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## Environmental sustainability of Alpine livestock farms

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2 **Environmental sustainability of livestock farms in the Alps**

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14  
15  
16 **Abstract**

17 The 2006 report concerning the environmental impact of the livestock sector published by  
18 FAO has generated scientific debate, especially considering the context of global warming and the  
19 need to provide animal products to a growing world population. However, this sector differs widely  
20 in terms of environmental context, production targets, degree of intensification and cultural role.  
21 The traditional breeding systems in the Alps were largely based on the use of meadows and pastures  
22 and produce not only milk and meat but also other fundamental positive externalities and ecosystem  
23 services, such as the conservation of genetic resources, water flow regulation, pollination, climate  
24 regulation, landscape maintenance, recreation and ecotourism and cultural heritage. In recent

25 decades, the mountain livestock, mainly represented by dairy cattle, have been affected by a  
26 dramatic reduction in the number of farms, a strong increase in the number of animals per farm, an  
27 increase in indoor production systems, more extensive use of specialised non-indigenous cattle  
28 breeds and the increasing use of extra-farm concentrates instead of meadows and pastures for  
29 fodder. The first section of this paper describes the livestock sector in the Italian Alps and analyses  
30 the most important factors affecting their sustainability. The second section discusses the need to  
31 assess the ecosystem services offered by forage-based livestock systems in mountains with  
32 particular attention to greenhouse gas (GHG) emission and its mitigation by carbon sequestration. It  
33 is concluded that the comparison between the different elements of the environmental sustainability  
34 of mountain livestock systems must be based on a comprehensive overview of the relationships  
35 between animal husbandry, the environment and the socio-economic context.

36

37 **Key words:** Environmental sustainability, Livestock farms, Alps, Greenhouse gases, Ecosystem  
38 services

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## 40 **Introduction**

41 The concept of sustainability relates to economic, social and ecological aspects that are often  
42 interconnected (Gamborg and Sandøe, 2005; Hocquette and Chatellier, 2011; Cavender-Bares *et al.*,  
43 2013). Lewandowski *et al.* (1999) defined sustainable agriculture as ‘the management and  
44 utilisation of the agricultural ecosystem in a way that maintains its biological diversity,  
45 productivity, regeneration capacity, vitality, and ability to function, so that it can fulfill – today and  
46 in the future – significant ecological, economic and social functions at the local, national and global  
47 levels and does not harm other ecosystems’.

48 The data published by FAO in 2006 about the impact of livestock (Steinfeld *et al.*, 2006) led  
49 to research and scientific debate on this issue, especially in the context of global warming and the

50 need to provide animal products to a growing world population (Nelson *et al.*, 2009; Gill *et al.*,  
51 2010; Pulina *et al.*, 2011). However, before assessing the impact of livestock, it is necessary to  
52 consider that this sector differs widely in terms of production targets, degree of intensification,  
53 environmental context and cultural role, among other characteristics.

54         The main focus of intensive systems is to ensure greater efficiency of production and a  
55 parallel reduction of environmental impacts (Guerci *et al.*, 2013). To this end, the concept of  
56 "precision livestock farming" (Auernhammer, 2001; Wang, 2001; Zhang *et al.*, 2002) has been  
57 proposed. Otherwise, livestock systems in mountain areas, which are mostly located in less  
58 favoured areas (LFA) and/or high nature value farmland (HNVF), should be based on multi-  
59 functionality (Lovell *et al.*, 2010; Bernues *et al.*, 2011; Sturaro *et al.*, 2013b). In fact, these  
60 traditional livestock systems are largely based on the use of meadows and pastures and produce not  
61 only food and fibre but also other fundamental services for society, such as conservation of genetic  
62 resources, water flow regulation, pollination, climate regulation, landscape maintenance, recreation  
63 and ecotourism and cultural heritage (MEA, 2005; EEA, 2010a; 2010b).

64         Important changes in this context have occurred over the last several decades due to the  
65 abandonment of marginal areas, such as slopes, and the concentration of activities in more  
66 favourable territories in the lowlands (MacDonald *et al.*, 2000; Strijker, 2005; Tasser *et al.*, 2007;  
67 EEA, 2010c; Sturaro *et al.*, 2012). The vertical transhumance has been replaced by permanent  
68 systems employing more productive breeds and high levels of extra-farm feed. Thus, livestock  
69 farms located in the mountains, which have mainly specialised in milk production, are becoming  
70 similar to the intensive farms of the plains (Streifeneder *et al.*, 2007). Different indicators for the  
71 total or partial evaluation of the sustainability of livestock farms have been proposed, and the  
72 synergies and trade-offs were highlighted (Smith *et al.*, 2008; Bernués *et al.*, 2011; Crosson *et al.*,  
73 2011).

74 This work discusses the recent evolution of livestock systems in Alpine areas in terms of  
75 management, level of intensification, use of grassland and dependence on external inputs. Next, this  
76 study considers the key factors to be considered when evaluating the sustainability of these systems.  
77 The contribution of Alpine livestock to global GHG emissions is also highlighted, taking into  
78 account the mitigating action of carbon sequestration. Finally, the need to incorporate ecosystem  
79 services (ES) offered in the evaluation of environmental sustainability with holistic methods, such  
80 as LCA, is discussed.

81

## 82 **Evolution and characterisation of livestock farming systems in the Alps**

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

87 In the Alps, cattle husbandry is historically based on small herds of local dual-purpose  
88 breeds for milk and calves or meat production, housed in closed barns located in the valley during  
89 winter and moved to high-pastures in the summer. Local dual-purpose breeds, well adapted to  
90 mountainous environments, were widespread in the Alpine regions.

91 Over the last several decades, the Alps experienced a general abandonment of traditional  
92 farms with different regional trends. According to Streifeneder *et al.* (2007; Table 1), the number of  
93 farms in the period between 1980 and 2000 decreased by 40% (from 608,199 to 368,235 farms).  
94 The highest percentage of farm closure occurred in the most decentralised areas of the Alps, where  
95 farm holdings, generally small and unprofitable, were abandoned (Giupponi *et al.*, 2006; Tasser *et*  
96 *al.*, 2007).

97 In the same context, in disadvantaged regions in terms of natural-site conditions, such as  
98 Südtiroler Berggebiet and Innsbruck Land in Austria, as much as 37% of the land has been

99 abandoned. Similarly, in Carnia (northeastern Italy), nearly 67% of formerly agriculturally used  
100 areas have been abandoned (Tasser *et al.*, 2007). In Austria and Germany, the changes were rather  
101 modest, whereas they were very strong in Italy, France and Slovenia. In particular, many of the  
102 smallest farms closed, with a tendency for the number of animals per farm to increase. The total  
103 number of livestock units reared in the Alpine regions decreased from 4,170,000 to 3,450,000 (-  
104 17%, Streifeneder *et al.*, 2007). The reduction was less evident than that of the number of active  
105 farms. Consequently, the Alps contain fewer farms with larger herd sizes than in the past. This  
106 process has led to the selection of more specialised breeds, such as Holstein Friesian or Brown  
107 Swiss, which are common on the more intensive farms. Small regional dual-purpose breeds are  
108 mainly maintained in small, traditional herds.

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

116         In Italy, it is possible to obtain an overview of the livestock system in the Alps using the  
117 latest official agricultural censuses (ISTAT, 2013; Table 2). In 2010, meadows and pastures  
118 represented approximately 800,000 ha, with a reduction of 27% over the period 1990-2010. In the  
119 same period, there has been a noticeable reduction in cattle farms (- 51%) and a less marked decline  
120 in the number of animals (- 23%). As a result, the number of animals per farm has increased by  
121 59%, from 13 animals per farm in 1990 to 21 in 2010. The dairy cow data exhibit a similar trend. In  
122 2010, the number fell below 200,000 heads, a decrease of 29% compared to 1990, with a 76%  
123 increase in the number of heads per farm. This trend is evident by analysing the distribution of

124 cattle farms in the Alps by classes of heads (Table 3). During the last two decades, the number of  
125 cows only increased in farms with more than 50 cows, decreasing in much smaller farms, which  
126 breed few animals but are able to effectively utilise the mountain territory.

127 Concerning sheep and goats (Table 2), the number of farms decreased (- 44% and - 38%,  
128 respectively), whereas the number of animals increased (+ 9% and + 6%, respectively). In this case,  
129 the number of heads per farm also greatly increased (+ 119.0% and + 106.4%, respectively).

130 A schematic framework of the livestock systems in the Italian Alps is shown in Table 4  
131 (Bovolenta *et al.*, 2008).

132 In intensive dairy cattle farms, genetically improved animals - mainly Holstein Friesian and  
133 Brown Swiss breeds – are bred in loose housing stables located in valley bottoms and fed with dry  
134 forage (often of extra-farm origin) supplemented by concentrates. Calving is distributed throughout  
135 the year as a result of the requirements of industrial dairy plants, i.e., uniformity of milk yield and  
136 quality.

137 Only a few Alpine farms still employ the traditional cattle livestock system, the distinctive  
138 element of which is highland pasture utilisation during the summer, where milk is often processed  
139 in small farm dairy plants and the products are sold directly on the farm. The gradual utilisation of  
140 pastures at different altitudes to exploit the vegetation gradient is practiced by a small number of  
141 farms.

142 Traditionally, sheep and goats were farmed together with cattle or for meat production;  
143 however, goat dairy farms have recently ceased to be unusual in Alpine areas. The common goat  
144 breeds, farmed for milk purposes, are Saanen and Camosciata delle Alpi. In the meat and dairy  
145 sheep system, wool was once a fundamental resource for peasant families. However, this product is  
146 now of little value as it has no market, despite several enhancement efforts.

147 Beef farms, which involve the production of suckled and weaned calves from grazing cows,  
148 are fairly widespread in the Apennines but not in the Italian Alpine region.



149

## 150 **Factors affecting the sustainability of livestock farms in mountainous areas**

151 The factors affecting the sustainability of mountain farming systems are many and are  
152 closely interconnected. At the farm level, technical and social aspects should be considered in  
153 relation to environmental impacts, as should the socio-economic context (Table 5).

154 From a technical perspective, it is important to consider the degree of specialisation. As  
155 mentioned above, intensive farms have gradually replaced traditional farms in the Alps. In the  
156 recent past, intensive production systems have increased production per head and farm income but  
157 have also led to environmental problems, the abandonment of marginal lands and loss of  
158 biodiversity (Cozzi *et al.*, 2006; Gusmeroli *et al.*, 2006, 2010; Penati *et al.*, 2011). The number of  
159 dairy plants has also decreased and their average size has increased, improving the safety and  
160 hygiene of products. However, industrial processing requires milk yield and quality standardisation.

161 In the mountains, the milk system is the principal productive sector. Alpine milk is mainly  
162 processed into dairy products, some of which are on the “traditional food product” (TFP) list  
163 established by the Italian Ministry of Agricultural, Food and Forestry Policies or are recognised by  
164 the European Union as having a protected designation of origin (PDO). Today, the competitiveness  
165 of Alpine systems is linked to the ability to provide a production area and environmental, historical  
166 and cultural values (Giupponi *et al.*, 2006; Bovolenta *et al.*, 2011). Subsequently, the constraints  
167 characterising the Alpine production systems could be transformed into competitive advantages and  
168 added product value (Sturaro *et al.*, 2013b). The establishment of the Mountain Products label by  
169 the Italian Ministry of Agricultural, Food and Forestry Policies is a specific initiative to enhance  
170 PDO Alpine products. This label is granted to those products whose entire manufacturing process  
171 takes place in the mountains and that meet specific requirements, such as forage self-sufficiency for  
172 dairy products. In this way, the European Parliament established the optional quality term  
173 ‘mountain product’ in 2012 to give a competitive advantage to producers in less favoured areas

174 (Reg. UE n. 1151/2012). The application of an environmental label for animal-origin products  
175 obtained in these less favoured regions is expected to cover environmental exigencies and social  
176 and ethical issues (e.g., convenient remuneration for producers, animal welfare). Another important  
177 issue is relevant to the access to pasture during most of the growing season, limiting concentrate  
178 feeding, avoiding GMOs and pesticides and favouring water and soil conservation and habitat  
179 protection (Oakdene Hollins, 2011).

180 In addition to management decisions and animal type, forage self-sufficiency plays a key  
181 role in landscape preservation and product quality. For landscape protection, forage self-sufficiency  
182 imposes limits on the livestock loads, thus avoiding the excessive production of manure and  
183 consequent risk of eutrophication of swards. It also stimulates the improvement and valorisation of  
184 forage, in contrast to the abandonment and degradation that occurs in marginal areas. Regarding the  
185 quality of the products, forage self-sufficiency strengthens the link between the territory and the  
186 identity of the products.

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

195 Animal welfare is another important issue for livestock farms sustainability. Although  
196 mountain livestock farming is considered to be respectful of animal welfare by European citizens, it  
197 can often result in restrictive conditions, such as tie-stalls. Furthermore, animals must adapt to the  
198 very different situation of summer grazing in Alpine pastures, which affects their welfare (Mattiello

199 *et al.*, 2005). Therefore, to consider animal welfare as a positive factor characterising Alpine  
200 farming systems, it is necessary to take these aspects into account (Mattiello *et al.*, 2005; Corazzin  
201 *et al.*, 2009, 2010; Comin *et al.*, 2011).

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

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

216 Regarding agricultural biodiversity, the plant varieties and animal breeds less frequently  
217 used in intensive agriculture are still preserved "in situ" in the more marginal territories. These  
218 resources are important for maintaining biodiversity (Oldenbroek, 2007).

219 In this context, it is important to support the dual-purpose cattle breeds still in existence in  
220 the Alpine region, such as Abondance and Tarentaise in France; Grigio Alpina, Valdostana and  
221 Rendena in Italy; Pinzgauer and Tiroler Grauvieh in Austria; and Herens in Switzerland (see  
222 [www.ferba.info](http://www.ferba.info)).

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

234 Finally, it is necessary to consider the rapidly changing socio-economic, political, and  
235 environmental context in which mountain farms operate. Synergies and trade-offs, evaluated in  
236 terms of positive or negative relationships between various sustainability factors at the farm level,  
237 are relevant to understanding this problem. For example, the opportunities to develop  
238 complementary activities, such as tourism and education, could be profitable but could also result in  
239 a reduction in farming labour (Bernués *et al.*, 2011). Although mountain farms play a crucial role in  
240 terms of biodiversity conservation, many authors (Cozza *et al.*, 1996; Shelton, 2002; Battaglini *et*  
241 *al.*, 2004; Boitani *et al.*, 2010; Dickman *et al.*, 2011) report that the return of predators such as  
242 wolves and bears have made these livestock systems less incentivising due to increased conflicts  
243 between different stakeholders. Nevertheless, the Common Agricultural Policy has an important  
244 role in encouraging diversity, allowing farmers to counter the associated economic pressures (Low  
245 *et al.*, 2003), and the choice to leave farming and sell the land is dramatically higher under the  
246 simulated scenario characterised by the abolition of the CAP (Bartolini *et al.*, 2013; Raggi *et al.*,

247 2013). This finding highlights the high dependence of farmers on payments set up by European  
248 policies.

249 Climate change may transform some currently non-arable landscapes into potentially  
250 productive croplands, especially at higher altitudes (Howden *et al.*, 2007). However, even under  
251 well-managed sustainable systems, if farmers increase the production level, intensification can lead  
252 to greater fertiliser and pesticide pollution, higher GHG emissions and a loss of biodiversity in  
253 intensively grazed pastures (FAO, 2003).

254

### 255 **GHG emission and carbon sequestration of forage-based livestock systems in the mountains**

256 FAO's 2006 report, 'Livestock's Long Shadow' (Steinfeld *et al.*, 2006), estimates that  
257 livestock activities contribute 18 % of the total anthropogenic greenhouse gas emissions, with  
258 carbon dioxide (CO<sub>2</sub>) accounting for 9 % of global anthropogenic emissions, methane (CH<sub>4</sub>)  
259 accounting for 35 to 40 % and nitrous oxide (N<sub>2</sub>O) accounting for 65 %.

260 Since the publication of this report, the environmental impact of agriculture and livestock,  
261 especially on GHG, has been the subject of numerous studies (see, for example, Garnett, 2009; Gill  
262 *et al.*, 2010; Lesschen *et al.*, 2011; Bellarby *et al.*, 2013; Gerber *et al.*, 2013), and the values  
263 proposed are often different and controversial (see, for example, Goodland and Anhang, 2009;  
264 Herrero *et al.*, 2011).

265 The development of more accurate assessments of this impact by the scientific community is  
266 expected. It is certain that livestock generates GHG, which occurs not only through direct emission,  
267 including respiration, rumen and enteric fermentation, manure and gas exchange with the soil  
268 (Kebreab *et al.*, 2006) but also by indirect release from the fodder production (through such inputs  
269 as fertilisers, pesticides and on-farm energy use) to the transport of processed and refrigerated  
270 animal products (West and Marland, 2002; Steinfeld *et al.*, 2006). Currently, little information is

271 available about the quantities and relevance of local and regional GHG in the Alpine region, and  
272 these values are surely different from the data averaged over the entire territory of the different  
273 countries of the Alpine macro-region (de Jong, 2009). Of the 16 million tons of CO<sub>2</sub> eq emissions  
274 per year from agriculture and other anthropic Alpine activities, it is estimated that approximately 15  
275 million could be held by conserving and managing forest areas, extending grassland surfaces and  
276 increasing the absorption capacity of moist areas, lakes and soils, thus allowing the Alpine territory  
277 to become CO<sub>2</sub> neutral in the future (Soussana *et al.*, 2010).

278 Methane is the main component of GHG emissions in the ruminant livestock system and  
279 results from microbial anaerobic respiration in the rumen (87%) and, to a lesser extent (13%), the  
280 intestine (Murray *et al.*, 1976; IPCC, 2006). Ruminant animals release approximately 5% of the  
281 ingested digestible C as CH<sub>4</sub> (Martin *et al.*, 2009). However, the amount of emissions varies as a  
282 function of animal characteristics (body weight, breed, age, production, physiological stage) and  
283 diet (level of intake, digestibility, composition) (Gibbs and Johnson, 1993; Hegarty *et al.*, 2007;  
284 Eckard *et al.*, 2010; Seijan *et al.*, 2011; Nguyen *et al.*, 2013). In addition, some CH<sub>4</sub> comes from  
285 manure management, with the amount depending on the quantity of manure produced, its C and N  
286 content, the anaerobic fermentations, the temperature and the storage duration and type. In general,  
287 when liquid manure storage is predominant, systems generate more CH<sub>4</sub> (whereas solid manure  
288 storage produces more N<sub>2</sub>O) (Amon *et al.*, 2006; IPCC, 2006; Sommer *et al.*, 2009). The IPCC  
289 (2006) estimates that the regional default emission factors generated from dairy cows range from 40  
290 kg CH<sub>4</sub>/head/year for Africa and the Middle East to 121 kg CH<sub>4</sub>/head/year for North America. For  
291 other cattle, the regional default emission factors range from 27 kg CH<sub>4</sub>/head/year for the Indian  
292 subcontinent to 60 kg CH<sub>4</sub>/head/year for Oceania and include beef cows, bulls, feedlot and young  
293 cattle. In mountainous systems, based primarily on grassland and grazing, CH<sub>4</sub> emissions are likely  
294 high because they are strongly correlated with fibre digestion in the rumen (McDonald, 1981;

295 Johnson and Johnson, 1995; Kirchgessner *et al.*, 1995; Clark *et al.*, 2011; Ramin and Huhtanen,  
296 2013).

297 Nitrous oxide is produced by the nitrification of ammonium to nitrate or the incomplete  
298 denitrification of nitrate (IPCC, 2006) and is the main GHG emission derived from manure (FAO,  
299 2006). The amount of N<sub>2</sub>O emitted depends on the amount and storage of manure, the animal feed,  
300 the soil and the weather (Soussana *et al.*, 2004; Gill *et al.*, 2010). It is often higher under conditions  
301 in which the available N exceeds the plant requirements, especially under wet conditions (Smith  
302 and Conen, 2004; Luo *et al.*, 2010). In addition, the volatilisation of manure applied to soils,  
303 fertilisers containing N, N lost via runoff and leaching from agricultural soils constitute indirect  
304 N<sub>2</sub>O emissions related to agriculture (FAO, 2006; Vérgé *et al.*, 2008; McGettigan *et al.*, 2010).  
305 Similarly to CH<sub>4</sub>, in grassland systems characterised by overgrazing, N<sub>2</sub>O emissions increase due  
306 to the deposition of animal excreta in the soil and the anaerobic conditions caused by the soil  
307 compaction resulting from animal trampling on the soil (van Groenigen *et al.*, 2005; Hyde *et al.*,  
308 2006; Bhandral *et al.*, 2010). This phenomenon is exacerbated by wet soil conditions soon after  
309 grazing (Saggar *et al.*, 2004; van Beek *et al.*, 2010).

310 Whereas CH<sub>4</sub> and N<sub>2</sub>O emissions are dominant in livestock systems, CO<sub>2</sub> plays a secondary  
311 role (Flessa *et al.*, 2002; Olesen *et al.*, 2006). CO<sub>2</sub> is a result of breathing and rumen fermentation,  
312 but most of it is due to the production of fertilisers, concentrate and electricity as well as on-farm  
313 diesel combustion (Steinfeld *et al.*, 2006; Yan *et al.*, 2013). Moreover, when land is overgrazed, the  
314 combination of vegetative loss and soil trampling can lead to soil carbon loss and the release of CO<sub>2</sub>  
315 (Abril *et al.*, 2005; Steinfeld *et al.*, 2006).

316 However, in forage-based systems, the carbon sequestration of meadows and pastures is  
317 important. Whereas the carbon balance is given by the difference between the photosynthetic flux  
318 and the flows of respiratory autotrophic and heterotrophic organisms in natural ecosystems, the  
319 balance in agro-ecosystems is complicated by any incoming organic inputs converted into humus in

320 the soil and by outputs in the form of carbon removed by crops and emitted for cultivation practices  
321 and the use and disposal of materials and machinery.

322 In grasslands, the carbon balance can be positive, corresponding to a net capture of CO<sub>2</sub>  
323 (Schulze *et al.*, 2009). Their absorption capacity is estimated to be 50-100 g/m<sup>2</sup> of C per year  
324 (Soussana *et al.*, 2007), which mainly depends on the management practices. For the European  
325 continent, the estimated average value is + 67 g/m<sup>2</sup> of C per year (Janssens *et al.*, 2003). In field  
326 crops, the balance is negative, with an average balance of - 92 g/m<sup>2</sup> per year, which is mainly due to  
327 the cultivation of the soil (Freibauer *et al.*, 2004). The positive balance of swards is potentially able  
328 to compensate approximately 75% of the CH<sub>4</sub> emitted by rumination (Tallec *et al.*, 2012). The  
329 difference between the carbon fluxes of grasslands and arable crops is much higher than these  
330 increases, making the preservation of grasslands one of the most important actions for countering  
331 global warming (Soussana *et al.*, 2010).

332 The CO<sub>2</sub> balance of grasslands varies by management practice and may be expressed in  
333 terms of energy flow auxiliary to the photosynthetic one (Figure 1). When the flow is moderate, i.e.,  
334 in the presence of extensive management, grasslands are maintained in an oligo-mesotrophic state,  
335 characterised by high or good biodiversity and non-top yields (Gusmeroli *et al.*, 2013). The higher  
336 the flow intensification, the lower the bounds of the growth of the system (availability of material  
337 resources, especially nutrients). Furthermore, the grassland reaches an eutrophic level in which  
338 biodiversity is lost in favour of productivity, and a few nitrophilous elements take over. Under  
339 extreme conditions, the grassland degenerates into a dystrophic status, as the productivity collapses  
340 because the system is disjointed, losing all functionality and organisation. If the auxiliary energy is  
341 predominantly biological, such as in a pasture or a meadow managed with minimal mechanical  
342 power and in the absence of mineral fertiliser, the CO<sub>2</sub> balance will tend to increase with the yield  
343 until reaching an eutrophic state, after which it will fall into a dystrophic state. Of course, it is  
344 difficult to reach these extreme levels with organic methods of management, and it is not



345 convenient from the viewpoint of forage quality or biodiversity conservation. If, instead, the  
346 auxiliary energy is principally fossil, as in a meadow managed with mechanical power and enriched  
347 synthetic materials, the balance will begin to show signs of decline in less advanced eutrophic  
348 stages. The high variability of soil, climate and management practices, however, makes it difficult  
349 to predict the point of inflection precisely.

350         The key element is represented by the level of intensification. In the traditional livestock  
351 model, which is substantially closed and with permanent grasslands, the auxiliary energetic flow is  
352 mainly represented by organic waste, which is fixed by the maintainable animal loads on the  
353 grassland (Gusmeroli *et al.*, 2006). Consequently, the system was self-regulated and stationary, with  
354 no risk of eutrophication. In the open intensive models, with recourse to extra-farm feeds imposed  
355 by the high performance of the livestock, the manure risk is no longer appropriate for the  
356 assimilative capacity of swards. The system is free from rigid constraints of growth and, without the  
357 removal of waste, risks reaching eutrophic levels. Therefore, the more productive the primary  
358 consumers, the more the system becomes eutrophic and the worse the CO<sub>2</sub> balance.

359

### 360 **The need to assess the ecosystem services offered**

361         Ecosystems provide humanity with several benefits, known as “ecosystem services”. As  
362 explained by the Millennium Ecosystem Assessment (MEA, 2005), these benefits include  
363 provisioning services, such as food, water and fibres; regulating services, such as the regulation of  
364 GHG and soil fertility, carbon sequestration and pollination; supporting services, such as habitats  
365 and genetic diversity for both wild and domestic animals; and cultural services, such as tourism and  
366 recreation, landscape amenity, cultural heritage and other non-material benefits. Nevertheless,  
367 humans have diminished and compromised services that are essential in many situations in an  
368 attempt to obtain food, water and fibres with the least possible effort (Leip *et al.*, 2010; Gordon *et*  
369 *al.*, 2010; Bernués *et al.*, 2011). In fact, intensive farming systems, which have developed in recent

370 decades, even in the mountain and high nature value areas, are responsible for many trade-offs  
371 (Power, 2010), such as landscape degradation (Scherr and Yadav, 1996; Tschardtke *et al.*, 2005),  
372 loss of biodiversity (Henle *et al.*, 2008; Hoffmann, 2011; Marini *et al.*, 2011), reduced soil fertility  
373 and erosion (Bernués *et al.*, 2005; Schirpke *et al.*, 2012) and loss of wildlife habitat (Foley *et al.*,  
374 2005; Stoate *et al.*, 2009).

375 The restoration of traditional grassland-based agricultural systems using few external inputs should  
376 help to mitigate these problems, also allowing synergies with the tourism sector in terms of rural or  
377 eco-tourism (Corti *et al.*, 2010; Parente and Bovolenta, 2012). However, many authors doubt the  
378 sustainability, both economic and environmental, of these systems, considering their low  
379 productivity (de Boer, 2003; Burney *et al.*, 2010; Steinfeld and Gerber, 2010). For example,  
380 increasing milk yield or meat per cow is one of the solutions often proposed to reduce GHG  
381 emissions from milk production. Capper *et al.* (2009), comparing the environmental impacts of  
382 dairy production in 1944 and 2007 in the USA, found that modern dairy practices require fewer  
383 resources than those in 1944. In this way, the production of CO<sub>2</sub> eq per kg of milk has decreased  
384 drastically from 3.65 to 1.35 kg of GHG. In another work, Gerber *et al.* (2011) processed data from  
385 155 countries and stressed how emissions decreased as productivity increased to 2000 kg FPCM  
386 (milk yield expressed as kg fat and protein corrected milk) per cow per year, from 12 kg CO<sub>2</sub>-eq/kg  
387 FPCM to approximately 3 kg CO<sub>2</sub>-eq/kg FPCM. As productivity increased to approximately 6000  
388 kg FPCM per cow per year, the emissions stabilised between 1.6 and 1.8 kg CO<sub>2</sub>-eq/kg FPCM. In a  
389 review comparing the environmental impacts of livestock products, de Vries and de Boer (2010)  
390 showed that the production of 1 kg of beef resulted in 14 to 32 kg of CO<sub>2</sub>-eq and the production of 1  
391 kg of milk resulted in 0.84 to 1.30 CO<sub>2</sub>-eq; the higher values within each range are for extensive  
392 systems, while the lower values are for intensive ones.

393 In fact, the growing world population and the high demand for food require the search for a  
394 “lower input” for equal production levels rather than a simple reduction of input per surface unit; in

395 other words, a higher efficiency per unit produced is needed (Godfray *et al.*, 2010; Gregory and  
396 George, 2011; Pulina *et al.*, 2011). In this historical moment (considering the international  
397 economic crisis and environmental emergency), especially for mountains and marginal areas, the  
398 challenge of low-input farms seems to be closely linked to multi-functional agriculture (Parente *et*  
399 *al.*, 2011; Di Felice *et al.*, 2012) and attempts to achieve the goal of being both “low input” and  
400 “high efficiency” (Nemecek *et al.*, 2011; Tilman *et al.*, 2011).

401 As previously described, livestock farming systems in mountains and less favoured areas  
402 differ widely in terms of intensification degree, environmental constraints, animal genetic resources,  
403 orientation of production, market context, etc. LCA is an established methodology for assessing the  
404 impact of production systems on the environment. Initially, LCA was developed to assess the  
405 environmental impact of industrial plants and production processes, but it has recently been utilised  
406 for agricultural production as well (de Vries and de Boer, 2010; Crosson *et al.*, 2011). This method,  
407 as described in the 14040 ISO standard (ISO, 2006), allows the evaluation of the environmental  
408 impact during all phases of a product or service’s life. Is LCA a useful tool for a global evaluation  
409 in this context?

410 LCA depends on the choice of functional unit, which defines what is being studied and  
411 provides a reference to which the inputs and outputs can be related. The functional units most  
412 commonly used are amount of final products, energy or protein content in the products, land use  
413 area, farm, livestock units and gross profit (Zhang *et al.*, 2010; Crosson *et al.*, 2011). When the  
414 production (such as 1 kg of milk or meat) is used as functional unit for evaluating effects on global  
415 warming or on eutrophication, intensive systems are more sustainable than extensive ones; in  
416 contrast, when using the surface (ha) as a functional unit, the opposite result is obtained (Pirlo,  
417 2012). However, the evaluation of the offered services might modify many of these results,  
418 especially for extensive systems. LCA can be used to evaluate the environmental impact of  
419 livestock systems in mountain areas, and many authors (Haas *et al.*, 2001; Beauchemin *et al.*, 2010;

420 Ripoll-Bosch *et al.*, 2012b) have stressed the importance of accounting for ecosystem services in  
421 LCA using a holistic approach.

422 Ripoll-Bosch *et al.* (2012a) highlight the issue of sheep farming system sustainability in the  
423 Spanish mountains in terms of GHG emissions. In fact, when the GHG were allocated to lamb meat  
424 production only, the emissions per kg of product decreased according to the intensification level.  
425 However, when pasture-based systems accounting for ecosystem services (calculated based on CAP  
426 agri-environmental payments), GHG emissions per kg of product increased according to the  
427 intensification level.

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

441 An economic evaluation of ecosystem services provided by mountain farms will allow the  
442 improvement of the compensation of farmers for the public goods they offer and the distribution of  
443 the environmental costs to not only the agricultural products but also these services.

444 Future research should consider these issues in a dynamic way, allowing the study of the  
445 results over time and from a viewpoint of the reversibility of the process.

446

## 447 **Conclusions**

448 The number of new issues that will affect the livestock sector in the next several decades is  
449 increasing due to the attention being paid to environmental protection. This general situation is  
450 leading to a clear anxiety on the part of the portion of the world population that consider the  
451 production of food of animal origin to be one of the main causes of environmental pollution and  
452 therefore inconsistent with sustainable development. As a consequence, a growing sense of  
453 responsibility among operators towards significant reductions in GHG is desired (to address climate  
454 change and other emergencies).

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

463

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- 874 \* All authors contributed equally to the preparation of this manuscript, and the list follows the  
875 alphabetical order.

**Table 1.** Variation of farms and livestock units in the Alps between 1980 and 2000 <sup>(1)</sup>

Country	Agricultural farms (n.)			Livestock units (LU), total			(LU/permanent grassland, ha)		
	2000	1980	2000-1980 (%)	2000	1980	2000-1980 (%)	2000	1980	2000-1980 (%)
Austria	96,205	119,837	-19,7	1,076,656	1,210,981	-11,1	0,7	0,8	-8,3
Switzerland	26,562	41,363	-35,8	538,066	607,310	-11,4	2,0	2,2	-8,6
Germany	22,511	31,623	-28,8	661,064	705,028	-6,2	2,1	1,7	24,2
France	28,571	52,647	-45,7	384,604	563,752	-31,8	0,7	1,1	-34,6
Liechtenstein	199	494	-59,7	4,608	6,524	-29,4	1,8	2,2	-18,5
Italy	171,038	309,146	-44,7	642,546	900,283	-28,6	0,6	0,7	-14,9
Slovenia	23,149	53,089	-56,4	146,399	181,282	-19,2	1,4	1,2	15,2
Alps total	368,235	608,199	-39,5	3,453,943	4,175,160	-17,3	0,9	1,0	-8,9

<sup>(1)</sup> Modify from Streifeneder *et al.*, 2007

**Table 2.** Livestock sector in the Italian Alps<sup>(1)</sup>

Year <sup>(2)</sup>	1990	2000	2010	Variation 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	7,901	6,279	4,402	-44.3
Heads	175,274	176,054	191,713	+9.4
Heads/farm	22.2	28.0	43.6	+96.3
Goats (n.):				
Farms	7,221	6,258	4,442	-38.5
Heads	84,455	95,872	89,625	+6.1
Heads/farm	11.7	15.3	20.2	+72.5

<sup>(1)</sup> On the basis of Italian agricultural censuses (ISTAT, 2013); mountainous areas in 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

<sup>(2)</sup> 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



**Table 3.** Number of farms with cattle in the Italian Alps, by classes of heads/farm, and variation 1990 - 2010<sup>(1)</sup>

Heads per farm	1-5	6-9	10-19	20-49	50-99	> 100
Farms with cattle (n.):						
year 1990	20,027	7,696	8,525	5,782	1,286	458
year 2000	9,511	4,448	5,831	5,181	1,405	573
year 2010	7,033	3,327	4,496	4,331	1,437	597
Variation 1990 - 2010 (%)	-65	-57	-47	-25	+12	+30

<sup>(1)</sup> On the basis of Italian national censuses (ISTAT, 2013)

**Table 4.** Classification of livestock systems in Italian alpine areas<sup>(1)</sup>

	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 (kids)
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 (or kids) - Summer: milk or cheeses
Transhumance sheep	- Winter: lowland, stalls - Spring- summer: alpine pastures	Pastures with few supplementary feeding	Seasonal	Lambs (in some cases cheeses and wool)
Suckling cows	- Winter: stalls - Spring- summer: pastures	Forages and pastures	Seasonal	Calves

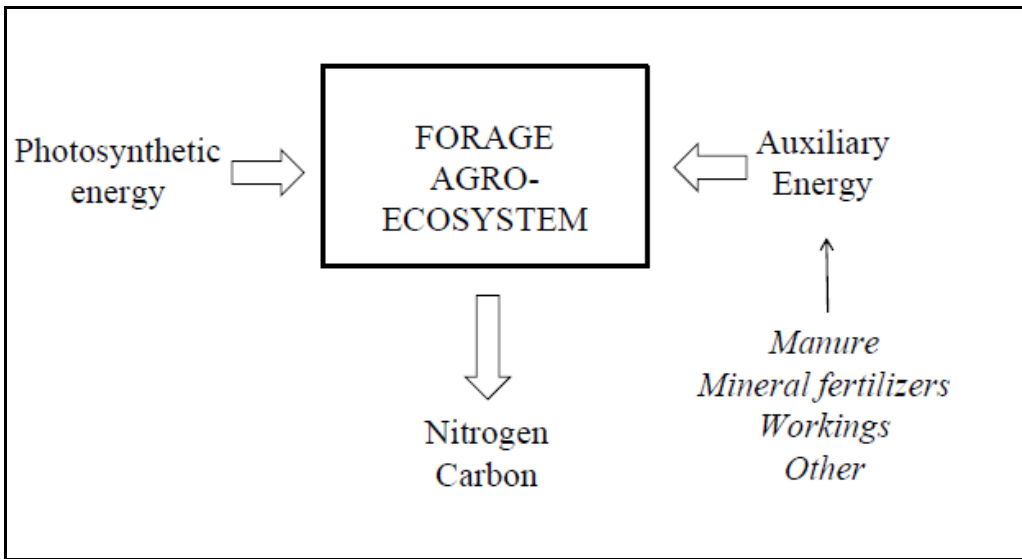
<sup>(1)</sup> Modified from Bovolenta *et al.*, 2008

**Table 5.** Factors affecting sustainability of livestock in alpine areas

Factors	Description	Contents
Technical	<ul style="list-style-type: none"> <li>- Specialization</li> <li>- Product</li> <li>- Animals</li> <li>- Forage self-sufficiency</li> </ul>	<ul style="list-style-type: none"> <li>- intensive farms gradually replace the traditional ones;</li> <li>- milk yield, milk quality, traditional products, label;</li> <li>- breeds, fertility, productivity, disease resistance;</li> <li>- landscape preservation and product quality.</li> </ul>
Social	<ul style="list-style-type: none"> <li>- Age of farmers</li> <li>- Intergenerational succession</li> <li>- Professional training</li> <li>- Animal welfare</li> </ul>	<ul style="list-style-type: none"> <li>- average age of farmers constantly increase;</li> <li>- scarce interest of young people for breeding activity;</li> <li>- assistance and promotion of pluriactivity;</li> <li>- agro-ecosystems conservation, landscape, rural tourism, maintenance of local traditions.</li> </ul>
Environmental	<ul style="list-style-type: none"> <li>- Biodiversity</li> <li>- Landscape</li> <li>- Fire risk</li> <li>- Soil erosion</li> <li>- GHG emission</li> <li>- Carbon sequestration</li> </ul>	<ul style="list-style-type: none"> <li>- local breed; agro-biodiversity;</li> <li>- homogeneity/amenity of landscape;</li> <li>- increase in biomass due to the abandonment</li> <li>- loss of ground</li> <li>- methane, nitrous oxide and carbon dioxide emissions from livestock activities;</li> <li>- carbon sink role of meadow and pastures in forage-based systems.</li> </ul>

889 **Figure 1.** Input and output in forage agro-ecosystems

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