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REVIEW ARTICLE

Environmental sustainability of Alpine livestock farms

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Abstract

The 2006 FAO report concerning the environmental impact of the livestock sector has generated scientific debate, especially considering the context of global warming and the need to provide animal products to a growing world population. However, this sector differs widely in terms of environmental context, production targets, degree of intensification and cultural role. The traditional breeding systems in the Alps were largely based on the use of meadows and pastures and produced not only milk and meat but also other fundamental positive externalities and ecosystem services, such as conservation of genetic resources, water flow regulation, pollination, climate regulation, landscape maintenance, recreation and ecotourism and cultural heritage. In recent decades, the mountain livestock, mainly represented by dairy cattle, has been affected by a dramatic reduction of farms, a strong increase of animals per farm, an increase in indoor production systems, more extensive use of specialised non-indigenous cattle breeds and the increasing use of extra-farm concentrates instead of meadows and pastures for fodder. This paper firstly describes the livestock sector in the Italian Alps and analyses the most important factors affecting their sustainability. Secondly, it discusses the need to assess the ecosystem services offered by forage-based livestock systems in mountains with particular attention to greenhouse gas emission and its mitigation by carbon sequestration. In conclusion, comparison between the different elements of the environmental sustainability of mountain livestock systems must be based on a comprehensive overview of the relationships among animal husbandry, environment and socio-economic context.

Introduction

The concept of sustainability relates to economic, social and ecological aspects that are often interconnected (Gamborg and Sandøe, 2005; Hocquette and Chatellier, 2011; Cavender-Bares *et al.*, 2013). Lewandowski *et al.* (1999) defined sustainable agriculture as *the management and utilisation of the agricultural ecosystem in a way that maintains its biological diversity, productivity, regeneration capacity, vitality, and ability to function, so that it can fulfill – today and in the future – significant ecological, economic and social functions at the local, national and global levels and does not harm other ecosystems*.

The data published by FAO in 2006 about the impact of livestock (Steinfeld *et al.*, 2006) led to research and scientific debate on this issue, especially in the context of global warming and the need to provide animal products to a growing world population (Nelson *et al.*, 2009; Gill *et al.*, 2010; Pulina *et al.*, 2011). However, before assessing the impact of livestock, it is necessary to consider that this sector differs widely in terms of production targets, degree of intensification, environmental context and cultural role, among other characteristics.

The main focus of intensive systems is to ensure greater efficiency of production and a parallel reduction of environmental impacts (Guerci *et al*., 2013a). To meet these purposes, the concept of *precision livestock farming* (Auernhammer, 2001; Wang, 2001; Zhang *et al.*, 2002) has been proposed. Otherwise, livestock systems in mountain areas, which are mostly located in less favoured areas (LFA) and/or high nature value farmland, should be based on multi-functionality (Lovell *et al.*, 2010; Bernués *et al.*, 2011; Sturaro *et al.*, 2013a). In fact, these traditional livestock systems are largely based on the use of meadows and pastures and produce not only food and fibre but also other fundamental services for society, such as conservation of genetic resources, water flow regulation, pollination, climate regulation, landscape maintenance, recreation and ecotourism and cultural heritage (MEA, 2005; EEA, 2010a, 2010b). Important changes in this context have occurred over the last several decades due to the abandonment of marginal areas, such as slopes, and the concentration of activities in more favourable territories in the lowlands (MacDonald *et al.*, 2000; Strijker, 2005; Tasser *et al.,* 2007; EEA, 2010c; Sturaro *et al.*, 2012). The vertical transhumance has been replaced by permanent systems employing more productive breeds and high levels of extra-farm feed. Thus, livestock farms located in the mountains, which have mainly specialised in milk production, are becoming similar to the intensive farms of the plains (Streifeneder *et al.*, 2007). Different indicators for the total or partial evaluation of the sustainability of livestock farms have been proposed, and the synergies and trade-offs were highlighted (Smith *et al.*, 2008; Bernués *et al.*, 2011; Crosson *et al.*, 2011).

This work discusses the recent evolution of livestock systems in Alpine areas in terms of management, level of intensification, use of grassland and dependence on external inputs. Next, this study proposes the key factors to be considered when evaluating the sustainability of these systems. The contribution of Alpine livestock to global greenhouse gas (GHG) emissions is also highlighted, taking into account the mitigating action of carbon sequestration. Finally, the need to incorporate

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ecosystem services offered in the evaluation of environmental sustainability with holistic methods, such as life cycle assessment (LCA), is discussed.

Evolution and characterisation of livestock farming systems in the Alps

Animal husbandry is highly diverse across mountainous areas in Europe. Geographic and climatic traits represent limits for feedstuff production, traditionally based on forages and pastures (Andrighetto *et al.*, 1996; Porqueddu, 2007). For centuries, cattle and small ruminants able to optimise these resources were reared in extensive or semi-extensive systems.

In the Alps, cattle husbandry is historically based on small herds of local dual-purpose breeds for milk and calves or meat production, housed in closed barns located in the valley during winter and moved to high-pastures in the summer. Local dual-purpose breeds, well adapted to mountainous environments, were widespread in the Alpine regions. Over the last several decades, the Alps experienced a general abandonment of traditional farms with different regional trends. According to Streifeneder *et al.* (2007), the number of farms in the period between 1980 and 2000 decreased by 40% (from 608,199 to 368,235 farms). The highest percentage of farm closure occurred in the most decentralised areas of the Alps, where farm holdings, generally small and unprofitable, were abandoned (Giupponi *et al.*, 2006; Tasser *et al.*, 2007).

In the same context, in disadvantaged regions in terms of natural-site conditions, such as Südtiroler Berggebiet and Innsbruck Land in Austria, as much as 37% of the land has been abandoned. Similarly, in Carnia (North-East Italy), nearly 67% of formerly agriculturally used areas have been abandoned (Tasser *et al.*, 2007). In Austria and Germany, the changes were rather modest, whereas they were very strong in Italy, France and Slovenia. In particular, many of the smallest farms closed, with a tendency for the number of animals per farm to increase. The total number of livestock units reared in the Alpine regions decreased from 4,170,000 to 3,450,000 (-17%; Streifeneder *et al.*, 2007). The reduction was less evident than that of the number of active farms. Consequently, the Alps harbour fewer farms with larger herd sizes than in the past. This process has led to the selection of more specialised breeds, such as Holstein Friesian or Brown Swiss which are common on the more intensive farms. Small regional dual-purpose breeds are mainly maintained in small, traditional herds.

Table 1. Livestock sector in the Italian Alps.

Year°	1990	2000	2010	Variation in 1990-2010, %
Meadows and pastures, ha	1,109,367	1,016,180	812,236	-26.6
Cattle, n				
Farms	43,774	26,949	21,221	-51.5
Heads	578,484	492,701	446,531	-22.8
Heads/farm	13.2	18.3	21.0	+59.2
Dairy cows	275,605	223,115	194,440	-29.4
Dairy farms	37,803	20,924	15,157	-59.9
Dairy cows/dairy farm	7.3	10.7	12.8	+76.0
Sheep, n				
Farms	7901	6279	4402	-44.3
Heads	175,274	176,054	191,713	+9.4
Heads/farm	22.2	28.0	43.6	+96.3
Goats, n				
Farms	7221	6258	4442	-38.5
Heads	84,455	95,872	89,625	+6.1
Heads/farm	11.7	15.3	20.2	+72.5

Values are presented on the basis of Italian agricultural censuses (ISTAT, 2013); mountainous areas cover the provinces of Imperia, Savona, Cuneo, Torino, Vercelli, Biella, Novara, Verbano-Cusio-Ossola, Aosta, Varese, Como, Lecco, Sondrio, Bergamo, Brescia, Trento, Bolzano, Verona, Vicenza, Belluno, Pordenone, and Udine. °The values for the years 1990 and 2000 differ from those published by ISTAT in the past because recalculated in accordance with the Community rules in force in 2010.

The evolution of livestock systems in Alpine areas has also disrupted the traditional link between livestock and grassland. In many Alpine summer pastures, the stocking rates are managed at sub-optimal levels and are therefore only partially constrained by pasture productivity (Sturaro *et al.*, 2013b). In some areas, the reduction of livestock units has not caused a general reduction of the pressure on forage resources; rather, the abandonment of vertical transhumance, the increasing prevalence of high-productivity breeds and the loss of meadows has concentrated the pressure in the most favourable areas (Gusmeroli *et al.*, 2010).

In Italy, it is possible to obtain an overview of the livestock system in the Alps using the latest official agricultural censuses (ISTAT, 2013; Table 1). In 2010, meadows and pastures represented approximately 800,000 ha, with a reduction of 27% over the period 1990-2010. In the same period, there has been a noticeable reduction in cattle farms (-51%) and a less marked decline in the number of animals (-23%). As a result, the number of animals per farm has increased by 59%, from 13 animals per farm in 1990 to 21 in 2010. The dairy cow data exhibit a similar trend. In 2010, the number fell below 200,000 heads, a decrease of 29% compared to 1990, with a 76% increase in the number of heads per farm. This trend is evident by analysing the distribution of dairy farms in the Alps by classes of heads (Figure 1). During the last decade, the number of cows only increased in farms with more than 50 animals, decreasing in much smaller farms, which breed few animals but are able to effectively utilise the mountain territory.

As regards sheep and goats (Table 1), the number of farms decreased (-44 and -38%, respectively), whereas the number of animals increased (+9 and +6%, respectively). In this case, the number of heads per farm also greatly increased (+96.3 and +72.5%, respectively). A schematic framework of the livestock systems in the Italian Alps is shown in Table 2 (Bovolenta *et al.*, 2008).

In intensive dairy cattle farms, genetically improved animals – mainly Holstein Friesian and Brown Swiss – are bred in loose housing stables located in valley bottoms and fed with dry forage (often of extra-farm origin) supplemented by concentrates. Calving is distributed throughout the year as a result of the requirements of industrial dairy plants, *i.e.* uniformity of milk yield and quality. Only a few Alpine farms still employ the traditional cattle livestock system, the distinctive element of which is highland pasture utilisation during the summer, where milk is often processed in small farm dairy plants and the products are sold directly on the farm. The gradual utilisation of pastures at different altitudes to exploit the vegetation gradient is practiced by a small number of farms. Traditionally, sheep and goats were farmed together with cattle for meat production; goat dairy farms have recently ceased to be unusual in Alpine areas. The common goat breeds, farmed for milk purposes, are Saanen and Camosciata delle Alpi. In the meat and dairy sheep system, wool was once a fundamental resource for peasant families. However, this product is now of little value as it has no market, despite several enhancement efforts. Beef farms, which involve the production of suckled and weaned calves from grazing cows, are fairly widespread in the Apennines but not in the Italian Alpine region.

Factors affecting the sustainability of livestock farms in mountainous areas

The factors affecting the sustainability of mountain farming systems are many and are closely interconnected. At the farm level, technical and social aspects should be considered in relation to environmental impacts, as should the socio-economic context (Table 3). From a technical perspective, it is important to consider the degree of specialisation. As mentioned above, intensive farms have gradually replaced traditional farms in the Alps. In the recent past, intensive production systems have increased production per head and farm income but have also led to environmental problems, the abandonment of marginal lands and loss of biodiversity (Cozzi *et al.*, 2006; Gusmeroli *et al.*, 2006, 2010; Penati *et al.*, 2011). The number of dairy plants has also decreased and their average size has increased, improving the safety and hygiene of products. However, industrial processing requires milk yield and quality standardisation.

In the mountains, the dairy system is the principal productive sector. Alpine milk is mainly processed into dairy products, some of which are on the traditional food product list established by the Italian Ministry of Agricultural, Food and Forestry Policies or are recognised by the European Union as having a protected designation of origin (PDO). Today, the competitiveness of Alpine systems is linked to the ability of providing a production area and environmental, historical and cultural values (Giupponi *et al.*, 2006; Bovolenta *et al.*, 2011). Subsequently, the constraints characterising the Alpine production systems could be transformed into competitive advantages and added product value (Sturaro *et al.*, 2013a). The establishment of the Mountain Products label by the Italian Ministry of Agricultural, Food and Forestry Policies is a specific initiative to enhance PDO Alpine products. This label is granted to those products whose entire manufacturing process takes place in the mountains and that meet specific requirements, such as forage self-sufficiency for dairy products. In this way, the European Parliament established the optional quality term *mountain product* in 2012 to give a competitive advantage to producers in LFA (Reg. UE n. 1151/2012; European Commission, 2012). The application of an environmental label for animal-origin products obtained in these less favoured regions is expected to cover environmental exigencies and social and ethical issues (*e.g.*, convenient remuneration for producers, animal welfare). Another important issue is relevant to the access to pasture during most of the growing season, limiting concentrate feeding, avoiding GMOs and pesticides and favouring water and soil conservation and habitat protection (Sengstschmid *et al.*, 2011).

In addition to management decisions and animal type, forage self-sufficiency plays a key role in landscape preservation and product quality. For landscape protection, forage self-sufficiency imposes limits on the livestock loads, thus avoiding the excessive production of manure and consequent risk of eutrophication of swards. It also stimulates the improvement and valorisation of forage, in contrast to

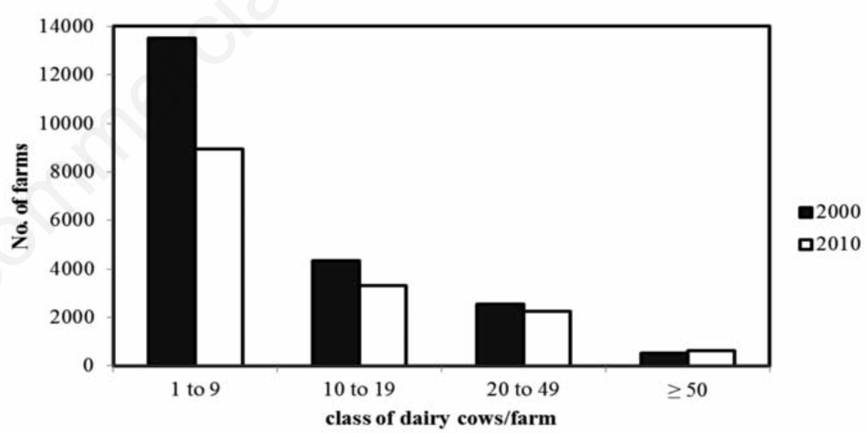

Figure 1. Number of dairy farms in the Italian Alps, by classes of heads/farm, on the basis of Italian agricultural censuses (ISTAT, 2013).

Table 2. Classification of livestock systems in Italian Alpine areas (modified from Bovolenta *et al.,* 2008).

	Management	Feeding	Reproduction	Products
Dairy cattle (or goats)	Free or tie barns (free for goats)	Dry forages and concentrates	All year long	Milk and calves
Dairy cattle (or goats)	Winter: free or tie stalls; summer: moved to Alpine pastures	Winter: dry forages and concentrates; summer: herbage and concentrates sometimes	Seasonal or all year long	Winter: milk and calves; summer: milk or cheeses
Transhumance sheep	Winter: lowland, stalls; spring-summer: Alpine pastures	Pastures with little supplementary feeding	Seasonal	Lambs (in some cases cheeses and wool)
Suckling cows	Winter: stalls; spring-summer: pastures	Forages and pastures	Seasonal	Calves

the abandonment and degradation that occurs in marginal areas. Regarding the quality of the products, forage self-sufficiency strengthens the link between the territory and the identity of the products.

From a social viewpoint, the average age of farmers and the intergenerational succession are relevant. It is well known that the average age of farmers in mountains is constantly increasing (Riedel *et al.*, 2007; ISTAT, 2010), and the generational turnover is poor due to the low interest of young people in farming (Bernués *et al.*, 2011; Ripoll-Bosch *et al.*, 2012). The harsh working conditions and low social consideration of farmers encourage young people to turn to other activities. The possibility of improving professional training for farmers and the promotion of pluriactivity in the farm could contribute to the permanence of agricultural households (Riedel *et al.*, 2007).

Animal welfare is another important issue for livestock farms sustainability. Although mountain livestock farming is considered to be respectful of animal welfare by European citizens, it can often result in restrictive conditions, such as tie-stalls. Furthermore, animals must adapt to the very different situation of summer grazing in Alpine pastures, which affects their welfare (Mattiello *et al.,* 2005). Therefore, to consider animal welfare as a positive factor characterising Alpine farming systems, it is necessary to take these aspects into account (Mattiello *et al.*, 2005; Corazzin *et al.*, 2009, 2010; Comin *et al.*, 2011).

Many methods have been proposed for assessing animal welfare from a scientific point of view. The Animal Needs Index (ANI 35L; Bartussek, 1999), developed for organic farms and based on structural and managerial conditions, assigns high positive scores to pastures. However, welfare is a multidimensional concept and cannot be truly assessed without direct observation of the animals. Environmental and animal-based criteria should be included together in an appropriate index for the welfare assessment, as proposed by the Welfare Quality® Consortium (Welfare Quality®, 2009). In fact, the peculiarities of mountain breeding have been poorly studied; consequently, the measure of welfare in these contexts still is an open issue.

Environmental sustainability is related to the maintenance of plant and animal biodiversity. Human activities over recent centuries have driven fundamental changes in the earth's land cover, increasing the extent of cropland and urban areas. These modifications in land use and the intensification of agriculture constitute the most dominant drivers of biodiversity loss globally, altering the composition, distribution, abundance and functioning of biological diversity (Kleijn *et al.*, 2009; Nagendra *et al.*, 2013).

Regarding agricultural biodiversity, the plant varieties and animal breeds less frequently used in intensive agriculture are still preserved *in situ* in the more marginal territories. These resources are important for maintaining biodiversity (Oldenbroek, 2007). In this context, it is important to support the dual-purpose cattle breeds still in existence in the Alpine region, such as Abondance and Tarentaise in France; Grigio Alpina, Valdostana and Rendena in Italy; Pinzgauer and Tiroler Grauvieh in Austria; and Herens in Switzerland (FERBA, 2013).

In mountainous areas, the strong link between local meadows and pastures and livestock has contributed to forming and maintaining a cultural landscape with high aesthetic and natural value. Several studies have shown that the abandonment of traditional livestock practices has caused grassland degradation and forest re-growth, with a consequent loss of biodiversity (MacDonald *et al*., 2000; Mottet *et al*., 2006; Cocca *et al*., 2012). Other important issues for evaluating the environmental sustainability of livestock farming in mountainous areas are the prevention of fires (Mirazo-Ruiz, 2011) and soil erosion (Pimentel and Kounang, 1998) and the emission of eutrophic pollutants (Nemecek *et al.*, 2011) and GHG. The international literature provides many reviews on these topics, but the issue of GHG emission in mountain systems deserves special attention. In particular, the possible mitigating effect of the carbon sequestration of meadows and pastures should be considered.

Finally, it is necessary to consider the rapidly changing socio-economic, political, and environmental context in which mountain farms operate. Synergies and trade-offs, evaluated in terms of positive or negative relationships between various sustainability factors at the farm level, are relevant to understanding this problem. For example, the opportunities to

Table 3. Factors affecting sustainability of livestock in Alpine areas.

Factors	Description	Contents
Technical and economic	Specialisation	Level of intensification, management model, length of production chains, multifunctionality
	Production	Production and milk quality, enhancement of meat production, traditional products, environmental labelling, direct sales, agri-ecotourism
	Animals	Use of local breeds, fertility, productivity, disease resistance, cultural value
	Forage self-sufficiency	Animal feed, product quality, landscape preservation, ties with the territory
Social	Age of farmers and intergenerational succession	Average age of farmers, social dignity of operators, lack of interest of young people in the agricultural and breeding activities, future prospects
	Professional training	Technical assistance and promotion of multifunctionality
	Tourism-recreational	Possibility to enable fruition forms of activities
	Animal welfare	Structures and breeding environment, animal management, ethological aspects
Environmental	Biodiversity	Local breed, agro-biodiversity, habitat maintenance
	Landscape	Visual value, accessibility, amenity of landscape
	Fire risk	Biomass abandonment
	Soil erosion	Loss of ground
	GHG emission	Global warming, methane, nitrous oxide, carbon dioxide, eutrophication, nitrogen
	Carbon sequestration	Carbon sink role of meadow and pastures

GHG, greenhouse gas.

develop complementary activities, such as tourism and education, could be profitable but could also result in a reduction in farming labour (Bernués *et al.*, 2011). Although mountain farms play a crucial role in terms of biodiversity conservation, many authors (Cozza *et al.*, 1996; Shelton, 2002; Battaglini *et al.*, 2004; Boitani *et al.,* 2010; Dickman *et al.*, 2011) report that the return of predators such as wolves and bears have made these livestock systems less incentivising due to increased conflicts between different stakeholders. Nevertheless, the Common Agricultural Policy has an important role in encouraging diversity, allowing farmers to counter the associated economic pressures (Low *et al.*, 2003), and the choice to leave farming and sell the land is dramatically higher under the simulated scenario characterised by the abolition of the CAP (Bartolini and Viaggi, 2013; Raggi *et al.*, 2013). This finding highlights the high dependence of farmers on payments set up by European policies. Climate change may transform some currently non-arable landscapes into potentially productive croplands, especially at higher altitudes (Howden *et al.*, 2007). However, even under well-managed sustainable systems, if farmers increase the production level, intensification can lead to greater fertiliser and pesticide pollution, higher GHG emissions and a loss of biodiversity in intensively grazed pastures (FAO, 2003).

Greenhouse gases emission and carbon sequestration of forage-based livestock systems in the mountains

FAO's 2006 report, livestock's long shadow (Steinfeld *et al.*, 2006), estimates that livestock activities contribute 18% of the total anthropogenic GHG emissions, with carbon dioxide (CO_2) accounting for 9% of global anthropogenic emissions, methane (CH_4) accounting for 35 to 40% and nitrous oxide (N_2O) accounting for 65%. Since the publication of this report, the environmental impact of agriculture and livestock, especially on GHG, has been the subject of numerous studies (Garnett, 2009; Gill *et al.*, 2010; Lesschen *et al.*, 2011; Bellarby *et al.*, 2013; Gerber *et al*., 2013), and the values proposed are often different and controversial (Goodland and Anhang, 2009; Herrero *et al.*, 2011).

The development of more accurate assessments of this impact by the scientific community is expected. It is certain that livestock generates GHG, which occurs not only through direct emission, including respiration, rumen and enteric fermentation, manure and gas exchange with the soil (Kebreab *et al.*, 2006) but also by indirect release from the fodder production (through such inputs as fertilisers, pesticides and on-farm energy use) to the transport of processed and refrigerated animal products (West and Marland, 2002; Steinfeld *et al.*, 2006). Currently, little information is available about the quantities and relevance of local and regional GHG in the Alpine region, and these values are surely different from the data averaged over the entire territory of the different countries of the Alpine macro-region (de Jong, 2009). Of the 16 million tons of CO_2 eq emissions per year from agriculture and other anthropic Alpine activities, it is estimated that approximately 15 million could be held by conserving and managing forest areas and grassland surfaces and increasing the absorption capacity of moist areas, lakes and soils, thus allowing the Alpine territory to become CO_2 neutral in the future (Soussana *et al.*, 2010).

Methane is the main component of GHG emissions in the ruminant livestock system and results from microbial anaerobic fermentation in the rumen (87%) and, to a lesser extent (13%), the intestine (Murray *et al.*, 1976; Eggleston *et al*., 2006). Ruminant animals release approximately 5% of the ingested digestible C as CH_4 (Martin *et al.,* 2009). However, the amount of emissions varies as a function of animal characteristics (body weight, breed, age, production, physiological stage) and diet (level of intake, digestibility, composition) (Gibbs and Johnson, 1993; Hegarty *et al.*, 2007; Eckard *et al.*, 2010; Seijan *et al.*, 2011; Nguyen *et al.*, 2013). In addition, some CH_4 comes from manure management, with the amount depending on the quantity of manure produced, its C and N content, the anaerobic fermentations, the temperature and the storage duration and type. In general, when liquid manure storage is predominant, systems generate more CH_4 (whereas solid manure storage produces more N_2O) (Amon *et al.*, 2006; Eggleston *et al*., 2006; Sommer *et al.*, 2009). The IPCC estimates (Eggleston *et al*., 2006) that the regional default emission factors generated from dairy cows range from 40 kg CH_4/head/year for Africa and the Middle East to 121 kg CH_4/head/year for North America. For other cattle, the regional default emission factors range from 27 kg CH_4/head/year for the Indian subcontinent to 60 kg CH_4/head/year for Oceania and include beef cows, bulls, feedlot and young cattle. In mountainous systems, based primarily on grassland and grazing, CH_4 emissions are likely high because they are strongly correlated with fibre digestion in the rumen (McDonald, 1981; Johnson and Johnson, 1995; Kirchgessner *et al.*, 1995; Clark *et al.*, 2011; Ramin and Huhtanen, 2013).

Nitrous oxide is produced by the nitrification of ammonium to nitrate or the incomplete denitrification of nitrate (Eggleston *et al*., 2006) and is the main GHG emission derived from manure (FAO, 2006). The amount of N_2O emitted depends on the amount and storage of manure, the animal feed, the soil and the weather (Soussana *et al.,* 2004; Gill *et al.*, 2010). It is often higher under conditions in which the available N exceeds the plant requirements, especially under wet conditions (Smith and Conen, 2004; Luo *et al.*, 2010). In addition, the volatilisation of manure applied to soils, fertilisers containing N, N lost via runoff and leaching from agricultural soils constitute indirect N_2O emissions related to agriculture (FAO, 2006; Vergé *et al.*, 2008; McGettigan *et al.*, 2010). Similarly to CH_4, in grassland systems characterised by overgrazing, N_2O emissions increase due to the deposition of animal excreta in the soil and the anaerobic conditions caused by the soil compaction resulting from animal trampling on the soil (van Groenigen *et al.*, 2005; Hyde *et al.*, 2006; Bhandral *et al.*, 2010). This phenomenon is exacerbated by wet soil conditions soon after grazing (Saggar *et al.*, 2004; van Beek *et al.*, 2010).

While CH_4 and N_2O emissions are dominant in livestock systems, CO_2 plays a secondary role (Flessa *et al.*, 2002; Olesen *et al.*, 2006). CO_2 is a result of breathing and rumen fermentation, but most of it is due to the production of fertilisers, concentrate and electricity as well as on-farm diesel combustion (Steinfeld *et al.*, 2006; Yan *et al.,* 2013). Moreover, when land is overgrazed, the combination of vegetative loss and soil trampling can lead to soil carbon loss and the release of CO_2 (Abril *et al.*, 2005; Steinfeld *et al.*, 2006).

However, in forage-based systems, the carbon sequestration of meadows and pastures is important. While the carbon balance is given by the difference between the photosynthetic flux and the flows of respiratory autotrophic and heterotrophic organisms in natural ecosystems, the balance in agro-ecosystems is complicated by any incoming organic inputs converted into humus in the soil and by outputs in the form of carbon removed by crops and emitted for cultivation practices and the use and disposal of materials and machinery.

In grasslands, the carbon balance can be positive, corresponding to a net capture of CO_2 (Schulze *et al.*, 2009). Their absorption capacity is estimated to be 50 to 100 g/m^2 of C per year (Soussana *et al.*, 2007), which mainly depends on the management practices. For the European continent, the estimated average value is +67 g/m^2 of C per year (Janssens *et al.*, 2003). In field crops, the balance is negative, with an average balance of -92 g/m^2 per year, which is mainly due to the cultivation of the soil (Freibauer *et al.*, 2004). It can be assumed that corn (the most important forage crop) has emission levels below the average, due to its high photosynthetic efficiency. Nevertheless, it cannot be compared to the permanent grassland. The positive balance of swards is potentially able to compensate approximately 75% of the CH_4 emitted by rumination (Tallec *et al.*, 2012). The difference between the carbon fluxes of grasslands and arable crops is much higher than these increases, making the preservation of grasslands one of the most important actions for countering global warming (Soussana *et al.*, 2010).

The CO_2 balance of grasslands varies by management practice and may be expressed in terms of energy flow auxiliary to the photosynthetic one (Figure 2). When the flow is moderate, *i.e.* in the presence of extensive management, grasslands are maintained in an oligo-mesotrophic state, characterised by high or good biodiversity and non-top yields (Gusmeroli *et al.,* 2013). The higher the flow intensification, the lower the bounds of the growth of the system (availability of material resources, especially nutrients). Furthermore, the grassland reaches an eutrophic level in which biodiversity is lost in favour of productivity, and a few nitrophilous elements take over. Under extreme conditions, the grassland degenerates into a dystrophic status, as the productivity collapses because the system is disjointed, losing all functionality and organisation. If the auxiliary energy is predominantly biological, such as in a pasture or a meadow managed with minimal mechanical power and in the absence of mineral fertiliser, the CO_2 balance will tend to increase with the yield until reaching an eutrophic state, after which it will fall into a dystrophic state. Of course, it is difficult to reach these extreme levels with organic methods of management, and it is not convenient from the viewpoint of forage quality or biodiversity conservation. If, instead, the auxiliary energy is principally fossil, as in a meadow managed with mechanical power and enriched synthetic materials, the balance will begin to show signs of decline in less advanced eutrophic stages. The high variability of soil, climate and management practices, however, makes it difficult to predict the point of inflec-

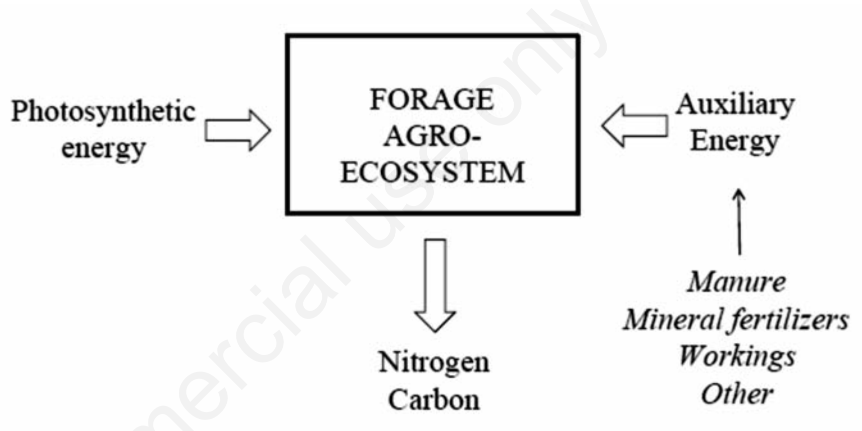

Figure 2. Input and output in forage agro-ecosystems.

Table 4. Environmental sustainability of the livestock sector in the Alps: state of the art.

Authors	Country and farming systems	Methodological approach	Category of impact					
			Eutrophication	GHG emission	Acidification	Energy demand	Ecotoxicity	Land use
Haas *et al.*, 2001	Germany, dairy farms (n=35): intensive, extensive and organic systems	LCA, N and P farm gate balances, estimation indexes for biodiversity, landscape image and animal welfare	X	X	X	X		
Penati *et al.*,2008	Italy, dairy farms (n=31)	N and P farm gate balances	X					
Alig *et al.,* 2011	Switzerland, dairy farms (n=66): plain, hills vs mountain regions	LCA	X	X		X	X	
Bassanino *et al.,* 2011	Italy, dairy farms (n=22)	N and P farm gate balances	X					
Schader *et al.*, 2012	Switzerland, organic dairy farm *vs* organic mixed farm (n=2)	LCA		X		X		
Penati *et al.*, 2013	Italy, dairy farms (n=28)	LCA	X	X	X	X		X
Guerci *et al.,* 2013b	Italy, dairy farms (n=32): summer grazing system *vs* no grazing system	LCA		X				

GHG, greenhouse gas; LCA, life cycle assessment.

tion precisely.

The key element is represented by the level of intensification. In the traditional livestock model, which is substantially closed and with permanent grasslands, the auxiliary energetic flow is mainly represented by organic waste, which is fixed by the maintainable animal loads on the grassland (Gusmeroli *et al.*, 2006). Consequently, the system was self-regulated and stationary, with no risk of eutrophication. In the open intensive models, with recourse to extra-farm feeds imposed by the high performance of the livestock, the manure risk is no longer appropriate for the assimilative capacity of swards. The system is free from rigid constraints of growth and, without the removal of waste, risks reaching eutrophic levels. Therefore, the more productive the primary consumers, the more the system becomes eutrophic and the worse the CO_2 balance.

Environmental sustainability of livestock sector in the Alps: state of the art

Table 4 summarises the state of the art about environmental sustainability of livestock sector in the Alps. In literature there are very few works on this item in this context. The environmental impact of Alpine milk production is assessed mainly by using LCA, or N and P farm-gate balances and different dairy livestock systems are studied. Often the methodology used to assess the impact categories is different, as well as the functional unit. For these reasons, data are difficult to compare.

Alig *et al.* (2011) and Penati *et al.* (2013) stress how farms in the mountain region had significantly higher energy demand per productive unit than farms in the lowland, mainly due to the more difficult climatic conditions [7.0 MJ eq/kg milk and 5.14 MJ/kg fat and protein corrected milk (FPCM) respectively for the two works]. About global warming potential, it is higher too for mountain farms (1.3, 1.4 and 1.6 kg CO_2 eq/kg milk, for plain, hill, and mountain farms respectively) (Alig *et al.*, 2011) and it increases for traditional farming system based on summer grazing when it is compared with a more intensive one (1.72 *vs* 1.55 kg CO_2 eq/kg FPCM) as a consequence of low milk yield and low feed efficiency (Guerci *et al.*, 2013b). Otherwise Haas *et al.* (2001) in a similar study found that GHG emissions for extensive dairy system are lower than in the intensive one per unit of produced milk (1.0 *vs* 1.3 t CO_2 eq/t milk), and per area (7.0 *vs* 9.4 t CO_2 eq/ha) this due mainly to mineral nitrogen fertiliser renounce. Farms with high feed self-sufficiency had significantly lower acidification potential than the others (Penati *et al.*, 2013) and this is also showed in the works where N and P surplus at the farm-gate is assessed: the most important item of N and P inputs was represented by purchased feeds and hay (Penati *et al.*, 2008; Bassanino *et al.*, 2011). All the considered studies have investigated the sustainability of Alpine livestock farms in terms of environmental impact. The analysis of literature showed several papers focused on the *positive* environmental externalities of traditional livestock farms, but there is still a lack of integration between these two approaches.

The need to assess the ecosystem services offered

Ecosystems provide humanity with several benefits, known as *ecosystem services*. As explained by the Millennium Ecosystem Assessment (MEA, 2005), these benefits include provisioning services, such as food, water and fibres; regulating services, such as the regulation of GHG and soil fertility, carbon sequestration and pollination; supporting services, such as habitats and genetic diversity for both wild and domestic animals; and cultural services, such as tourism and recreation, landscape amenity, cultural heritage and other non-material benefits. Nevertheless, humans have diminished and compromised services that are essential in many situations in an attempt to obtain food, water and fibres with the least possible effort (Gordon *et al.*, 2010; Leip *et al.*, 2010; Bernués *et al.*, 2011). In fact, intensive farming systems, which have developed in recent decades, even in the mountain and high nature value areas, are responsible for many trade-offs (Power, 2010), such as landscape degradation (Scherr and Yadav, 1996; Tscharntke *et al.*, 2005), loss of biodiversity (Henle *et al.*, 2008; Hoffmann, 2011; Marini *et al.*, 2011), reduced soil fertility and erosion (Bernués *et al.*, 2005; Schirpke *et al.*, 2012) and loss of wildlife habitat (Foley *et al.*, 2005; Stoate *et al.*, 2009).

The restoration of traditional grassland-based agricultural systems using few external inputs should help to mitigate these problems, also allowing synergies with the tourism sector in terms of rural or eco-tourism (Corti *et al.*, 2010; Parente and Bovolenta, 2012). However, many authors doubt the sustainability, both economic and environmental, of these systems, considering their low productivity (de Boer, 2003; Burney *et al.*, 2010; Steinfeld and Gerber, 2010). For example, increasing milk yield or meat per cow is one of the solutions often proposed to reduce GHG emissions from milk production. Capper *et al.* (2009), comparing the environmental impacts of dairy production in 1944 and 2007 in the USA, found that modern dairy practices require fewer resources than those in 1944. In this way, the production of CO_2 eq per kg of milk has decreased drastically from 3.65 to 1.35 kg of GHG. In another work, Gerber *et al.* (2011) processed data from 155 countries and stressed how emissions decreased as productivity increased to 2000 kg FPCM per cow per year, from 12 kg CO_2-eq/kg FPCM to approximately 3 kg CO_2-eq/kg FPCM. As productivity increased to approximately 6000 kg FPCM per cow per year, the emissions stabilised between 1.6 and 1.8 kg CO_2-eq/kg FPCM. In a review comparing the environmental impacts of livestock products, de Vries and de Boer (2010) showed that the production of 1 kg of beef resulted in 14 to 32 kg of CO_2-eq and the production of 1 kg of milk resulted in 0.84 to 1.30 CO_2-eq; the higher values within each range are for extensive systems, while the lower values are for intensive ones. In fact, the growing world population and the high demand for food require the search for a lower input for equal production levels rather than a simple reduction of input per surface unit; in other words, a higher efficiency per unit produced is needed (Godfray *et al.*, 2010; Gregory and George, 2011; Pulina *et al.*, 2011). In this historical moment (considering the international economic crisis and environmental emergency), especially for mountains and marginal areas, the challenge of low-input farms seems to be closely linked to multi-functional agriculture (Parente *et al.*, 2011; Di Felice *et al.*, 2012) and attempts to achieve the goal of being both low input and high efficiency (Nemecek *et al.*, 2011; Tilman *et al.*, 2011).

As previously described, livestock farming systems in mountains and LFA differ widely in terms of intensification degree, environmental constraints, animal genetic resources, orientation of production, market context, *etc.* Life cycle assessment is an established methodology for assessing the impact of production systems on the environment. Initially, LCA was developed to assess the environmental impact of industrial plants and production processes, but it has recently been utilised for agricultural production as well (de Vries and de Boer, 2010; Crosson *et al.*, 2011). This method, as described in the 14040 ISO standard (ISO, 2006), allows the evaluation of the environmental impact during all phases of a product or service's life. Is LCA a useful tool for a global evaluation in this context? Life cycle assessment depends on the choice of functional unit, which defines what is being studied and provides a reference to which the inputs and outputs can be related. The functional units most commonly used are amount of final products, energy or protein content in the products, land use area, farm, livestock units and gross profit (Zhang *et al.*, 2010; Crosson *et al.*, 2011). When the production (such as 1 kg of milk or meat) is used as functional unit for evaluating effects on global warming or on eutrophication, intensive systems are more sustainable than extensive ones; in contrast, when using the surface (ha) as a functional unit, the opposite result is obtained (Pirlo, 2012). However, the evaluation of the offered services might modify many of these results, especially for extensive systems. Life cycle assessment can be used to evaluate the environmental impact of livestock systems in mountain areas, and many authors (Haas *et al.*, 2001; Beauchemin *et al.*, 2010; Ripoll-Bosch *et al.*, 2012) have stressed the importance of accounting for ecosystem services in LCA using a holistic approach.

Ripoll-Bosch *et al.* (2013) highlight the issue of sheep farming system sustainability in the Spanish mountains in terms of GHG emissions. In fact, when the GHG were allocated to lamb meat production only, the emissions per kg of product decreased according to the intensification level. However, when pasture-based systems accounting for ecosystem services (calculated based on CAP agri-environmental payments), GHG emissions per kg of product increased according to the intensification level.

It is necessary to note that assessing the relative weight of these services through the CAP agro-environment payments alone does not always seem accurate, and different approaches are needed to obtain a realistic value. Although valuing ecosystem services in monetary terms can be complex and controversial, many economists are working on such a project (Costanza *et al.*, 1997; Gios *et al.*, 2006; Liu *et al.*, 2010; Maes *et al.*, 2013). In general, the evaluation method may be direct if a market value exists or indirect, which is generally defined as *willingness-to-pay*, *i.e.* the amount that people are prepared to pay in exchange for a service without a market price (De Groot *et al.*, 2002; Vanslembrouck *et al.*, 2005; Swinton *et al.*, 2007; Sukhdev, 2010). The following are generally utilised: *avoided costs*, when the services allow the society to avoid costs that it would have otherwise had to pay in the absence of the same; *replacement costs*, when the services could be replaced with human-made systems; *income factors*, when the services enhance incomes; *travel costs*, when the services may require transfer costs in the area; and *hedonic pricing*, which are the prices people will pay for goods associated with services.

An economic evaluation of ecosystem services provided by mountain farms will allow the improvement of the compensation of farmers for the public goods they offer and the distribution of the environmental costs to not only the agricultural products but also these services. Future research should consider these issues in a dynamic way, allowing the study of the results over time and from a reversibility of the process viewpoint.

Conclusions

The number of new issues that will affect the livestock sector in the next several decades is increasing due to the attention being paid to environmental protection. This general situation is leading to a legitimate anxiety of those who consider the production of food of animal origin to be one of the main causes of environmental pollution and therefore as inconsistent with sustainable development. As a consequence, a growing sense of responsibility among operators towards significant reductions in GHG is desired (to address climate change and other emergencies).

There is an obvious conflict between the intensification of animal husbandry, which aims to optimise the resource use per unit of output, limiting its impact, and the preservation of pastoral systems of disadvantaged regions, such as upland areas, which are crucial to maintaining ecosystems characterised by high biodiversity, as demonstrated by mixed livestock systems based on traditional pasture and forage, which are still present in a number of semi-natural habitats in Europe. Encouraging the development of these systems will allow activities linked to livestock production and provide different externalities and ecosystems, thereby supporting the environment-supporting programmatic indications of the future Common Agricultural Policy.

Finally, regarding Alpine farming system, much more research is required and there is the need to adopt common methods to have more data that can be compared.

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