quality and high intra- and inter-year variability (de Rancourt and Mottet, 2008). In these areas, suitable conditions for other agricultural production are scarce. In contrast to those located in more favourable areas, pasture-based sheep farming systems are multifunctional; thus, their economic, environmental and social roles need to be considered in any strategy or policy aimed at the sustainable management of Mediterranean pastoral areas.

Pasture-based animal production, meat sheep production in particular, has suffered a strong decline in the last few decades in most European Mediterranean regions, in terms of the number of both holdings and animals (Bernués et al., 2011). Depopulation and a continuous reduction or abandonment of agriculture in rural areas across Europe (MacDonald et al., 2000; Strijker, 2005) have been identified as general drivers of this decline. Meat sheep production systems seem to have suffered this process to a greater extent. Several factors, both on the farm scale and on the socio-economic and physical context within which farms operate, can be underlined as contributors to this phenomenon. These include the decreasing profitability of the activity and growing risk of economic marginalisation (de Rancourt et al., 2006); the general process of intensification to increase animal productivity, which does not always result in higher economic performance and efficiency (Lorent et al., 2009); the low animal and labour productivity compared to the productivity of beef animals, partly due to the lower importance of CAP subsidies in the total revenue of farms (Bernués et al., 2011); deficient technical and economic management (Pérez et al., 2007); the lack of generational turnover and the total or partial substitution of agriculture with other activities when opportunities arise (Bernués et al., 2011; Riedel et al., 2007).

For dairy sheep, the situation and perspectives are somewhat different. Production systems included in breeding schemes have improved the technical and economical results significantly when compared to meat production systems (de Rancourt, 2010; Ruiz et al., 2010). However, there has also been a reduction in the number of flocks due to a significant change in the structure of the dairy sheep sector, with many farmers abandoning the activity or transitioning to part-time livestock farming. Among the remaining professional farmers, an increasing importance of on-farm transformation and commercialisation activities has enabled the capture of added value in the context of a growing demand for quality cheese (Ruiz et al., 2010). Despite structural limitations, atomisation and the small scale of production and processing units, local cheese production can find comparative commercial advantages in niche markets in most Mediterranean areas (Dubeuf et al., 2010).

There is widespread agreement regarding the importance and desirability of sustainability in agricultural production (Hansen, 1996). The numerous definitions, methodological approaches and research studies on sustainability in recent years emphasise the need to consider the ecological, economic and societal consequences of development choices (Bezlepkina et al., 2011). However, the sustainability of farming systems depends on many, often interrelated, factors (level of intensification, resource use and management, location, productive orientation, etc.) that differ among farming systems and change with time. A holistic and dynamic framework of analysis is therefore required, taking into account the diverse and evolving nature of the factors affecting sustainability.

There are different frameworks to evaluate sustainability at different aggregation levels or scales and using different criteria and indicators [comprehensive redactions have been attempted by Van Cauwenbergh et al. (2007) and Binder et al. (2010)]. Among them, two indicator-based frameworks follow a holistic approach, can be applied at different scales including the farm scale and are hierarchical in nature. The SAFE (Sustainability Assessment of Farming and the Environment) framework (Van Cauwenbergh et al., 2007) includes the three classical pillars of sustainability and is structured in content-based principles, criteria and indicators; however, it is a top-down approach (Binder et al., 2010). The MESMIS (Framework for Assessing the Sustainability of Natural Resource Management Systems) framework (López-Ridaura et al., 2002; Masera et al., 2000) is organised around sustainability attributes (productivity, stability, reliability, resilience, adaptability, equity and self-reliance), although these indicators can also be classified into the three sustainability pillars. MESMIS is a bottom-up, participatory and interdisciplinary process in which sustainability is not measured per se but rather is expressed in comparative terms between two or more systems or between different stages of the same system after improvements have been implemented. MESMIS has been widely used in sustainability evaluations of smallholder agricultural farms in different countries and agro-ecological regions (Speelman et al., 2007). However, integrative bottom-up approaches to identify and analyse the relevant indicators at the farm level can be complex in practice, as there are different stakeholders with diverse perceptions of sustainability and diverse temporal and spatial scales involved. Multiple trade-offs between indicators, pillars and stakeholders' perceptions can appear during the process.

The aims of this study were (i) to perform a comprehensive participatory assessment of sustainability in sheep farming systems in north eastern Spain (indicators were defined, measured and integrated into a general evaluation framework using MESMIS, and critical factors when applying the evaluation framework were identified and discussed) and (ii) to identify key features of sustainability, in terms of both weaknesses and opportunities, using contrasting case-study farms with different levels of intensification and production orientation (meat or dairy).

2. Material and methods

2.1. The MESMIS framework for sustainability evaluation

The MESMIS framework allows the derivation, measurement, and monitoring of sustainability indicators as part of a systemic, participatory, interdisciplinary, and flexible evaluation process (López-Ridaura et al., 2002). According to Binder et al. (2010), this method contributes better than others to meeting the current needs of agricultural sustainability assessment, such as multidimensionality and multi-functionality aspects, and identifying conflicting goals and trade-offs by including the interaction between indicators. The framework is based on seven defined systemic attributes:

(a) productivity (capacity to provide the required level of goods and services);
(b) stability (ability to maintain a constant level of productivity under normal conditions);
(c) reliability (maintaining productivity at levels close to equilibrium under normal environmental shocks);
(d) resilience (return to equilibrium or productivity levels similar to the initial level after serious disturbance);
(e) adaptability or flexibility (ability to find new levels of balance or to continue offering benefits to long-term changes in the environment);
(f) equity (a system's ability to distribute both intra-and inter-generational benefits and costs fairly);
(g) self-reliance (system's ability to regulate and control interactions with the outside).

Stability, reliability and resilience attributes can be grouped together (henceforth called "stability"), to express the ability of the system to cope with change (López-Ridaura et al., 2002). Together with adaptability, these attributes help to analyse the sustainability of farming systems in a dynamic way that allows consideration of the physical and socio-economic context in which farms operate.

There are different stages in the evaluation process:

(i) Stage 1 – definition and description of the system or systems to be evaluated: identifying the biophysical, technological and socio-economic components as well as interactions, inputs, outputs and boundaries. This stage was completed as described in Section 2.2.
(ii) Stage 2 – identification of critical points of the system: positive or negative aspects that provide strength or vulnerability, i.e., technical, social and economic factors or processes that individually or in combination may have a crucial effect on the system attributes described above. For this purpose, we used technical data and reports, and we carried out in-depth interviews ($n = 7$) with different stakeholders in each location (farmers and technical advisers) to elaborate a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis and identify critical points.
(iii) Stage 3 – selection of the diagnostic criteria and indicators: the aim of this process is to provide the necessary link between the attributes and the critical points on the one hand and the critical points and indicators on the other. In this sense, the difference between the diagnostic criteria and the indicators is that the first describes the attributes of sustainability and the second describes a specific process within the system. The final list and definition of indicators ($n = 37$) and their correspondence to system sustainability attributes and pillars was elaborated within a focus group that included technical advisers and researchers. To select the indicators, the results of the SWOT analysis from the previous stage were presented to the focus group participants and discussed.
(iv) Stage 4 – measuring and monitoring of indicators: several methods can be used, such as literature review, surveys, direct measures using sampling techniques, or simulation models. In this case, most indicators derived directly from information obtained through direct questionnaires or monitoring activities performed on the farms. Some indicators were derived from the literature (e.g., the role of farming in the conservation of natural protected areas/species), and others were simulated based on the on-farm information (e.g., degree of feed self-sufficiency).
(v) Stage 5 – integration of results: thresholds or reference values need to be set for each indicator using references in the literature or specific values for the region under study in the case of social or economic indicators. The optimum reference values therefore varied according to the nature of the indicators. In some cases, the reference values represented the minimum or maximum values observed within the sample (e.g., net margin per working unit), and in other cases, the reference values were regional averages (capture of added value) or were derived from expert opinions (problems in access to grazing land) (see Table 3). For each sustainability attribute, the indicators were weighted to reflect the different relative importance they have in explaining the sustainability of the system. Participants in the focus group (Stage 3) were asked to rank the indicators –within each systemic sustainability attribute– in order of importance (the lowest rating given the rank of lowest importance). The average rank of the indicator in relation to the mean rank of indicators within the attribute was used to weight the final value. Quantitative, qualitative, and graphical or mixed procedures can be used to integrate the results and are presented in Section 3.
(vi) Stage 6 – conclusions and recommendations on management: each farm was considered as a different case study within a particular sheep system and was evaluated in comparative terms to provide judgments like, "this farm seems to be more sustainable in this attribute, but less in the other." The objective was to identify the aspects that prevent or allow the system to be more sustainable and analyse the process of assessment to identify their strengths and weaknesses. This stage is developed in Section 4.

A complete description of MESMIS is given by Masera et al. (2000) and López-Ridaura et al. (2002); some of its applications have been discussed by Astier and Hollands (2007) and Speelman et al. (2007). The results obtained in the main stages of the evaluation process are presented in Section 3.

2.2. Case study research: area of study and selection of farms

We aimed to achieve a comparative evaluation of sustainability in different sheep farming systems in north eastern Spain according to the type of production [meat vs. dairy (D)] and the intensification level in meat systems [using the type of reproductive management as proxy: one lambing in 1 year (1L/1Y); three lambings in 2 years (3L/2Y); and five lambings in 3 years (5L/3Y)]. Fourteen farms located under diverse agro-ecological conditions of the European Mediterranean basin, including: dairy sheep (Latxa breed in Basque Country), extensive meat systems (Rasa Aragonesa breed in Aragon), and intensive meat systems (Lacaune breed in Catalonia), were selected to encompass a wide range of scenarios of production, reproductive system of flocks and general management of on-farm and off-farm feeding resources. The data for the years 2007 and 2008 were collected through an in-depth semi-structured questionnaire covering information on land use and agricultural and forage production, use of communal grazing areas, household composition and on-farm and off-farm labour, flock composition, reproductive management and productive performances, feeding and grazing calendar and management, machinery and facilities, sales and marketing of products, European Union Common Agricultural Policy (CAP) and other subsidies, as well as purchases and costs. A specific section of the questionnaire aimed to collect information on farm dynamics during the previous 5 years (main changes in structure, management or technologies) to assess the prospects of the farm continuity and its main determinants and to evaluate the quality of life and self-reported personal well-being of the farmer and his family. The interviews took place in one session, although in most cases one or more additional visits were necessary to collect complementary information, especially information on sales and purchases, subsidies received, and surfaces and flock numbers registered in CAP application official forms.

MESMIS operates at the farm level, and collecting data to obtain the relevant sustainability indicators described in the previous section is a very intensive process; therefore, synthesis and integration of results is not an easy task (López-Ridaura et al., 2002). For these reasons, we opted to follow a case-study investigation approach (Yin, 2009) that allowed us to gain an in-depth understanding of the critical factors that affect sustainability on a reduced sample of typical farming systems with contrasting features. Case-study research is based on in-depth investigation of single individuals, groups, or events. Case studies may be descriptive or explanatory; the latter type is used to explore causation to find underlying principles (Yin, 2009) and is useful to both generate and test hypotheses. Case-study research makes the statistical extrapolation of results

Table 1
Characterization of the case study farms.

Farm Agro-ecosystem	1 Alpine mountain	2 Semi-arid valley (rain fed)	3 Semi-arid valley (irrigated)	4 Atlantic mountain
Location	Aragon	Aragon	Catalonia	Basque country
Altitude (m)	1360	186	130	277
Rainfall (mm)	1300	380	190	884
Annual average temperature (°C)	7.5	14.6	14.0	14.1
WU[a]	1.0	2.0	3.0	2.0
Household off-farm work	Yes	Yes	No	Yes
Production	Meat	Meat	Meat	Dairy (cheese)
Other productions	Goats	Cereals sunflower	Cereals forage crops	No
Flock size (No. ewes)	520	1417	1500	274
LA[b] (ha)	111	760	77	23
Feed crops (ha)	0	228	24	0
Forage crops (ha)	3	22	50	5
Grazing (meadows) (ha)	36	10	3	18
Ranging (grassland) (ha)	72	500	0	0
Communals (ha)	850	1000	0	0
Reproductive system[c]	1L/1Y	3L/2Y	5L/3Y	1L/1Y
Added value products	No	No	No	PDO Idiazabal

[a] WU: working unit (time spent on an activity by one person for 1 year).
[b] LA: land area.
[c] 1L/1Y one lambing in one year; 3L/2Y three lambings in two years; 5L/3Y five lambings in three years.

impossible; however, if case studies are selected properly, it is possible to generalise the results, uncover underlying principles and patterns and contribute to scientific development (Flyvbjerg, 2006).

Four farms were retained to illustrate the results of the analysis, one for each type of sheep-farming system described above. In an attempt to take key case studies, representative farms were selected according to their main characteristics and the previous experience and knowledge of the researchers in the respective geographical areas. The main characteristics of the four farms that illustrate the sustainability analysis can be observed in Table 1.

3. Results

3.1. SWOT analysis and selection of key indicators

The ideas summarising the main discussion points during the interviews with stakeholders are described in Table 2. The strengths for sheep production were related to the optimisation of the use of local resources, either in terms of pastures, breeds or markets. For dairy sheep, the organised structure of production and marketing of well-recognised, quality cheese allowed the capture of added value by farmers. For meat systems, cooperative production and the integration of sheep and cereal production were mentioned. Opportunities were also related to better valorisation of local resources, infrastructures and products, including quality products and ecosystem services demanded by society. Part-time agriculture was perceived as an opportunity for locations where labour markets existed, although this could become a threat due to the displacement of agriculture by other activities in many areas.

A greater number and diversity of weaknesses were perceived, including structural and productive problems (conflicts for land and land access, structural problems of the farms or low productivity ratios), market problems (low prices of outputs and concentration of power on intermediate actors in the food chain), social problems (lack of generational turnover, lack of training and technical advice), stringent sanitary regulations and centralisation of

Table 2
Main result obtained in the SWOT analysis of sheep farming.

Strengths	Weaknesses
– Good conditions for production: grazing resources – Local breeds adapted to the exploitation of such resources – Proximity to population centres and consumers – Specific to dairy systems: – Structured and organised sector – Breeding and management programs running with successful results – Good market position of PDO cheese – Specific to extensive meat systems: – Tradition in cooperative production and marketing – Mixed integrated cereal-sheep farms	– Conflicts in land use (access to grazing areas, pressure from other uses) – Structural problems (small size) – High hygienic and sanitary standards for artisan activities (comparable to industrial) – Monopsony or oligopsony, especially for meat and raw milk – Excessive dependence on external inputs with increasing prices – Low labour availability and recruitment problems – Lack of generational turnover – Lack of self-esteem and training – Technical advice is not tailored to the production system – Low technical and productivity ratios (e.g. fertility) – Centralisation for slaughterhouses – Dependency on CAP subsidies
Opportunities – Optimise further the use of forage resources to reduce feeding costs – Transformation and commercialisation activities to capture greater added value – Improve and shorten marketing channels – High public awareness and niche market for local/cheese products – Establishment of local/regional slaughterhouses, mobile facilities – Valorisation of positive externalities or ecosystem services (cultural landscape, biodiversity, prevention of fire hazards, especially in protected areas) – Part-time agriculture and off-farm labour of household member in certain production systems and locations	Threats – Decoupling and modulation; uncertainty about future CAP reforms – Low and decreasing price of outputs, diminishing profitability – Increasing pressure for alternative land uses – Decrease in consumption of lamb – Imports of meat with lower production costs (globalisation) – Opportunity cost of labour in other economic activities and higher perceived quality of working conditions outside agriculture – Risks of intensification due to low net margin per unit of product and rising input costs (especially fuel and feed) – Conflicts with wildlife – Marginalization of rural areas

Table 3
List of indicators, definition, threshold values and weight.

Attribute	Indicator	P[a]	Unit/definition	Threshold[b]	Weight[c]
Productivity (*n* = 8)	Labour profitability	€	Net margin[d]/WU (€)	min–max	16.4
	Animal profitability	€	Net margin[d]/LUe (€)	min–max	14.4
	Economic efficiency	€	Agricultural outputs[e]/total costs (ratio)	min–max	14.1
	Land productivity	€	Agricultural outputs[e]/ha (€)	min–max	12.9
	Feed efficiency	€	MJ in product/MJ in feeds (ratio)	min–max	12.6
	Animal productivity	€	Animal outputs/LUe (€)	min–max	12.1
	Lambing rate	€	No. of lambings/LUe (%)	min–max	9.1
	Animals per WU	€	LUe/WU	min–max	8.3
Stability, Reliance, Resilience (*n* = 5)	Farm continuity	S	Continuity in the next 15 years (scale)	0–5[f]	32.1
	Off-farm income	€	Off-farm income/total income (%)	0–max	22.4
	Advisory services	S	Scale	0–6[g]	20.6
	Facilities	S	Scale (qualitative evaluation)	0–10	14.5
	Wildlife conflicts	E	Scale (qualitative evaluation)	0–3	10.3
Adaptability (*n* = 7)	No. Incomes	€	Number of different income sources	1–max	22.4
	Main agric. income	€	Major agric. income/total agric. income (%)	min–100	17.2
	Land access problem	S	Scale (qualitative evaluation)	0–4	17.2
	Farmer education	S	Scale	0–4[h]	16.2
	Distance markets	S	Travel time to closest city > 10,000 inhabitants (min)	min–max	10.4
	Communal grazing areas	E	Dichotomic	yes/no	10.1
	Distance slaughterhouse	S	Travel time to closest slaughterhouse (min)	min–max	6.5
Equity (*n* = 10)	Salary level	S	Net Margin per WU/reference salary (%)	min–max	14.4
	Satisfaction level	S	Scale (farmer self assessment)	0–10	13.2
	Grazing	E	MJ from grazing/total flock requirements (%)	0–100	13.1
	Energy efficiency	E	MJ E inputs[i]/total agric. income (ratio)	min–max	12.6
	Grazing protected areas	E	Dichotomic	yes/no	10.9
	Distance to services	S	Travel time to closest services[j] (min)	min–max	10.6
	Hired labour	S	Contracted WU/total WU (%)	0–100	8.1
	Leisure time	S	Holiday days per WU per year (d)	0–30	6.3
	Stocking rate	E	LUe/ha of forage areas (ratio)	1.4–2.1	5.6
	Local breeds	E	Number of local breeds/varieties	0–max	5.3
Self-reliance (*n* = 7)	Feed self-sufficiency	€	On-farm feed MJ/total feed MJ (%)	0–100	18.2
	Forage self-sufficiency	€	On-farm forages/total forages MJ (%)	0–100	16.2
	Indebtedness	€	Financial costs[k]/net margin (%)	min–max	15.3
	Family labour	S	Family WU/total WU (%)	0–100	14.3
	Own area	€	Owned land area/total land area (%)	min–max	13.0
	Subsidies	€	Total subsidies/net margin (%)	min–max	12.7
	Added-value	€	Price per unit of product/reference price (%)	min–max	10.4

WU working unit; LUe livestock unit (adult ewes); MJ megajoule;
[a] Sustainability pillar: € economic; E environmental; S social.
[b] Max = maximum observed value; min = minimum observed value.
[c] weight in % (total weight per attribute is 100%).
[d] Net Margin = agricultural outputs + subsidies – variable costs (feeding costs, cropping costs, veterinary and sanitary costs, machinery and building maintenance, fuel and electricity, insurances, temporary labour and other variable costs) – fixed costs (permanent labour, financial costs and amortization).
[e] All incomes from agricultural activities excluding subsidies.
[f] Children (0 = no children or not in the household; 1 = children under 18; 2 = children working on the farm or willing to take the activity) + age (3 = <40 years; 2 = 40–55; 1 = 55–65; 0 = >65).
[g] Animal health, reproduction, breeding, nutrition, general management, product quality.
[h] 0 = no education; 1 = basic education; 2 = intermediate education; 3 = university degree; 4 = agriculture university degree.
[i] Fuel and electricity.
[j] Health and education.
[k] Debts and depreciation.

abattoirs or excessive dependency on CAP subsidies. Lack of self-esteem was also mentioned by some farmers. The most important threats from the general context in which the sector operates were related to the uncertainty of the future agricultural policy, the general economic situation of international and domestic markets and households, and the pressure for alternative land uses. Some environmental constraints were also discussed, including energy costs and pollution derived from manure in more intensive farming systems and conflicts between agriculture and conservation objectives in pasture-based systems (wildlife-livestock interactions, such as predation) Lack of acknowledgement of the role of the farmer and social marginalisation were also perceived as threats.

The issues above were considered to be positive and negative critical aspects of sustainability, from which 37 indicators were selected and classified according to the systemic attributes explained above and the classical sustainability pillars after discussion during the focus group session (Table 3). If we consider just the classification of sustainability in three pillars, the focus group discussion identified 46% of indicators under the economical pillar, 35% under the social pillar and 19% under the environmental pillar. However, if we consider only the top three indicators per attribute, according to the weight given by the focus group participants, these percentages changed to 60%, 33% and 7%, for the economic, social and environmental pillars, respectively.

3.2. Attributes and pillars of sustainability

Fig. 1 represents the score obtained by the four individual farms for attributes and pillars of sustainability as defined in Table 3.

The farms showed a relationship between the scores in the productivity attribute and the intensification level (reproductive management) in meat systems, with the dairy farm scoring better than the meat systems (Fig. 1a). Each farm scored better for different attributes: the 5L/3Y farm scored best for stability (although differences between the farms were small); the D farm followed by the 3L/2Y farm scored best for self-reliance and adaptability; the 1L/1Y farm scored best for equity. Conversely, the 3L/2Y farm performed worst for equity, the 1L/1Y farm was the worst for productivity, adaptability and self-reliance, and the D farm was the worst for stability.

In terms of the pillars of sustainability, the differences were also considerable (Fig. 1b). Economic sustainability indicators decreased along with the extensification of the reproductive system in meat farms, whereas the dairy system received the highest score. A similar trend was observed for the social sustainability indicators: the 5L/3Y farm showed the highest score and 1L/1Y farm the lowest, with the 3L/2Y and D systems located in an intermediate position. In contrast, environmental indicators clearly showed an opposite trend, i.e., higher economic sustainability led to lower environmental sustainability.

3.3. Sustainability indicators

The average weighted score obtained by each farm for any sustainability attribute/pillar only gives aggregate information. An analysis of individual indicators is necessary to describe farming systems in detail. Table 4 offers the values of the 37 indicators considered in this study, and Fig. 2 represents the values of the top three indicators per attribute, as weighted by the participants in the focus group.

Large differences in the top three *productivity* indicators were observed between the farms. Labour profitability (defined in this study as net margin per working unit) was above 30,000€ WU^{-1} for the 3L/2Y, 5L/3Y and D farms whereas it was only 16,700€ WU^{-1} for the 1L/1Y farm. However, we should take into account that for this farm, 75% of the total household income came from off-farm activities (included in the stability attribute). Animal profitability (net margin per livestock unit) was low for the meat-lamb farms in comparison to the dairy farm, mainly due to the added value captured in cheese making. Regarding economic efficiency (agricultural outputs excluding subsidies related to total costs), the D farm obtained a much higher score than the 5L/3Y and 3L/2Y farms (with values barely above 1) and could therefore be considered as economically efficient.

Land productivity showed large differences (Table 4), with very high values for the higher animal profitability farms (5L/3Y and D) and low values for the lower animal profitability farms (1L/1Y and 3L/2Y). However, the farm size was different (comparatively small in the 5L/3Y and D farms) as was the type and intensity of land use (related to different location, agro-ecological conditions and utilisation). Feed efficiency (measured in our study as the MJ contained in the products per MJ contained in feeds) was much higher for the 5L/3Y and D farms and lower for 3L/2Y farm. Animal productivity was greater for the 1L/1Y farm than for the 3L/2Y farm due to lower lamb mortality (4% vs. 14%), which can be related to the large amount of animals managed per working unit and the low price per kg in the 3L/2Y farm. In the case of the dairy farm, the high score for animal productivity was due to the cheese-making activity. The lambing rate (reproductive efficiency) was associated with the reproductive system implemented in each farm, except that the 3L/2Y farm showed a lower rate than theoretically expected.

Despite the global score for the *stability/reliability/resilience* attribute being similar in the four case studies, large differences were observed in some individual indicators. The score for farm continuity was medium to high across the farms, although this indicator was weighted the highest (Table 3). However, large differences were observed in the proportion of total household income coming from agriculture (25% for 1L/1Y; 45% for 3L/2Y; 100% for 5L/3Y and 86% for D farm). In contrast, the access to advisory services was much higher for the intensive meat and dairy farms. Conflicts between sheep and predators (scavenger birds, wolves and reintroduction of the brown bear) were perceived as a threat to the stability of the agricultural activities in mountain areas.

Large differences were observed in the *adaptability* indicators. The dairy farm scored the highest because the sources of income were diversified, and short commercialisation channels for the cheese were exploited. This farm scored high despite problems with access to more land and no possibility to use communal pastures. In contrast, the 1L/1Y farm had only two sources of agricultural income (although nearly 90% of its total income was derived from lambs) and is located far away from markets and industry operators, although access to more land and communal grazing areas was not a problem in this case. The education level of the farmers was similar across all the farms.

Many indicators defined the *equity* attribute, making it more complicated to interpret the global score obtained by the individual farms. The 1L/1Y farm scored the highest due to better performance on environmental indicators (energy requirements covered

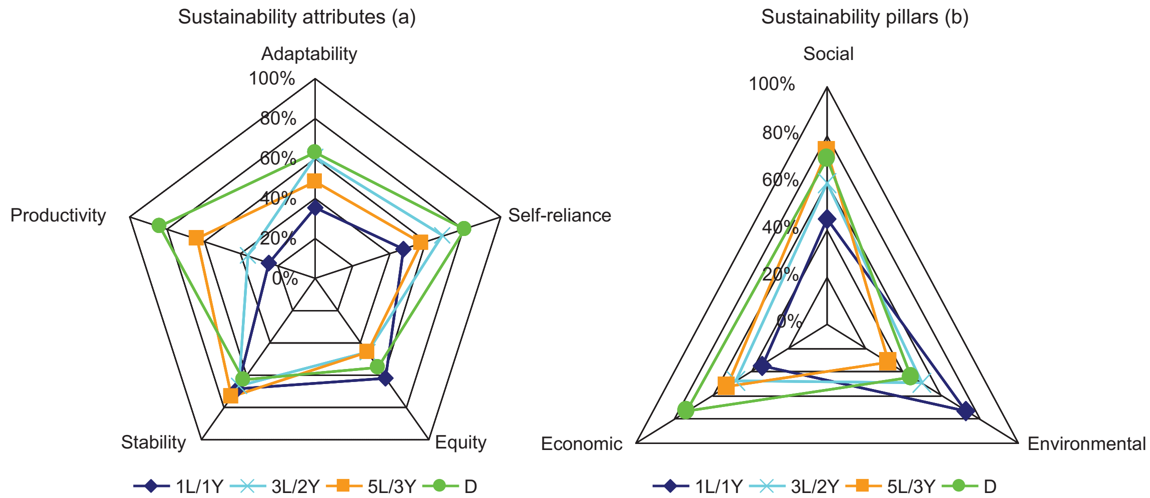

Fig. 1. Scores obtained for sustainability attributes (a) and pillars (b). 1L/1Y one lambing in one year; 3L/2Y three lambings in two years; 5L/3Y five lambings in three years; D dairy sheep.

Table 4
Values of indicators per attribute.

Attribute	Indicator	1L/1Y	3L/2Y	5L/3Y	D
Productivity	Labour profitability	16,689	33,628	31,268	35,162
	Animal profitability	32.1	45.7	62.5	256.7
	Economic efficiency	0.84	1.03	1.14	2.14
	Land productivity	305.2	113.2	3565.0	4831.7
	Feed efficiency	0.062	0.052	0.156	0.161
	Animal productivity	65	53	156	420
	Lambing rate	87.5	96.0	161.9	94.2
	Animals per WU	520	709	500	137
Stability, Reliance, Resilience	Farm continuity	4	4	5	3
	Off-farm income	75	54	0	14
	Advisory services	2	2	6	5
	Facilities	7	5	7	8
	Wildlife conflicts	2	0	0	0
Adaptability	No. Incomes	2	4	2	5
	Main agric. income	88.3	86.8	82.3	79.3
	Land access problem	1	2	2	3
	Farmer education	3	2	3	2
	Distance markets	90	28	10	11
	Communal grazing areas	1	1	0	0
	Distance slaughterhouse	80	28	15	45
Equity	Salary level	104.3	210.2	195.4	219.8
	Satisfaction level	10	9	3	8
	Grazing	60.8	75.2	54.4	45.2
	Energy efficiency	0.83	4.46	2.66	2.08
	Grazing protected areas	1	0	0	0
	Distance to services	35	28	10	11
	Hired labour	0	0	33	0
	Leisure time	7.0	7.0	15.7	15.0
	Stocking rate	0.10	0.14	1.97	1.79
	Local breeds	2	1	0	1
Self-reliance	Feed self-sufficiency	60.8	100.0	77.8	45.2
	Forage self-sufficiency	60.8	100.0	95.0	98.8
	Indebtedness	42.7	25.5	34.0	15.1
	Family labour	100.0	100.0	66.7	100.0
	Own area	36.9	34.2	34.0	73.0
	Subsidies	137.8	104.3	64.0	15.3
	Added-value	111.9	99.7	95.0	204.4

by grazing, consumption of fuel and electricity, utilisation of protected areas, low stocking rates and use of local breeds). However, social equity indicators (salary level, distance to services, hired labour and leisure time), with the exception of the satisfaction obtained from farming (the second in weight), were comparatively low. The other three farms (3L/2Y, 5L/3Y and D) showed similar global scores for equity, but with different contributions of individual indicators (Table 4). Paradoxically, these farms showed higher salary levels but lower satisfaction scores (especially for the high intensity meat system, 5L/3Y). Environmental indicators were generally worse than for the 1L/1Y farm.

Global scores for the *self-reliance* attributes showed a somewhat inverse pattern with respect to equity, with lower values for the 1L/1Y farm and higher values for the other three farms. The 3L/2Y farm showed the highest global score, as the values for feed and forage self-sufficiency were very high due to the large land area in food/feed crops and grazing resources and low indebtedness. In contrast, the 1L/1Y farm score was the lowest, mainly because of low feed and forage self-sufficiency (60%), high indebtedness and dependency on subsidies.

4. Discussion

4.1. The methodological framework

Recent literature on sustainability assessment of agricultural systems defends the adoption of integrated, flexible, participatory and multi-scale approaches to address complex issues involving various disciplines and stakeholders (Barbier and López-Ridaura, 2010; Bezlepkina et al., 2011). However, methodological concerns and problems can appear when applying such an approach.

Higher importance is given at the local level (farmers, technical advisers) to economic and social issues than to environmental sustainability. Within the environmental sustainability pillar, the disappearance of grazing practices and sheep flocks, particularly in mountain or communal areas, the changes in vegetation and landscape, and the risk of fire hazards are very relevant to local stakeholders, whereas global issues such as greenhouse gas emissions are not considered. Moreover, some indicators are perceived as positive by some stakeholders and negative by others; e.g., farming-wildlife interactions can produce synergies in terms of conservation of key species (Fonderflick et al., 2010; Olea and Mateo-Tomas, 2009) but can also produce conflicts due to predation (Gazzola et al., 2008) or restrictions in land use.

These divergences may be partially due to the different spatial/temporal scales involved (Darnhofer et al., 2010b), but it seems clear that different views exist, and it could even be argued that the understanding of sustainability is different among the actors. This can have large implications in terms of policy application and effectiveness, as measures to improve environmental sustainability need to be implemented at the farm level (Rivington et al., 2007), and farmers would play a crucial role. Policies that focus only on reducing the environmental impacts of production systems do not ensure the economic and social reproducibility of the farms (Bezlepkina et al., 2011; Darnhofer et al., 2010b). To avoid partial assessments, facilitate communication among stakeholders and ensure policy effectiveness, relevant indicators corresponding to the environmental, economic and social pillars must be included

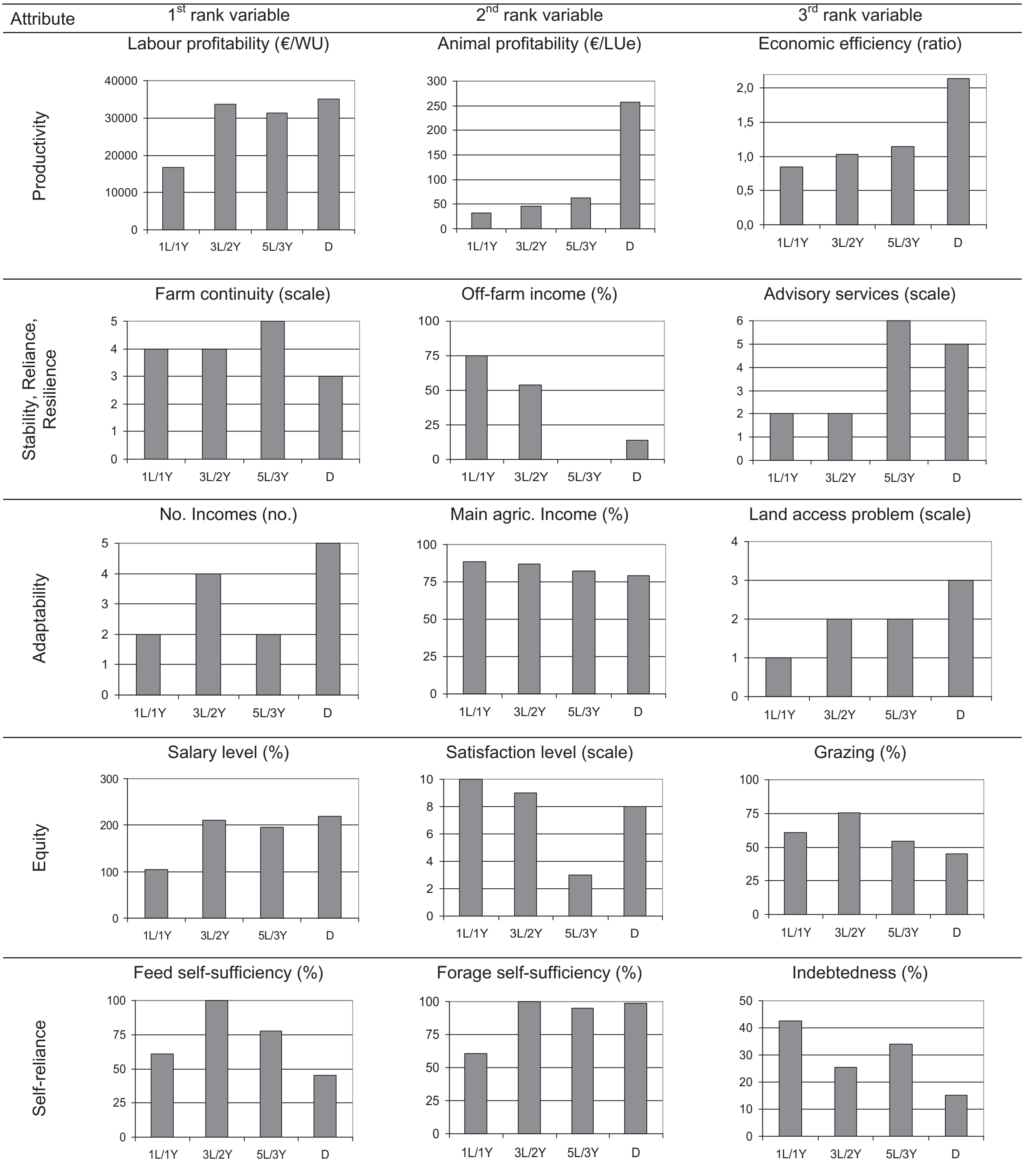

Fig. 2. Values obtained for the three highest weighed indicators per sustainability attribute. 1L/1Y one lambing in one year; 3L/2Y three lambings in two years; 5L/3Y five lambings in three years; D dairy sheep.

and weighted according to the different perceptions, even though this is a very sensitive area due to the subjectivity of the method (Barbier and López-Ridaura, 2010).

During the participatory process, we found that it was difficult to agree on a reduced number of indicators and to aggregate individual indicators into particular attributes. For example, off-farm income could be assigned to stability (it can contribute to maintenance of the agricultural activity) or adaptability or even self-reliance (it can be a source of diversification and flexibility, or it could mean less dependence on external funding). Similar average scores for sustainability attributes can also hide large differences within individual indicators. This is the case for the stability attribute, for which similar scores were found for the four farms considered but with very different values for individual indicators such as off-farm income and advisory services. Therefore, the classification of indicators in the traditional sustainability pillars could be more straightforward and understandable. In contrast, the attributes as defined by MESMIS can include uncertainty and dynamic aspects of sustainability evaluation (e.g., possibilities of adaptation to new socio-economic contexts) and trade-offs between attributes (e.g., productivity vs. stability or adaptability) and indicators (Binder et al., 2010).

The critical points of sustainability (and their reference values) can vary across spatial/temporal scales, and therefore, the relevance of certain indicators will not be the same for different intensification levels, agro-ecological regions, socio-economic context, or at different times (Fernandes and Woodhouse, 2008). Moreover, our objective was to compare farming systems within a gradient of intensification and for different production purposes, using representative case-study farms; however, the heterogeneity of farms within a certain system type increases with the number of indicators under consideration and can be as large as between systems. It follows that the comparison of sustainability with multiple indicators across farming systems/regions is challenging if not impossible.

Finally, we can mention a number of weak points where further research is required to implement a holistic framework for sustainability assessment. First, the process of data collection among stakeholders needs to be better defined and standardised; i.e., which stakeholders should be considered and how the information should be collected to better define and weight the relevant indicators. Second, stability and adaptability are key attributes to farm survival in an increasingly uncertain and ever-changing context (changing agricultural policies, new environmental and food safety regulations, variability of climatic conditions, volatility in prices of inputs and outputs) (Darnhofer et al., 2010a). However, relevant factors explaining farm capacity to cope with change are not clearly identified (Darnhofer et al., 2010b), and therefore, further research on indicators for adaptability, resilience and stability is needed. Evolutionary analysis of farms could help in this purpose. Third, positive externalities or environmental services provided by farming systems, such as conservation of biodiversity or maintenance of cultural landscapes (Piorr, 2003), are difficult to measure due to the temporal and spatial scales involved (Dale and Polasky, 2007). For this reason, and despite their importance, these services tend to be ignored in sustainability analyses. Significant research efforts deserve to be allocated to studying which environmental indicators to use and how to assess, value and integrate them into the evaluation frameworks.

4.2. Sustainability evaluation of sheep farms

As mentioned in the methodology, although case-study research does not allow for statistical extrapolation of results, we can discuss some underlying patterns that have been identified in the 4 farms under study, which can provide some insights to the sustainability debate in Mediterranean sheep-farming systems.

Labour profitability is a very important indicator for the economic sustainability of farms (Veysset et al., 2005), but we need to consider total household income including off-farm activities to understand the dynamics of farming systems (Davis et al., 2009; García-Martínez et al., 2011). In our case studies, part-time farming (farm 1L/1Y) and labour availability (farm 3L/2Y) seem to affect many other sustainability indicators (in particular animal productivity and economic efficiency but also grazing management, use of advisory services, etc.). The accommodation of farming activities to the labour force becomes central to explaining sustainability at the farm level (Madelrieux et al., 2009).

Animal profitability in dairy systems depends on the capture of added value through cheese production and in meat systems on both reproductive management and fertility, but above all, on CAP subsidies (García-Martínez et al., 2009; Veysset et al., 2005). Economic efficiency (which does not consider subsidies) is again related to added-value activities in dairy systems, but in meat systems, it involves the combination of high animal productivity (farm 5L/3Y) with high forage and feed self-sufficiency (farm 3L/2Y), in agreement with the findings of Benoit and Laignel (2010).

For stability, reliability and resilience, large differences and trade-offs exist between individual indicators. For example, the 1L/1Y farm is located close to a national park and profits from development opportunities related to the tourism industry while maintaining agriculture as a complement; however, there is also a risk of abandonment due to the low labour profitability, the lack of technical advice and conflicts with wildlife conservation. On the other extreme, intensive farms, despite having better advisory services and facilities, could be more sensitive to changes in the markets of inputs and outputs.

Diversification is a relevant strategy to cope with uncertainty; however, diversification of production and use of resources or income sources is limited in sheep-farming systems (Bernués et al., 2011). The mixed cereal-sheep systems, still traditional in Spanish semi-arid areas, might have advantages as the farmers can decide to sell the cereals or feed the animals depending on market conditions or even use failed crops as pastures if the climatic conditions are very adverse.

Some trade-offs exist between the environmental and social indicators aggregated in the equity attribute. The remoteness of a farm location is related to better environmental performance but also to the fewer health and education services available. Additionally, the top two social equity indicators, as ranked by the stakeholders, show an inverse relationship: the higher the salary level of the farmer, the less satisfaction is obtained from farming and vice versa. The particular objectives of farmers and the way they perceive and rate their activity is crucial to determining continuity in farming (Lien et al., 2009). Lifestyle and job satisfaction are key components of the quality of life for the farmer and, therefore, of the evolution of farms (Bernués et al., 2011).

For self-reliance, despite the high availability of natural resources, farms located in remote marginal areas can be less self-sufficient in terms of forages and feeds due to the seasonality of production (harder physical environment); conversely, farms located in areas that are more favourable for agriculture can utilise a wider diversity of resources in different seasons. However, these farms are normally more dependent on fossil fuels because they use more machinery for cropping and transport of on-farm inputs (stall-feeding instead of animals grazing). A location close to the markets can also mean higher pressure for land (e.g., urbanisation) and less access to forage resources.

Upscaling the results from farms to farming systems is not straightforward. In the four farms under study, an inverse relationship between environmental sustainability and intensification was observed, but there was a clear trade-off between the socio-economic and environmental pillars. The picture is less clear when we aggregate indicators into attributes or consider the multiple synergies and trade-offs existing between them (e.g. efficiency and adaptability; productivity and self-reliance). Moreover, sustainability depends not only on the farm and the farmer but also on the type of changes that will happen, especially under the current state of increasing variability and unpredictability. Therefore, the potential for farmers to respond will depend on location, time and the context within which the farm operates.

5. Conclusions

Sustainability is a complex and dynamic concept that involves multiple dimensions, some of which are dependent on location, time and socio-economic context. Despite the current concerns about the global environmental impacts of livestock production, local stakeholders prioritise economic, social and a few local environmental factors of sustainability. Therefore, finding relevant indicators that can be applied and compared across farming systems and geographical regions remains a great challenge.

A positive relationship between productivity and level of intensification was observed. However, there was a clear trade-off between economic and social sustainability and environmental sustainability. Nevertheless, it is difficult to extrapolate the results from farms to farming systems or farm types, as we need to consider many other variables, including farm size and structure, location, off-farm activities, management skills, or the objectives of the farmer.

The economic efficiency of farming (without considering subsidies) was mainly explained by the capture of added value in dairy systems and the combination of high animal productivity and high forage and feed self-sufficiency in meat systems. Social issues were also central to explaining sustainability at the farm level, including the prospects of generational turnover and the way farmers perceive and rate their activity.

In the uncertain and ever-changing context in which farms operate, attributes other than productivity and efficiency acquire relevance. Stability (resilience), adaptive capacity and self-reliance are key attributes in understanding how farms might face changes in the future. However, there are trade-offs or tensions between these, particularly between productivity and adaptability, that need to be further investigated.

Integrated sustainability assessment of agro-ecosystems should not only include economic, social and environmental sustainability indicators but should also follow a participatory approach to understand the multiple relationships (trade-offs and synergies) between the sustainability pillars, attributes and indicators and between stakeholders' priorities. The different spatial and temporal scales in which these indicators operate and the increasing uncertainty that surrounds agricultural production pose new methodological challenges to understanding the evolution of farming systems and designing strategies towards sustainability.

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