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Research article

Greenhouse gas balance of mountain dairy farms as affected by grassland carbon sequestration

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ABSTRACT

Recent studies on milk production have often focused on environmental impacts analysed using the Life Cycle Assessment (LCA) approach. In grassland-based livestock systems, soil carbon sequestration might be a potential sink to mitigate greenhouse gas (GHG) balance. Nevertheless, there is no commonly shared methodology. In this work, the GHG emissions of small-scale mountain dairy farms were assessed using the LCA approach. Two functional units, kg of Fat and Protein Corrected Milk (FPCM) and Utilizable Agricultural Land (UAL), and two different emissions allocations methods, no allocation and physical allocation, which accounts for the co-product beef, were considered. Two groups of small-scale dairy farms were identified based on the Livestock Units (LU) reared: <30 LU (LLU) and >30 LU (HLU). Before considering soil carbon sequestration in LCA, performing no allocation methods, LLU farms tended to have higher GHG emission than HLU farms per kg of FPCM (1.94 vs. 1.59 kg CO_2-eq/kg FPCM, $P \leq 0.10$), whereas the situation was reversed upon considering the m^2 of UAL as a functional unit (0.29 vs. 0.89 kg CO_2-eq/m^2, $P \leq 0.05$). Conversely, considering physical allocation, the difference between the two groups became less noticeable. When the contribution from soil carbon sequestration was included in the LCA and no allocation method was performed, LLU farms registered higher values of GHG emission per kg of FPCM than HLU farms (1.38 vs. 1.10 kg CO_2-eq/kg FPCM, $P \leq 0.05$), and the situation was likewise reversed in this case upon considering the m^2 of UAL as a functional unit (0.22 vs. 0.73 kg CO_2-eq/m^2, $P \leq 0.05$). To highlight how the presence of grasslands is crucial for the carbon footprint of small-scale farms, this study also applied a simulation for increasing the forage self-sufficiency of farms to 100%. In this case, an average reduction of GHG emission per kg of FPCM of farms was estimated both with no allocation and with physical allocation, reaching 27.0% and 28.8%, respectively.

1. Introduction

Recent scientific literature have often assessed carbon footprint of dairy production systems using the Life Cycle Assessment (LCA) approach. LCA is a method of evaluating and quantifying the environmental impacts associated with a product/process/activity throughout the whole life cycle, from raw material to the end of life ("from the cradle to the grave"), and it is governed by ISO 14040-3. However, the application of LCA to dairy farms remains controversial (Flysjö et al., 2012; Pirlo, 2012), and there is no commonly accepted approach to accounting for soil carbon sequestration (Batalla et al., 2015). Carbon sequestration is the process of removing carbon from the atmosphere and depositing it temporarily in a reservoir such as the soil. The time of carbon storage in agricultural soil depends on both abiotic and biotic environmental factors, as well as the types of crops and the land management actions. The magnitude of these fluxes is strongly influenced by the climate and can provide feedback on the climate system (Davidson and Janssens, 2006; IPCC, 2007b). Moreover, grassland soil carbon sequestration could be seen as an important mitigating action (Soussana et al., 2010).

The application of LCA to dairy farms usually does not consider the multifunctional character of livestock systems, and final environmental emissions are apportioned only to the milk and the co-product meat. In this way, when considering the LCA approach for assessing greenhouse gas (GHG) emissions, the small-scale mountain dairy farms are in a disadvantaged position with respect to intensive farms because of their limited productivity (Gerber et al., 2011). However, on the other hand, small-scale dairy farms are characterized by the high presence of grassland, low

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presence of arable crops, low extra-farm inputs, and a lower density of animals per hectare (Battaglini et al., 2014). The presence of grassland also has a positive effect on energy consumption because it increases self-sufficiency in feed, reducing the impact of the production and transport of purchased feed (Guerci et al., 2013), and reduces the field operations required for tillage, planting, and harvesting in comparison with arable crops (Belflower et al., 2012). Moreover, small-scale dairy farms should be considered multi-functional systems (OECD, 2001) that produce milk and meat and, especially in less favoured areas, contribute positively to other control functions, providing a wide range of ecosystem services (ES) (Battaglini et al., 2014; Bernués et al., 2014; Kiefer et al., 2015; Salvador et al., 2016).

To our knowledge, very few studies about the assessment of GHG emissions in small-scale dairy farms are available, and no one has focused on the role of grassland (meadow, for hay production, and pasture, directly grazed) on GHG balance.

The aim of this study is to assess the effect of grassland carbon sequestration accounting on the climate change impact of small-scale dairy farms in the Italian Alps.

2. Materials and methods

2.1. Data collection and sample description

For this study, thirty-four mountain farms, classified as small-scale dairy farms (EFSA, 2015) and representative of the Italian Alpine region, were considered. In particular, these farms were located over 600 m in altitude, were handled by family members, had a high forage self-sufficiency (min 46.3%), and held dual-purpose breeds (mainly Rendena and Italian Simmental). The size of the herd varied considerably, and the average Livestock Units (LU) reared were 38.8; calving was concentrated in autumn, and the total farmland was on average 50.2 ha. They did not manage arable crops and used meadows, for the production of hay offered to animals during the winter period, and pastures, directly grazed by the animals during summertime (at least for heifers, min 60 days/year). More details are reported in Table 1.

Within the small-scale dairy farms considered, two groups of 17 farms each were identified on the basis of the LU reared. One group reared fewer than 30 LU (LLU), while the other group reared more than 30 LU (HLU). The threshold chosen for discriminating the two groups is the limit identified by the Italian Ministerial Decree 18354/2009 regarding organic farms (Reg. UE 834/2007; Reg. UE 889/2008) under which small farms are allowed to rear animals in tie stall.

To obtain a detailed inventory, the farms were analysed by field investigation and through a farmer questionnaire, as well as by consultations with local associations. The Italian livestock breeders association and dairies provided information about the amount of milk and its protein and fat composition. The questionnaire covered farm structure, management, summer grazing period, and input and output mass flow (forage, concentrate feed, milk, meat, fertilizer, and pesticides) data.

Table 1
Main characteristics of 34 small-scale dairy farms sampled in Italian Alps.

	Mean	SE
Total farm land, ha	50.2	11.23
Highland pasture, ha	33.5	10.04
Permanent grassland, ha	16.7	1.81
Herd size, LU	38.8	7.6
Grazing days per cow, n	98	10.1
Grazing days per heifer, n	127	6.0
Forage self-sufficiency, %	79.7	3.06
Milk yield, kg FPCM/cow/year	4621	181.3
Animals sold, kg LW/farm/year	3708	577.6

SE: Standard Error; LU: Livestock Units; FPCM: Fat and Protein Corrected Milk; LW: Live Weight.

2.2. Description of methodology for calculating the carbon footprint and impact category

Carbon footprint of the sampled farms were calculated using the LCA approach (Guinèe et al., 2001), and following the indications of the Intergovernmental Panel on Climate Change (IPCC, 2006a, 2006b). Climate change was selected as impact category. The global warming potentials (GWP) computed according to the CO_2 equivalent factors in a 100 year time horizon were 1 kg CH_4 = 25 kg CO_2-eq, and 1 kg N_2O = 298 CO_2-eq (IPCC, 2007a).

2.2.1. Functional unit and system boundaries

In this study, two functional units were used: kg of Fat and Protein Corrected Milk (FPCM), FPCM (kg) = kg of milk × (0.337 + 0.116 × % fat + 0.060 × % protein) (Gerber et al., 2010) and m^2 of Utilizable Agricultural Land (UAL).

Small-scale farms were analysed in a “cradle to farm-gate” LCA approach which implies that GHG emissions were assessed for all processes involved until the milk leaves the farm, excluding transport or raw milk processing. All the processes related to the on-farm activity (i.e. animals rations, manure storage, cropping system and fuel consumption) and related emissions were taken into account. Emissions from off-farm activities were also estimated. Farm buildings and machineries, medicines, and other minor stables supplies were excluded from the assessment. Fig. 1 illustrates the system boundaries of this study.

2.2.2. Calculation of emissions and allocation method

Methane (CH_4) emissions from enteric fermentation and manure management were estimated according to Tier 2 of IPCC (2006a) guidelines. CH_4 from enteric fermentation, based on dry matter (DM) intake of the herd, was calculated by using a Y_m of 6% for lactating cows and 4% for young cattle (ISPRA, 2008; Pirlo and Carè, 2013). Management of manure was the same for the two groups of farms, and CH_4 conversion factors (MCF) used for manure emission were 2% for solid storage and 1% for dung deposition during grazing time, with an annual average temperature of 10 °C (IPCC, 2006a).

Direct nitrous oxide (N_2O) emissions at storage level were also estimated as proposed by Tier 2 of the IPCC (2006a) and the count was based on excretion of nitrogen (N), estimated as the DM intake and the N content of the diet. The protein of indoor diet was calculated on the basis of data provided by commercial feed producers for the purchased concentrates and on the basis of laboratory analysis for farms concentrate and forage. Analyses to estimate N content were performed according to Kjeldahl method (AOAC, 2000) and crude protein content was calculated (%N × 6.25). The total contribution of grazing to the diet resulted from nutrient requirements of cattle (NRC, 2001) and resources grazed were included in the diet depending on the period spent on high pastures. Emission factors used for direct N_2O was 0.005. The Tier 1 (IPCC, 2006b) was applied for estimating direct and indirect N_2O emissions at field level and for N_2O emissions produced from leaching and runoff. Direct N_2O emissions at field level were calculated applying the emissions factors of 0.01 for managed soils (meadows) and 0.02 for grazed soils (IPCC, 2006b). Direct deposition of dung and urine on pasture was determined computing the average time spent outdoors by the animals. Indirect N_2O emissions at field level were calculated applying the following emissions factors: 0.01 N_2O-N/kg of N volatilized (IPCC, 2006b); 0.092 for

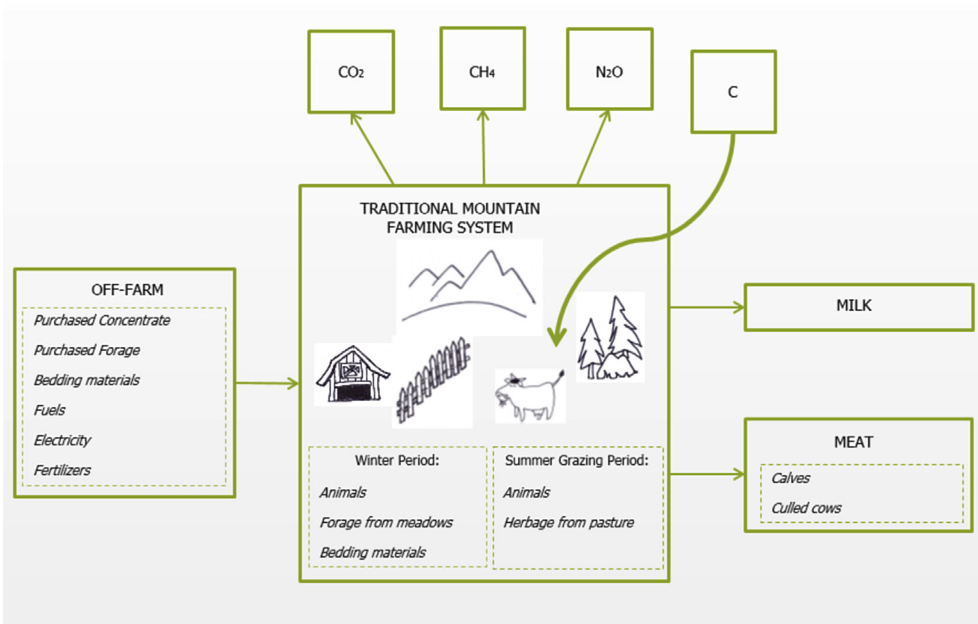

Fig. 1. System boundaries diagram of Life Cycle Assessment applied to mountain dairy farms also considering the carbon sequestration capacity of hay meadows and grass pasture.

volatilization from synthetic fertilizer (ISPRA, 2008) and 0.2 from dung and urine one (IPCC, 2006b); 0.0075 N_2O-N/kg of N that is lost for leaching and runoff (IPCC, 2006b) with a fraction of total N of 0.26 (Bretscher, 2010).

Fuel and electricity used for agricultural operations were estimated on the basis of farms invoices. The emission factors used for carbon dioxide (CO_2) emissions were 3.13 kg of CO_2 per kg of diesel fuel (APAT, 2003; Pirlo and Carè, 2013) and 0.47 kg of CO_2 per kWh of electricity (ISPRA, 2011; Pirlo and Carè, 2013).

The estimation of off-farm emissions that occur during the production chain of commercial feed (from crop cultivation to the arrival of the final product to the farm, including transport) was carried out with the assistance of SimaPro 7.3 (Pré Consultants, 2012) software and the Ecoinvent (2007) database and assessed according to Nielsen (2003). The emissions related to purchase forages and bedding materials were estimated according the database of Nemecek (2007), while the database of Patyk and Reinhardt (1997) was used to assess emissions for the production of chemical fertilizers. Data used for estimation of diesel fuel and energy production were taken from Jungbluth (2007). The emission factor associated with purchased replacement animals was 11 kg CO_2-eq per kg live weight (Rotz et al., 2010).

Two allocation methods were considered: no allocation, when the total emissions were apportioned only to the FPCM, and physical allocation, when total emissions were apportioned to FPCM and to produced beef (IDF, 2010).

2.2.3. *Statistical analysis*

The statistical analysis was performed using SPSS software version 17 (SPSS Inc., Illinois). The normality of data distribution was tested with Shapiro-Wilk test. Data were subjected to one-way analysis of variance (ANOVA), farm's size (LLU vs. HLU) was treated as fixed effect. When the ANOVA assumptions were violated, Mann Whitney U non parametric test was used. $P \leq 0.05$ level was established for statistical significance.

Farm characteristics and GHG balance were also processed by Principal Component Analysis (PCA) carried out using the software R version 2.14.1. Variables with correlations above 0.9 were excluded from analysis in order to avoid redundancy (Tabachnick and Fidell, 2001).

2.3. *Role of grassland in environmental impact*

2.3.1. *Including carbon sequestration in LCA*

As there is no commonly accepted approach in the literature for accounting for soil carbon sequestration in LCA, this work applied the methodology suggested by Petersen et al. (2013), based on a 100 year perspective, when 10% of the total carbon added to the soil will be sequestered. The annual carbon inputs into grassland were calculated considering herbage residues and manure.

The biomass production of grasslands is subject to fluctuations on a spatial and temporal scale. The spatial variability depends essentially on flora characteristics, elevation and soil fertility. The temporal variability is linked to production variability within the seasonal cycle, and the annual weather patterns (Gusmeroli et al., 2005). In Alpine mountains, the productivity variation is represented by the range of 0.5–6.5 t DM/ha (Cavallero et al., 1992). For this work, the meadows' total yields were based on the farmer questionnaire, while for pasture productivity, the average value of 2.97 t DM/ha was used, calculated on the basis of a database obtained from studies conducted in different pastures of the Italian Alps (VV.AA, 1989). Meadow and pasture residues were calculated according to Batalla et al. (2015) (40% and 16% of total yield, respectively, for above- and below- ground residues), assuming a carbon content of 45% of DM.

The amount of manure and N excreta per animal per year were estimated according to Tier 2 of the IPCC (2006a) guidelines, while the C:N ratio of cattle manure was 21.2 (Escudero et al., 2012).

2.3.2. *Forage self-sufficiency*

To investigate how forage self-sufficiency can affect the GHG emissions of small-scale farms, two scenarios were considered. In the first, the real data were considered, while in the second, it was assumed that all the farms in this study were self-sufficient in terms of forage. Consequently, the purchased forage was supposed to be entirely replaced by forage produced in additional meadows for each farm (VV.AA, 1989).

In addition, within the simulated scenario, the physical allocation method to apportion emissions to milk was considered, and carbon sequestration was included.

3. Results and discussion

3.1. Farms

The characteristics of the two groups of farms are reported in Table 2. The LLU farms identified in this work were significantly smaller than the HLU ones in term of lactating cows (8.7 vs. 40.6 cows, $P \leq 0.01$). In terms of milk productivity, LLU farms tended to produce less than the HLU group (4300 vs. 4942 kg FPCM/cow/years; $P \leq 0.10$). The average total value of 4621 kg FPCM/cow/years was lower than the production levels registered by other authors in the same alpine area (Penati et al., 2011; Sturaro et al., 2013) and confirms the low productivity level that characterized the mountain dairy farms using highland pasture (Guerci et al., 2014). The DM intake of cows, was significantly higher in LLU than in HLU farms (22.1 vs. 18.7 kg DM/cow/day, $P \leq 0.01$), and the average value was higher than reported by Bovolenta et al. (2008, 2009). Moreover, while in LLU farms concentrate feed was 16.8%, in the HLU farms this percentage reached 28.9% ($P \leq 0.01$). As a consequence of the limited amount of concentrate used, the feed efficiency of these farms was also low and differed significantly between farm groups (0.54 vs. 0.72 kg FPCM/kg DM intake for LLU and HLU farms, respectively, $P \leq 0.01$), and it was lower than the value reported by Guerci et al. (2014), which was 1.09 kg FPCM/kg DM intake. LLU small-scale farms managed a smaller agricultural surface, both as grasslands and as highland pasture, than HLU farms (5.8 vs. 61.3 ha of highland pasture, $P \leq 0.05$, and 13.4 vs. 20.0 ha of permanent grassland, $P \leq 0.10$, for LLU and HLU, respectively). The local climate, elevation and slope exposure could explain the high variability of the meadows yield for LLU, which showed a lower value than the HLU farm (4.11 vs. 7.39 t DM/ha, respectively, $P \leq 0.01$). The stocking rate was lower for LLU than HLU farms (0.8 vs. 1.9 LU/ha, respectively, $P \leq 0.05$) and the average value recorded was lower than was observed by other authors (Sturaro et al., 2013; Guerci et al., 2014). Despite the low production of the meadows, LLU small-scale farms were more successful than HLU ones at supporting their animal stocks: forage self-sufficiency is higher in LLU farms than in the HLU group (84.8 vs. 71.8%, $P \leq 0.05$). In general, comparing the two farms groups, HLU farms were more efficient in terms of production, and the higher level of concentrate in the rations indicates that these farms are entering a process of intensification (Sturaro et al., 2013).

3.2. Environmental impact without carbon sequestration

Performing no allocation, and using FPCM as the functional unit, slightly significant differences were found between the two groups of farms, and the values registered for LLU farms tended to be higher than for the HLU group (1.94 vs. 1.59 kg CO_2-eq/kg FPCM, $P \leq 0.10$, Table 3). This result is consistent with other works that highlight how more extensive farms, less productive and less efficient from an environmental perspective, have a greater impact than intensive systems (Capper et al., 2009; Gerber et al., 2010). On the other hand, when physical allocation was performed, the difference between the two groups became less noticeable due to the different management systems ($P > 0.05$; Table 3). LLU farms sold on average more beef than HLU ones, stressing the dual-purpose character of alpine livestock systems and the co-product meat. In this way, the percentage of total emissions assigned to milk (rather than beef) is much lower in LLU than in HLU farms (64.0 vs. 81.5%, $P \leq 0.05$; data not reported in Tables). On average, 72.8% of total emissions were assigned to milk, which is lower than the 85.0% reported by Guerci et al. (2014) and the default allocation value of 85.6% suggested by the IDF (2010). Total GHG emissions per kg of FPCM were on average 1.22 kg CO_2-eq, ranging from 0.57 to 2.11 kg CO_2-eq/kg FPCM. These results are lower than the GHG emissions estimated by Guerci et al. (2014) in the central Italian Alps on traditional dairy farms (1.60 kg CO_2-eq/kg FPCM), as well as the value recorded by Kiefer et al. (2015) in grassland-based areas of southern Germany (1.53 kg CO_2-eq/kg FPCM). Other authors reported lower values in alpine dairy farms than the ones obtained in our trial (1.14 kg CO_2-eq/kg FPCM, Penati et al., 2013; 1.08 kg CO_2-eq/kg FPCM, Schader et al., 2014).

When total GHG emissions were divided by m^2 of UAL, the two groups of farms were found to be significantly different, and LLU farms registered lower values than HLU ones without any allocation ($P \leq 0.05$, Table 3).

As shown in Table 4, LLU farms have higher GHG contributions from manure storage ($P \leq 0.05$) and lower GHG contributions from purchased feeds ($P \leq 0.01$) than HLU farms. Since the

Table 2
Characteristics of the two groups of small-scale dairy farms identified on the basis of Livestock Units (LU): LLU and HLU small-scale farms, rearing less than and more than 30 LU, respectively.

	LLU (n = 17)		HLU (n = 17)	
	Mean	SE	Mean	SE
Lactating cow, n	8.7^A	1.02	40.6^B	7.60
Milk yield, kg FPCM/cow/year	$4,300^\alpha$	207.7	$4,942^\beta$	282.0
DM intake lactating cows, kg DM/cow/day	22.1^A	0.32	18.7^B	0.48
Concentrate feed, %	16.8^A	1.34	28.9^B	2.53
Feed efficiency, kg FPCM/kg DM intake/cow	0.54^A	0.029	0.72^B	0.031
Total farm land, ha	19.2^a	2.37	81.3^b	19.85
Highland pasture, ha	5.8^a	1.75	61.3^b	17.79
Permanent grassland, ha	13.4^α	1.92	20.0^β	2.91
Meadows yield, t DM/ha	4.11^A	0.336	7.39^B	1.085
LU total, n	11.7^A	0.95	65.8^B	12.26
Stocking rate, LU/ha	0.8^a	0.10	1.9^b	0.47
Forage self-sufficiency, %	84.8^a	4.24	71.8^b	4.75
Culling rate, %	21.5	1.09	19.0	1.19

SE: Standard Error; FPCM: Fat and Protein Corrected Milk; DM: Dry Matter.
^{A,B}: $P \leq 0.01$; ^{a,b}: $P \leq 0.05$; $^{\alpha,\beta}$: $P \leq 0.10$.

Table 3
Greenhouse gas emissions of LLU (Livestock Units reared<30) and HLU (Livestock Units reared >30) small-scale farms. Emissions are expressed as CO_2-eq per kg of Fat Protein Corrected Milk (FPCM) and per m^2 of Utilizable Agricultural Land, before and after including the contribution of soil carbon sequestration.

	LLU (n = 17)		HLU (n = 17)	
	Mean	SE	Mean	SE
No soil carbon included				
No allocation				
kg CO_2-eq/kg FPCM	1.94^α	0.175	1.59^β	0.101
kg CO_2-eq/m^2	0.29^a	0.045	0.89^b	0.220
Physical allocation				
kg CO_2-eq/kg FPCM	1.16	0.096	1.28	0.064
Carbon sequestration included				
No allocation				
kg CO_2-eq/kg FPCM	1.38^a	0.115	1.10^b	0.124
kg CO_2-eq/m^2	0.22^a	0.038	0.73^b	0.207
Physical allocation				
kg CO_2-eq/kg FPCM	0.60	0.118	0.79	0.100

SE: Standard Error.
^{A,B}: $P \leq 0.01$; ^{a,b}: $P \leq 0.05$; $^{\alpha,\beta}$: $P \leq 0.10$.

Table 4
Greenhouse gas emission contribution (kg CO_2-eq) per kg of Fat Protein Corrected Milk from different sources in LLU (Livestock Units reared <30) and HLU (Livestock Units reared >30) small-scale farms.

	LLU (n = 17)		HLU (n = 17)	
	Mean	SE	Mean	SE
Manure	0.42^b	0.097	0.21^a	0.055
Enteric emission	0.82	0.062	0.72	0.025
Meadows and pasture	0.20^β	0.016	0.17^α	0.011
Feed purchased	0.15^A	0.012	0.27^B	0.025
Fertilizers and pesticides purchased	0.00	0.00	0.00	0.004
Energy and fuel	0.27	0.036	0.20	0.013

SE: Standard Error.
$^{A,B:}$ $P \leq 0.01$; $^{a,b:}$ $P \leq 0.05$; $^{\alpha,\beta:}$ $P \leq 0.10$.

management of manure was the same, these results were probably linked to the utilization of bedding materials. LLU small-scale farms, characterized by tie stalls, used more wheat straw or sawdust than the farms managed with free animals with access to rubber mattresses. In this way, LLU farms increase not only manure quantity but also the contribution of off-farm emissions due to the purchased bedding materials. The different contributions from feed purchased to GHG emissions are mainly linked to the different levels of concentrates included in the animals' diet. In percentage terms (data not reported in Tables), the average on-farm contribution to GHG emissions was 81.5%. Enteric emissions and manure storage together represented on average 62.2% of the total GHG emissions. Enteric emissions were the largest contributor to GHG emissions (46.3% on average). The other main contribution to GHG emissions was represented by electricity and fuel consumption (13.6% on average).

3.3. Including soil carbon sequestration in GHG balance

As shown in Table 3, performing no allocation, LLU farms registered higher values per kg of FPCM than HLU farms (1.38 vs. 1.10 kg CO_2-eq/kg FPCM, $P \leq 0.05$), whereas the situation was reversed considering m^2 of UAL as the functional unit (0.22 vs. 0.73 kg CO_2-eq/m^2, $P \leq 0.05$). However, when physical allocation was performed, statistical analysis did not show significant differences between the two groups of farms per kg of FPCM (Table 3).

Performing no allocation, when the contribution from soil carbon sequestration was included in the LCA, the GHG emission per kg of FPCM was reduced by 29.7% on average (by 28.9 and 30.8% for LLU and HLU farms, respectively). Considering beef as a co-product of the farm, the percentage of reduction was 43.0% on average (48.3 and 38.3% for LLU and HLU farms, respectively), and GHG emission per kg of FPCM in some cases could be even negative: a minimum value of −0.19 kg CO_2-eq/kg FPCM was recorded among LLU small-scale farms.

Fig. 2 shows the principal component analysis (PCA) performed on farm characteristics and GHG emission per kg of FPCM. In particular, GHG emission calculated with physical allocation is separated by GHG emission calculated with no allocation method along the first component, which explains 35.5% of the variability. The first dimension is positively correlated with feed efficiency, milk yield, concentrate level in diet, stocking rate and GHG emissions calculated with the physical allocation method. Conversely, the second dimension, which explains 22.2% of the variability, is positively correlated with GHG emissions calculated by both allocation methods, as well as with stocking density, and negatively correlated with forage self-sufficiency.

In the literature, few works include carbon sequestration in milk LCA, and there is a lack of consensus on how to correctly assess it in

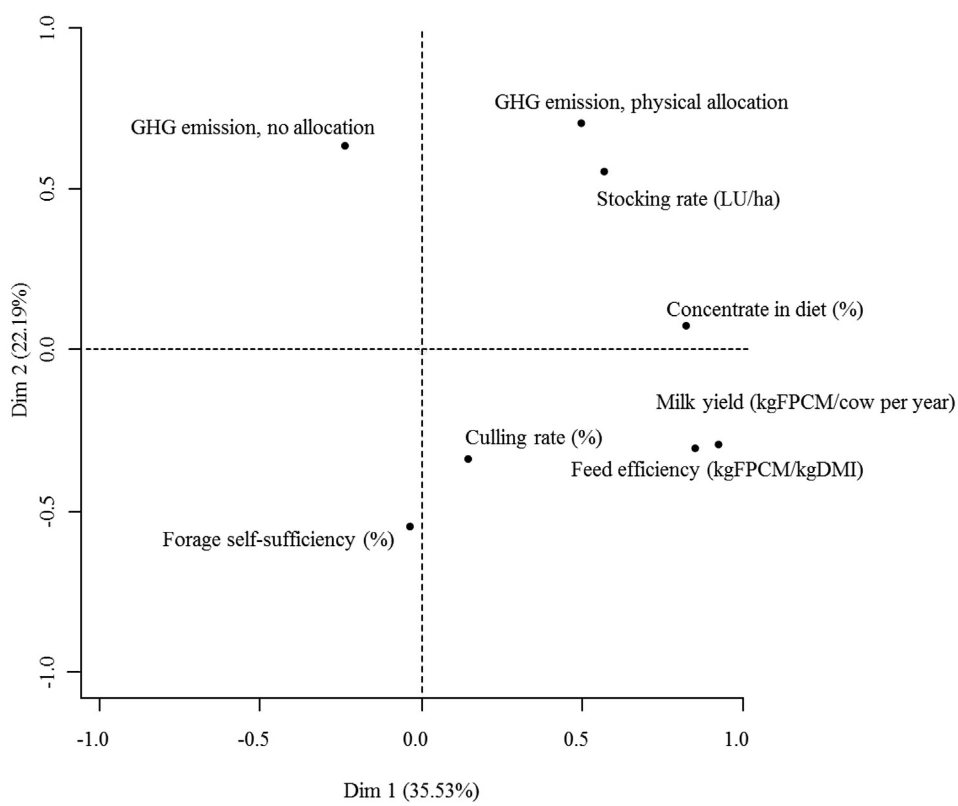

Fig. 2. Principal component analysis of farm characteristics and greenhouse gas (GHG) emission expressed as CO_2-eq per kg of Fat Protein Corrected Milk (FPCM) including carbon sequestration with no allocation (GHG emission, no allocation) and the physical allocation method (GHG emission, physical allocation).

the analysis. Batalla et al. (2015) applied different approaches to estimate and include soil carbon sequestration in the LCA of milk from sheep farming systems in Spain and argue the importance of considering it in LCA as an important climate mitigation potential of grazing systems. O'Brien et al. (2014) highlight how, when carbon sequestration is included in LCA, the Irish grass-based dairy system had the lowest carbon footprint per ton of energy corrected milk, but omitting sequestration suggested that grass-based and confinement dairy systems have similar GHG emissions. In a recent study, Battini et al. (2016) found a modest contribution of carbon sequestration to GHG. They found more carbon sequestration in farming systems of smaller size and lower efficiency, located in hilly and mountain areas and partially based on grassland crops, than in intensive farms.

3.4. Increasing forage self-sufficiency to 100%

In the case where the forage self-sufficiency is increased to 100% for all farms and the carbon sequestration included in the LCA methods, the GHG emission per kg of FPCM was similar between HLU and LLU farms, both considering no allocation and physical allocation (Table 5). Considering the real data shown in Table 3, these results highlighted the importance of forage self-sufficiency in the GHG emission calculation and reduction due to the removal of off-farm forage emissions. In particular, if the soil carbon sequestration was not considered in the physical allocation method, the percentage of GHG emission reduction per kg of FPCM was 2.5% on average (1.7 vs. 3.1% for LLU and HLU farms, respectively). As expected, the reduction became more important when the carbon sequestration was also considered: 26.1 and 28.2% if no allocation was performed, and 40.0 and 20.3% considering the co-product beef for LLU and HLU farms, respectively. Penati et al. (2013) argued that enhancing feed self-sufficiency through increasing mountain pasture exploitation can be a suitable strategy to reduce the environmental impact of dairy farms.

The increase of forage self-sufficiency has important implications not only on reducing environmental emissions but also on the landscape, as to be completely self-sufficient, farms would need to manage more land. Indeed, in this simulation, permanent grasslands increase by an average of 3.64 ha, at 1.59 and 5.70 ha per farm for LLU and HLU farms, respectively.

Table 5
Greenhouse gas emissions of LLU (Livestock Units reared <30) and HLU (Livestock Units reared >30) small-scale farms considering 100% the forage self-sufficiency. Emissions are expressed as CO_2-eq per kg of Fat Protein Corrected Milk (FPCM) and per m^2 of Utilizable Agricultural Land, before and after including the contribution of soil carbon sequestration.

	LLU (n = 17)		HLU (n = 17)	
	Mean	SE	Mean	SE
No soil carbon included				
No allocation				
kg CO_2-eq/kg FPCM	1.92$^{\alpha}$	0.176	1.54$^{\beta}$	0.097
kg CO_2-eq/m^2	0.26^{a}	0.039	0.74^{b}	0.176
Physical allocation				
kg CO_2-eq/kg FPCM	1.14	0.096	1.24	0.062
Carbon sequestration included				
No allocation				
kg CO_2-eq/kg FPCM	1.02	0.160	0.79	0.106
kg CO_2-eq/m^2	0.15^{a}	0.027	0.52^{b}	0.152
Physical allocation				
kg CO_2-eq/kg FPCM	0.36	0.135	0.63	0.094

SE: Standard Error.
^{A,B}: $P \leq 0.01$; ^{a,b}: $P \leq 0.05$; $^{\alpha,\beta}$: $P \leq 0.10$.

4. Conclusions

If no allocation is considered, the GHG emission per kg of FPCM tended to be different within small-scale mountain dairy farms, with the farms that reared the lowest number of animals showing the highest value. However, when the co-product beef was considered, this difference disappeared, stressing the importance of a proper weighting of the co-produced beef in this type of farms. Considering the derivation of carbon sequestration by meadow and pasture action, the average GHG emission per kg of FPCM was reduced by 29.7% and 43.0% for the no allocation and physical allocation methods, respectively. The key role played by meadows and pastures was also highlighted by increasing the simulated self-sufficiency of forage farms to 100%. In this case, an average reduction of the GHG emission per kg of FPCM of farms was observed both with no allocation and with physical allocation, reaching 27.0% and 28.8%, respectively.

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