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TESI DI DOTTORATO DI RICERCA

ENVIRONMENTAL SUSTAINABILITY OF ALPINE DAIRY FARMS

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Summary

Dairy farming systems in mountain areas play an essential role from the economic, social and environmental point of view. However, extensive mountain farms appear rather unsustainable from an environmental perspective when pollutant emissions are allocated on the quantity of milk produced. Many works carried out using Life Cycle Assessment (LCA) approach and the kilogram of milk as functional unit, lead to this misleading result.

LCA is a methodology that allows the evaluation of the environmental impact during all phases of a product or service's life. It involves the systematic analysis of production system, to account for all inputs and outputs associated with a specific product within a defined system boundary. Researchers have applied LCA to milk production to obtain valid carbon footprint numbers for raw milk, but there is still room for interpretation. In particular, when assessing traditional small-scale farms in mountain areas, it is necessary consider that they are able to use native breeds, to maintain grasslands and their biodiversity and to conserve the traditional landscape. In this way, multifunctional farms deliver, in addition to the co-product meat, also important ecosystem services (ES) to the community to which is important recognizing a cost in terms of emissions.

The aim of this thesis is to evaluate environmental impacts of small-scale dairy farms in alpine areas through a LCA approach, tacking also into account their multi-functionality. The thesis consists of three works.

The first paper is a review and it describes the evolution and characterization of livestock sector in Italian Alps analyzing the most important factors affecting their environmental sustainability. The review discusses the adoption of LCA to evaluate the environmental impacts and the need to assess also the ES provided by forage-based farms.

The aim of the second paper is to estimate the environmental impact of organic and conventional small-scale dairy farms in Eastern Italian Alps. The farms object of this study were assessed for global warming potential, acidification and eutrophication impacts through a LCA approach in two scenario: Baseline Scenario, based on the real farm data, or Milk-Beef production system Scenario, assuming that calves exceeding the culling rate were directly fattened on-farm. Different allocation methods were considered to accounting also for co-product beef (physical allocation) and for ES (economic allocation) provided by farms.

Performing no allocation, the average values obtained for global warming potential, acidification and eutrophication per kg of FPCM (Fat Protein Corrected Milk) were respectively 1.43 kg CO_2-eq, 25.84 g SO_2-eq and 3.99 g PO_4^{3-}-eq within the Baseline Scenario, and respectively 1.64 kg CO_2-eq, 29.67 g SO_2-eq and 4.10 g PO_4^{3-}-eq within the Milk-Beef production system Scenario.

In Baseline Scenario, considering 1 kg of FPCM as functional unit, the reduction of greenhouse gas emissions from no allocation to economic allocation was on average 34.1%, and from physical allocation to economic ones was 21.3%.

This study provided a double-folded advice suggesting first, to strengthen beef production in dual-purpose breeds in order to reduce emissions apportioned to milk, and second, to account for multi-functionality considering ES provided by the farms in the LCA.

The third paper takes into account the potential of soil carbon sequestration. Two groups of farms were identified on the basis of the Livestock Units (LU): TRADITIONAL farms (< 30 LU), and MODERN ones (> 30 LU). Before considering soil carbon sequestration in LCA, performing no allocation, per kg of FPCM, the value registered for TRADITIONAL farms tended to be higher than the other group (1.94 *vs.* 1.59 kg CO_2-eq/kg FPCM, $P \leq 0.10$). When physical allocation was performed, the difference between the two groups became less noticeable because TRADITIONAL farms sold on average more beef respect modern ones stressing more the dual-purpose character of alpine livestock systems.

When the contribution from soil carbon sequestration was included in the LCA, performing no allocation, the global warming potential was reduced on average by 29.6% and considering the beef as a co-product of the farm, the percentage of reduction was on average 45.8%.

To point out how the presence of grasslands is crucial for small-scale farms carbon footprint, in this study was also applied a simulation for increasing forage self-sufficiency of farms. To produce enough forage for all animals reared, permanent grasslands increase on average of 3.64 ha. This has important implications not only on the reduction of environmental emissions, but also on the maintenance of landscape and biodiversity.

This thesis stresses how it is fundamental to apply “systems thinking” to efficiently capture the dynamics between the production of milk, the co-product meat and the provisioning of other services to avoid incorrect assessment of traditional small-scale farms.

Sommario

La zootecnia da latte ha un imprescindibile ruolo economico, sociale e ambientale in territorio montano. Tuttavia le aziende zootecniche estensive di montagna, a causa di numerosi e diversi vincoli, appaiono poco sostenibili dal punto di vista ambientale qualora le emissioni totali di inquinanti vengano ripartite solo sulla quantità di latte prodotto. Numerose analisi effettuate utilizzando approcci Life Cycle Assessment (LCA) e il chilogrammo di latte come "unità funzionale" portano infatti a questo risultato evidentemente fuorviante. L'LCA è una metodologia che permette di valutare l'impatto ambientale di un prodotto o di un servizio lungo tutto il suo ciclo produttivo, considerando input e output in un sistema dai confini ben definiti. Nell'applicare questa metodologia alla produzione di latte in zone di montagna, è necessario considerare che le aziende tradizionali a piccola scala forniscono, oltre al co-prodotto carne, anche importanti servizi ecosistemici (SE) alla comunità - come ad esempio la tutela dell'agro-biodiversità, il mantenimento di prati e pascoli, la prevenzione da incendi o dal dissesto idrogeologico - ai quali sembra opportuno riconoscere un costo anche in termini di emissioni.

Scopo di questa tesi è quello di valutare l'impatto ambientale di aziende da latte a piccola scala che operano in area alpina attraverso un approccio LCA, tenendo in considerazione il loro carattere multifunzionale. La presente tesi si articola in tre lavori.

Il primo lavoro è una review e vuole descrivere l'evoluzione e le caratteristiche del settore zootecnico nelle Alpi italiane analizzando i fattori più importanti che ne influenzano la sostenibiltà ambientale. Viene qui discussa l'importanza di adottare la metodologia LCA nella valutazione dell'impatto ambientale dei sistemi zootecnici alpini e la necessità di condividere un metodo multicriteria per non escludere i SE forniti dalle aziende tradizionali basate sull'utilizzo di prati e pascoli.

Nel secondo lavoro vengono stimati gli impatti ambientali di aziende da latte a piccola scala, biologiche e convenzionali, situate nelle Alpi Orientali italiane. Le aziende oggetto dello studio vengono valutate, applicando la metodologia LCA, per il potenziale di riscaldamento globale, l'acidificazione e l'eutrofizzazione, in due scenar lo Scenario "Baseline", basato sui dati reali rilevati in azienda, e lo Scenario "Milk Beef production system", in cui si assume che i vitelli eccedenti la rimonta vengano ingrassati direttamente in azienda. In questo lavoro le emissioni totali finali vengono allocate in diversi modi per tenere in considerazione anche il co-prodotto carne (allocazione fisica) e i SE (allocazione economica) forniti dalle aziende.

Nel caso in cui non venga effettuata alcuna allocazione, i valori medi registrati per il potenziale di riscaldamento globale, l'acidificazione e l'eutrofizzazione, per kg di FPCM (Fat Protein Corrected Milk), risultano essere rispettivamente 1.43 kg CO_2-eq, 25.84 g SO_2-eq e 3.99 g PO_4^{3-}-eq all'interno dello Scenario "Baseline", e 1.64 kg CO_2-eq, 29.67 g SO_2-eq e 4.10 g PO_4^{3-}-eq all'interno dello Scenario "Milk-Beef production system".

Nello Scenario "Baseline", considerando 1 kg di FPCM come unità funzionale, la riduzione media dei gas serra emessi dalle aziende risulta essere del 34.1%, passando da nessuna allocazione all'applicazione dell'allocazione economica, e del 21.3% passando dall'allocazione fisica a quella economica.

Questo lavoro vuole fornire una duplice chiave di lettura sottolineando innanzi tutto l'importanza di considerare anche i SE nella valutazione della sostenibilità ambientale delle aziende da latte tradizionali di montagna, e dimostrando come il rafforzamento della produzione di carne in aziende che già allevano razze a duplice attitudine, può portare a ridurre le emissioni attribuibili al latte.

Scopo del terzo lavoro è quello di considerare nell'applicazione del LCA anche il potenziale di sequestro del carbonio del suolo. In questo studio vengono identificati due gruppi di aziende sulla base delle UBA: aziende TRADIZIONALI (< 30 UBA), e aziende MODERNE (> 30 UBA). Senza considerare l'effetto del sequestro del carbonio, non applicando alcuna allocazione e per kg di FPCM, il valore registrato per le aziende TRADIZIONALI tende ad essere più alto rispetto all'altro gruppo (1.94 *vs.* 1.59 kg CO_2-eq/kg FPCM, $P \leq 0.10$), mentre nel momento in cui viene applicata l'allocazione fisica, la differenza tra i due gruppi diventa meno significativa in quanto le aziende TRADIZIONALI vendono in media più carne rispetto alle MODERNE riuscendo in questo modo a sfruttare maggiormente il carattere di duplice attitudine tipico della zootecnia alpina.

Considerando nel calcolo del LCA anche il contributo del sequestro del carbonio da parte del suolo, il potenziale di riscaldamento globale viene ridotto in media del 29.6% non applicando allocazioni, e del 45.8% nel caso in cui venga applicata l'allocazione fisica.

In questo lavoro viene inoltre simulato l'incremento dell'autosufficienza foraggera delle aziende per mettere in luce come la presenza di prati e pascoli sia cruciale per la valutazione della sostenibilità ambientale dei sistemi zootecnici a piccola scala. Per produrre foraggio sufficiente per alimentare gli animali allevati, si registra un incremento medio aziendale di prati e pascoli di 3.64 ha: dato che avrebbe ricadute importanti non solo nel conteggio delle emissioni dei gas serra finali, ma anche nel mantenimento del paesaggio e della biodiversità montana.

Questa tesi, in definitiva, vuole sottolineare come sia necessario applicare sistemi olistici per catturare in modo efficace le dinamiche che regolano i sistemi zootecnici tradizionali di montagna, basati sulla produzione di latte, ma anche di carne, e importanti per la comunità in quanto forniscono molteplici SE, per evitare una loro scorretta valutazione.

Table of Contents

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1. Introduction

1.1. Environmental sustainability and livestock sector

Actually, there is an increasing awareness about environmental sustainability. Human activities generate so-called "anthropogenic" greenhouse gases (GHGs), distinct from the GHG emissions naturally present in the atmosphere. Those emissions alter the atmosphere's composition leading to climate change and global warming. The GHG emissions covered by the Kyoto Protocol have increased by 80% since 1970 and 30% since 1990, totalling 49 gigatonnes of CO_2 equivalent ($GtCO_2$-eq) in 2010. Under current global emissions trends (+2.2% per year between 2000 and 2010), the rise in average global temperatures should come to between 3.7 °C and 4.8 °C by 2100. According to the work of the Intergovernmental Panel on Climate Change (IPCC, 2014), a rise in the global temperature of more than 2 °C would have serious consequences. Future climate change, and associated impacts, will differ from region to region around the globe. Effects include global warming temperature, rising sea levels, changing precipitation, expansion of deserts, ocean acidification and species extinctions due to shifting temperature regimes. Warming is expected to be greater over land than over the oceans and greatest in the Arctic, with the continuing retreat of glaciers and the melting of permafrost and sea ice. Other likely changes include more frequent extreme weather events such as droughts, heat waves, heavy rainfall with floods and heavy snowfall. Significant effects to humans' societies include the abandonment of populated areas due to rising sea levels and the threat to food security from decreasing crop yields. Agriculture, in the coming decades, will be heavily influenced by the consequences of climate change: water availability, crop yields, production types, soil protection, and insurance systems, are just some of the parameters involved. IPCC estimates that, over the next 30 years, the rice, wheat and corn yields will drop by 50% and yields will be reduced by 10% for each degree increase in temperature. To limit the atmospheric concentrations to 450 ppm CO_2-eq by 2100 and achieve the goal of keeping global warming below 2 °C, humans' GHG emissions should be reduced by 40-70% by 2050 compared to 2010 levels, and drop to levels close to zero $GtCO_2$-eq by 2100 (COP21, 2015).

The interest in environmental issues is increasing also in non scientific community, included the Christian Churches, in the past often criticized for their anthropogenic view of nature (Malossini, 2006). In 1989 the Patriarch Dimitrios of Costantinopolis proposed the date of September 1st as the day of integrity of Creation; the Catholic Church introduced the same celebration in 2006. More recently, Pope Francesco in his encyclical letter *Laudato si* critiqued consumerism and irresponsible development, with the consequent environmental degradation and global warming and called all peoples of the world to a "swift and unified action" (Francesco, 2015). In the same year 2015, the Pope proclaimed the date of September 1st *World day of prayer for the care of Creation*.

From November 30th to December 11th 2015, Paris has just hosted the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21) to establishing international agreements in order to limit climate change. "This Agreement aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by: (i) Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change; (ii) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; (iii) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development" (COP21, 2015).

FAO's 2013 report (Gerber *et al.*, 2013) estimates that livestock activities contribute 14.5% of the total anthropogenic GHG emissions, totalling 7.1 GtCO_2-eq in 2005, with carbon dioxide (CO_2) accounting for 27% of global anthropogenic emissions, methane (CH_4) accounting for 44% and nitrous oxide (N_2O) accounting for 29%. GHG emissions from cattle represent about 65% of the livestock sector emissions (4.6 GtCO_2-eq), making cattle the largest contributor to total sector emissions. Beef production contributes 41% of total sector emissions (2.9 GtCO_2-eq) while emissions from milk production amount to 1.4 GtCO_2-eq or 20% of total sector emissions.

The world's population has reached nearly 7 billion people and, according to several reliable projections, it is expected to increase of 33.3%, to reach 9 billion, by 2050 (FAO, 2014). With the population growth, the demand for food will increase doubling consumption of animal products by 2050. However, while rural population will decrease by 28.6% in developed countries and by 5.8% in developing countries, urban population will sharply increase in developing countries (83.4%) compared to developed countries (19.3%). For the first time in history, by 2017, rural population will be less than urban population in developing countries. Indeed, people who live in cities consume more meat and milk than people living in the countryside. The increasing demand for products of animal origin will lead to an increase of ruminant population, especially in developing countries, where the economic growth of 2.9% per year is expected in the future (FAO, 2011; Smith *et al.*, 2012). These conditions will contribute to reduce gradually the gap between developed and developing countries with respect to beef and milk consumption, respectively 23.3 kg *vs.* 6.8 kg and 209.0 kg *vs.* 68.1 kg pro capite per year. The lack of Utilized Agricultural Area (UAA) is another major issue. Steinfeld *et al.* (2006) highlight that ruminant presence is related to locally available feed and pasture and there are no longer lands which can be easily converted into pasture or meadows.

In this scenario, world animal production, which emits significant amounts of GHGs, is facing different challenges: how feeding a rapidly increasing global population while meeting the obligation to reduce emissions (Gerber *et al.*, 2013)? A gradual structural change of livestock sector will be necessary and farms will need to place more emphasis on improving efficiencies. This should takes place in developed countries, where productivity has already increased, but at the cost of significant impacts on the environment, and also in developing countries. In those regions, such as Tropical ones, where the availability of land and pasture limits the possibility of increasing the number of ruminants, production must increase, as well as efficiency is needed to avoid soil erosion and desertification (Corazzin *et al.*, 2015; Oosting *et al.*, 2014).

Livestock systems are complex and heterogeneous, and production methods and technologies used by more intensive farms, are not often applicable in marginal areas (Bernués *et al.*, 2011). However, to meet the needs related to the demographic trend, even the smallest production systems could be important: they ensure the food supply to a local level and their presence avoid the loss of UAA. Within this framework is placed also the particular case of the mountain. Mainly characterized by milk production, the low-input farming system in mountainous areas is facing the low production efficiency and the decrease of meadows and pastures, with the consequent loss of UAA due to abandonment and the resulting reforestation.

The deepening of these issues is postponed to the first paper reported in the thesis. This paper argues about alpine livestock systems and their sustainability, stressing how it is fundamental to apply "systems thinking" to efficiently capture the dynamics between the production of milk, the co-product meat (Flysiö *et al.*, 2012) and the provisioning of other services to avoid incorrect assessment of small-scale farms in mountain areas. It is necessary to analyze the full life cycle of a product – from cradle to grave – to address environmental emissions and to find solutions for increasing efficiency. Nevertheless, when assessing low-inputs livestock systems, it is necessary also to account for their multifunctional character because the provision of services has a cost also in terms of GHG emissions.

1.2. Eastern Italian Alps: a brief territorial framework

The studies reported in the thesis took place in East Italian Alps covering the Autonomous Provinces of Trento and Bolzano (Trentino Alto Adige Region), the provinces of Belluno, Verona and Vicenza (Veneto Region), and the provinces of Pordenone and Udine, bordering with Austria and Slovenia (Autonomous Region of Friuli Venezia Giulia) (Fig. 1).

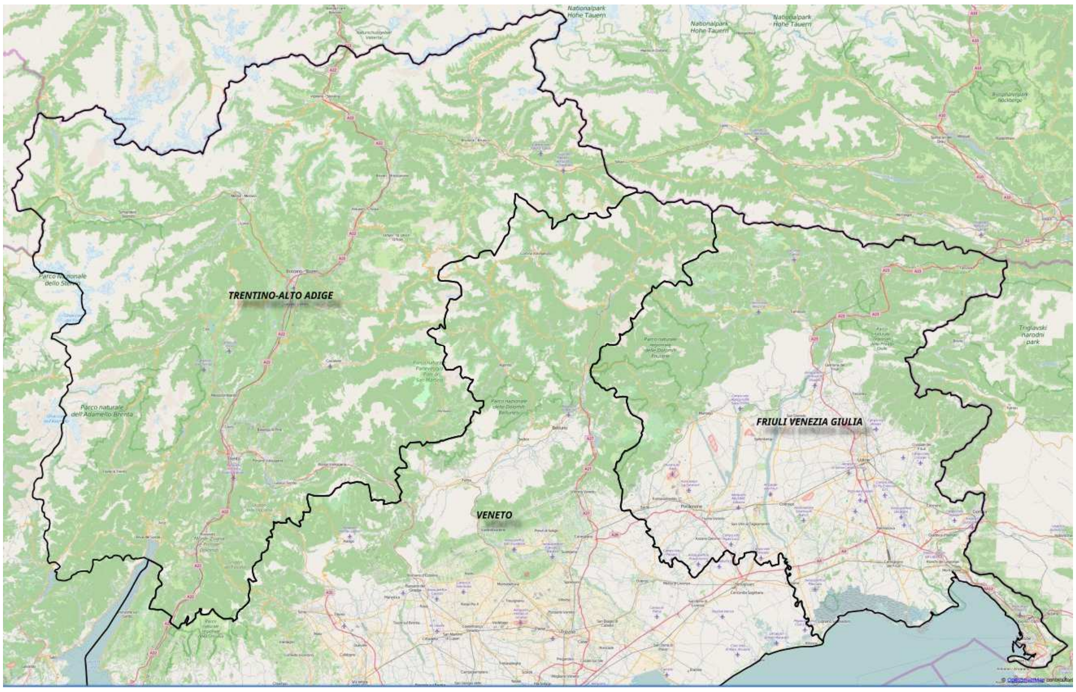

Figure 1. East Italian Alps (OpenStreetMap®).

The territory of Trentino Alto Adige extends for 13,619 km^2 and it is entirely mountainous, while Veneto and Friuli Venezia Giulia, which extend for 18,264 and 7,845 km^2 respectively, are for 29 and 43% alpine mountain area.

The rocks composing this mountain area are diorites and gabbros, while the massif in general is composed of granites. East Italian Alps are characterized by a temperate-humid climate with some differences in the amount of precipitation during the year: the wettest periods are the late spring (May-June) and the central part of the Autumn (November), while the less rainy months are February and July. The average annual precipitation is very variable ranging from a low of 2,600 mm to 3,600 mm per year, with the higher levels occurring at high altitudes. At altitudes between 1,000 and 3,000 m, snowfall begins in November and accumulates through to April or May when the melt begins.

The habitats of Eastern Italian Alps range from meadows, woodland (deciduous and coniferous) areas to soilless scree, rock faces and ridges. A natural vegetation limit with altitude is given by the presence of the deciduous trees like oak, beech and ash. Their upper limit corresponds to the change from a temperate to a colder climate that is further proved by a change in the presence of wild herbaceous vegetation. This limit usually lies about 1,200 - 1,500 m above the sea.

These alpine regions are characterized by a great variety of environments and socio-economic situations, which are quite difficult to standardize. The elevation pattern generates a great heterogeneity of micro-climatic conditions, which affect settlements and economic activities, including agriculture. Dairy livestock, strongly linked to old traditions and local resources utilization, is still a leading sector for agricultural economy of alpine regions, except for Tretino Alto Adige Region where products diversification - especially fruit and wine - reduced its role.

Forests also are very important and play a key role in the landscape. The natural protected areas are a great environment resource around which various tourist activities develop becoming an important part of Alps economy.

1.3. Life Cycle Assessment methodology. A general overview

Life Cycle Assessment (LCA) is an established methodology for assessing the impact of production systems on the environment. This technique, called originally Environmental-LCA (E-LCA), was developed in the late 1960's to address the desire of enterprises, but also policy makers, to understand the environmental impacts of different packaging options. The scope of environmental impacts grew with time and initially the sectors of interest were energy and solid wastes, followed after some time by air and water pollutants.

During the 1970's, 1980's and early 1990's the LCA was applied to an increasing variety of products and methods for life cycle environmental impact assessment began to be developed. LCA procedures and methods were developed as part of ISO's standards on environmental management and four ISO standards (ISO 14040-14044) were published in the years 1997-2000, all of which were replaced in 2006 with two standards, ISO 14040 (2006a) and ISO 14044 (2006b).

LCA was in this way developed to assess the environmental impact of industrial plants and production processes, but over the last 15 years has been adapted to assess impacts of agriculture as well (Gerber *et al.*, 2010). This method, as described in the 14040 ISO standard (ISO, 2006a), allows the evaluation of the environmental impact during all phases of a product or service's life. It involves the systematic analysis of production system, to account for all inputs and outputs associated with a specific product (or service) within a defined system boundary.

The ISO standards identify four phases for conducting a LCA (Fig. 2, ISO, 2006a):

- Goal and scope definition: where the purpose of the study is described as well as the functional unit. In this phase system boundary, method for co-product handling, data and data quality requirements are defined. Co-product handling is usually performed using allocation. Allocation means apportioning the environmental emissions between co-products based on, for instance, their amount or their economic value.

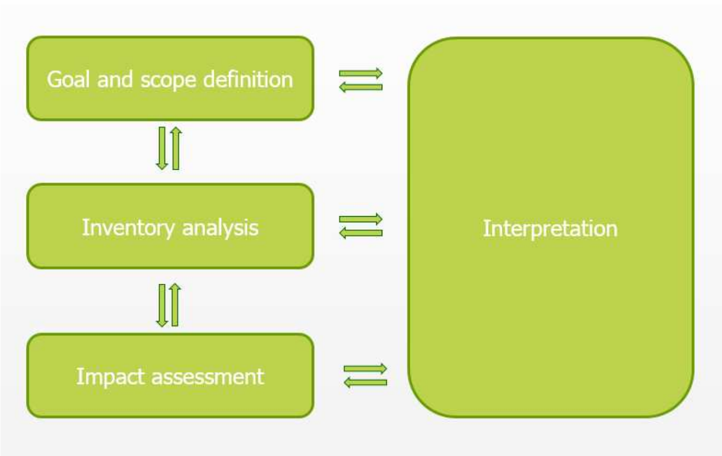

Figure 2. Life Cycle Assessment diagram illustrating the different phases defined in ISO 14040 (ISO, 2006a).

- Life Cycle Inventory (LCI): where the product (or service) system are evaluated. In this second phase, data are collected to determine flows, including inputs from nature (e.g. extracted raw materials, land or water used) and outputs to nature (e.g. emissions to air, water and soil). The amount of emissions are quantified per functional unit, as defined in the first phase.

- Life Cycle Impact Assessment (LCIA): where the degree and significance of environmental impacts associated with the flows compiled during the previous phase are evaluated. This is done by classifying emissions in impact categories and multiplying them by their characterization factor.

- Life Cycle Interpretation: where the findings of the previous two phases are combined with the defined goal and scope in order to reach conclusions and recommendations for the future.

1.3.1. Attributional LCA (ALCA)

ALCA gives information on the total amount of emissions resulting from the life cycle of a product. It focus on describing the physical flows to and from the process leading to the birth of the product, but it doesn't consider effects arising from changes in the output of the system due to different conditions related to an expansion/reduction of the production (Finnveden *et al.*, 2009). ALCA should typically be applied for comparing emissions from processes and to identify its 'hot spots'. It is useful to stress opportunities for reducing emissions within the system through improving the different life cycle stages or introducing new technologies. In general ALCA is considered easier to comprehend and apply than Consequential LCA (CLCA).

1.3.2. Consequential LCA (CLCA)

CLCA quantifies the variation in emissions amount in the cycle life of the product due to a change in the level of output. This approach is close to an economic one because it takes into account direct and indirect effects linked to a decision, usually represented by a change in demand for a product (Brander *et al.*, 2008). While in ALCA method co-products allocation is frequently used, but system expansion to handle them is optional, in CLCA method, system expansion is always used. A scenario analysis with the expansion of the system boundaries and the inclusion of additional processes is a useful way to deal with co-products within a CLCA study, reflecting also the consequences of a change in product consumption or disposal. CLCA approach is of great relevance to policy makers because of its capacity to analyze future strategies, and to account for consequences on affected systems (Brander *et al.*, 2008).

1.4. LCA applied to milk production at farm level

As described before there are an increasing concern about the ecological footprint of animal production because livestock systems have been associated to emission of GHG, deforestation, eutrophication, acidification, soil erosion, loss of biodiversity (Steinfeld *et al.*, 2006). Increased global demand for dairy products and the resulting increased intensification has exacerbated environmental impact and led to research and scientific debate on this issue. In recent years, researchers have applied LCA to milk production to obtaining valid carbon footprint numbers for raw milk, but there is still room for interpretation. The challenges are scientific but have implications for industry as well as for policy-makers and consumers. Industry needs robust methods to find improvement potentials, whereas policy-makers and consumers need robust science to base their decision-making for regulations and food choice (Flysiö *et al.*, 2012).

In general, there are large uncertainties in emissions estimate (Basset-Mens *et al.*, 2009), depending on assumptions and methodology (Pirlo, 2012), as well as large variations between farms (Kristensen *et al.*, 2011; Thomassen *et al.*, 2008). In the dairy sector, the assessment can involves the entire production chain of cow milk, from feed production through to the final processing of milk and meat, including transport to the retail sector. Raw milk is most frequently assessed in European studies through the *cradle to farm-gate* approach that end up to the point where the products leave the farm. *Farm-gate to retail* covers also transport to dairy plants, dairy processing, production of packaging, and transport to the retail distributor and there are only a limited number of studies on processed dairy products (Flysio, 2012; Guerci, 2012). Figure 3 represents a typical LCA framework study applied to a dairy farm.

The most common functional unit considered in LCA applied to dairy cattle systems is the amount of milk, using 1 kg energy corrected milk (ECM) or 1 kg fat and protein corrected milk (FPCM):

kg ECM = kg milk x (0.25 x 0.122 x Fat % + 0.077 x Protein %)

kg FPCM = kg milk x (0.337 + 0.116 x Fat % + 0.06 x Protein %)

Some authors in milk LCA studies consider the use of the soil expressing environmental impacts on 1 ha or 1 m^2 (Haas *et al.*, 2001).

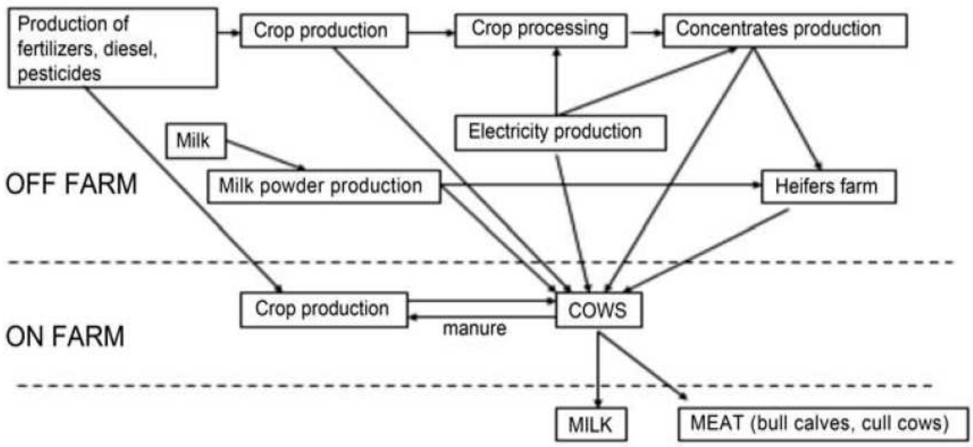

Figure 3. System boundaries diagram of a typical cradle to farm gate Life Cycle Assessment applied to the product milk (Penati *et al.*, 2013).

Handling of co-products in terms of inputs and outputs is one of the most important methodological aspects in milk LCA studies (Flysjö, 2012). As the dairy farm system produce different goods, environmental impacts are usually attribute to milk and meat, but often non-edible products and services can be considered such as forages, concentrates, manure and leather. In this way, the final amount of emissions is apportioned to the different products and services by means of allocation methods (*e.g.* physical and economic) (IDF, 2010). For milk production at farm level it is also possible to apply systems expansion to conduct sensitivity analysis on critical parameters (Cederberg and Stadig, 2003; Flysjö *et al.*, 2011; Thomassen *et al.*, 2008).

In the LCIA phase specific environmental impact categories are considered and for each of them characterization factors are applied to obtain relative values of emissions amount. The baseline impact categories considered in milk LCA studies are Global Warming Potential (GWP), acidification, eutrophication, land use, toxicity and biodiversity. The following sections deal in more detail the categories of GWP, acidification and eutrophication, as these are the categories addressed in the papers reported in the thesis.

1.4.1. Global Warming Potential (GWP)

The environmental impact which deals with the unnatural warming of the Earth's surface is called "global warming" The GWP expresses the contribution to the greenhouse effect of the different GHG (CH_4, N_2O and CO_2) relative to the effect of CO_2, whose reference potential is equal to 1. Each value of GWP is calculated for a specific period (usually 20, 100 or 500 years).

More than half, and often about two thirds, of the GHG emissions from dairy production consist of CH_4 and N_2O emissions (Gerber *et al.*, 2010) and they are typically calculated using one of the 'tier methods' descripted in the IPCC Guidelines for National Greenhouse gas Inventories (2006). Tier 1 is the most simple (using default numbers on country basis) and Tier 3 is the most detailed (using detailed country-specific data, models and field measurements). Factors are expressed as GWP for a time horizon of 100 years, in kg CO_2 equivalent (kg CO_2 eq).

Globally, CH_4 emissions make up round 14% of the GHG emissions induced by human activities and the main source (30%) of these emissions is enteric fermentation of ruminants (Steinfeld *et al.*, 2006). CH_4 is the main component of GHG emissions in the ruminant livestock system and results from microbial anaerobic respiration in the rumen (87%) and, to a lesser extent (13%), the intestine (IPCC, 2006). 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) (Seijan *et al.*, 2011; Nguyen *et al.*, 2013). In addition, some CH_4 comes from manure, and the amount depend 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) (IPCC, 2006).

For milk, N_2O contributes around 26-40% to total GHG emissions at farm gate (Flysö *et al.*, 2011; Thomassen *et al.*, 2008). N_2O is produced by the nitrification of ammonium to nitrate or the incomplete denitrification of nitrate and is the main GHG emission derived from manure (Steinfeld *et al.*, 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). 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 (McGettigan *et al.*, 2010).

While CH_4 and N_2O emissions are dominant in livestock systems, CO_2 plays a secondary role. 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). 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 (Steinfeld *et al.*, 2006).

Tables 1, 2, 3, 4 and 5 report equations and emission factors (EF) used in the works collected in this thesis to estimate direct and indirect CH_4 and N_2O emissions. A time horizon of 100 years is typically used when estimating GWP and the characterising factors used in this thesis are: 1 kg CH_4 = 25 kg CO_2-eq, and 1 kg N_2O = 298 CO_2-eq (IPCC, 2007).

Table 1. Equations and emission factors for the estimation of methane (CH_4) from enteric fermentation

Amount	EF[1]	References
EF=[GE[2]*(Ym[3]/100)*365]/55.65		Eq.10.21, IPCC (2006)
GE=[[(NEm[4]+NEa[5]+NEl[6]+Nep[7])/REM[8]]+(NEg[9]/REG[10])]/(DE[11]/100)		
DE	65% for organic dairy cow	IPCC (2006); INRA (2010)
	68% for conventional dairy cow	
	62% for heifers	
	59% for calves	
Ym	6% for mature cattle	ISPRA (2008)
	4% for young cattle	

[1]EF: emission factor; [2]GE: gross energy; [3]Ym: methane conversion factor; [4]NEm: net energy by the animal for maintenance; [5]NEa: net energy for animal activity; [6]NEl: net energy for lactation; [7]NEp: net energy required for pregnancy; [8]REM: ratio of net energy available in a diet for maintenance to digestible energy consumed: [9]NEg: net energy required for growth; [10]REG: ratio of net energy available for growth in a diet to digestible energy consumed; [11]DE: digestible energy.

Table 2. Equations and emission factors for the estimation of methane (CH_4) emissions at storages level

Amount	EF[1]	References
$CH_4=VS^{(2)}*Bo^{(3)}*0.67*\sum(MCF^{(4)}/100)*MS^{(5)}$		Eq. 10.23, IPCC (2006)
$VS=[GE^{(6)}*(1-DE^{(7)}/100)+(UE^{(8)}*GE)]*((1-Ash^{(9)})/18.45)$		Eq.10.24, IPCC (2006)
Ash	0.08	IPCC (2006)
Bo	0.24 m^3 CH_4/kg VS for dairy cattle 0.18 m^3 CH_4/kg VS for heifers and calves	IPCC (2006)
MCF	pasture: 1.0% solid storage: 2.0%	IPCC (2006)
MS	1	

(1)EF: emission factor; (2)VS: daily volatile solid excreted; (3)Bo: maximum methane producing capacity for methane produced; (4)MCF: manure methane conversion factors (with an annual average temp.=10°C); (5) MS: fraction of livestock category manure handled using manure management system S; (6)GE: gross energy; (7)DE: digestible energy; (8)UE: urinary energy; (9) Ash content of manure calculate as a fraction of dry matter feed intake.

Table 3. Equations and emission factors for the estimation of nitrous oxide (N_2O) emissions at storages level

Amount	EF[1]	References
N_2O=Nex[2]*MS[3]*EF3*44/28[4]		Eq. 10.25, IPCC (2006)
Nex=Nintake*(1-Nretention)		Eq. 10.31, IPCC (2006)
MCF[5]	1.0%	
EF3	solid storage: 0.005 (pasture: included in emissions from managed soils)	IPCC (2006)

[1]EF: emission factor; [2]Nex: annual average N excretion; [3] MS: fraction of livestock category manure handled using manure management system S; [4]44/28: conversion factor from N-N_2O to N_2O [5]MCF: manure methane conversion factors (with an annual average temp.=10 °C).

Table 4. Equations and emission factors for the estimation of direct nitrous oxide (N_2O) emissions at field level

Amount	EF[1]	References
N_2O=(N_2O-Ninputs[2]+N_2O-Nprp[3])*44/28[4]		Eq. 11.2, IPCC (2006)
N_2O-Ninputs=(Fsn[5]+Fon[6]+Fcr[7])*EF1		
N_2O-Nprp=Fprp[8]*EF3		Eq. 11.1, IPCC (2006)
EF1	0.01	IPCC (2006)
EF3	0.02	IPCC (2006)

[1]EF: emission factor; [2]N_2O-Ninputs: annual direct N_2O-N emissions from N inputs to managed soils; [3]N_2O-Nprp: annual direct N_2O-N emissions from urine and dung inputs to grazed soils; [4]44/28: conversion factor from N-N_2O to N_2O; [5]Fsn: annual amount of synthetic fertilizer N applied to soil; [6]Fon: annual amount of managed animal manure applied to soil; [7]Fcr: annual amount of N in crop residues; [8]Fprp: annual amount of urine and dung N deposited by grazing on pasture.

Table 5. Equations and emission factors for the estimation of indirect nitrous oxide (N_2O) emissions at field level

Amount	EF[1]	References
$N_2O(atd)^{(2)}=((Fsn^{(3)}*Frac\_GasF^{(4)})+((Fon^{(5)}+Fprp^{(6)})*Frac\_GasM^{(7)}))*EF4*44/28^{(8)}$		Eq. 11.11, IPCC (2006)
Frac_GasF	0.092	ISPRA (2008)
Frac_GasM	0.29	ISPRA (2008)
EF4	0.01	IPCC (2006)
$N_2Ol^{(9)}=(Fsn+Fon+Fprp+Fcr^{(10)})*Frac\_Leach^{(11)}*EF5*44/28$		Eq. 11.10, IPCC (2006)
Frac_Leach	0.26	Bretscher (2010)
EF5	0.0075	IPCC (2006)

(1)EF: emission factor; (2)N_2O(atd): annual amount of N_2O produced from atmospheric deposition of N volatilised from managed soils; (3)Fsn: annual amount of synthetic fertilizer N applied to soil; (4)Frac_GasF: fraction of Fsn N that volatilises as NH_3 and NO_x; (5)Fon: annual amount of managed animal manure applied to soil; (6)Fprp: annual amount of urine and dung N deposited by grazing on pasture; (7)Frac_GasM: fraction of Fon and Fprp N that volatilises as NH_3 and NO_x; (8)44/28: conversion factor from N-N_2O to N_2O; (9)N_2Ol: annual amount of N_2O produced from leaching and runoff; (10)Fcr: annual amount of N in crop residues; (11)Frac_Leach: fraction of total N added to soils that is lost for leaching and runoff.

1.4.2. Acidification

Over GHG, the livestock sector is an important source of other air pollutants as ammonia (NH_3), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and other volatile organic compounds. In the presence of atmospheric moisture and oxidants, SO_2 and nitrogen oxides are converted to sulphuric and nitric acids. These airborne, noxious to respiratory system, return to earth in the form of acid rain, and as a dry deposited gases and particles, which may damages crops and forests and makes lake and streams unsuitable for fish and plant and animal life. NH_3 volatilization (nitrified in the soil after deposition) is among the most important causes of acidifying wet and dry atmospheric deposition, and 94% of global anthropogenic atmospheric emission of NH_3 is produced by the agricultural sector. The livestock sector contributes about 68% of the agriculture share, mainly from deposited and applied manure (Steinfeld *et al.*, 2006).

During storage the nitrogen (N) present in faeces and urine starts to mineralize to NH_3/NH_4^+, providing the substrate for nitrifiers and denitrifiers and hence, eventual production of N_2O. For the most part these excreted N compounds mineralize rapidly. In urine, typically over 70% on the N is presented as urea (IPCC, 1997). Turning to NH_3, rapid degradation to urea and uric acid to ammonium leads to very significant N losses through volatilization during the storage and the treatment of manure. While actual emissions are subject to many factors, in particular to manure management system and ambient temperature, most of the NH_3-N volatilizes during storage (typically about one-third of the initially voided N) and before application or discharge (Steinfeld *et al.*, 2006).

Another share of direct emissions attribute to livestock comes from fertilizer applied to crop fields: 20 to 25% of worldwide mineral fertilizer used (about 20 million tonnes N) can be ascribed to feed production for the livestock sector. The average mineral fertilizer NH_3 volatilization loss rate is 14% (FAO/IFA, 2001).

The more used methodology to estimate acidification in milk LCA studies is the tier 1 developed by IPCC that does not take into account of regional differences in terms of which areas are more or less susceptible to acidification. It accounts only for acidification caused by SO_2 and NO_x including acidification due to mineral fertiliser use.

In Tables 6 and 7 are reported equations and EF used in the works collected in this thesis to estimate NH_3 emissions. Acidification potential is expressed using the reference unit kg SO_2 equivalent (kg SO_2 eq).

Table 6. Equations and emission factors for the estimation of ammoniac (NH_3) emissions at storage level

Amount	EF[1]	References
Nvolatilization[2]=Nex[3]*MS[4]*Frac_GasMS[5]/100*17/14[6]		Eq. 10.26, IPCC (2006)
MS	1	
Frac_GasMS	solid storage: 29%	ISPRA (2008)

[1]EF: emission factor; [2]Nvolatilization: amount of manure N that is lost due to volatilization of NH_3 and NO_X; [3]Nex: annual average N excretion; [4]MS: fraction of livestock category manure handled using manure management system S; [5]Frac_GasMS: N loss from MMS due to volatilization of N-NH_3 and N-NO_X; [6]17/14: conversion factor from N-NH_3 to NH_3.

Table 7. Equations and emission factors for the estimation of ammoniac (NH_3) emissions at field level

Amount	EF[1]	References
NH_3=(Fsn[2]+Fon[3]+Fprp[4])*EF1		EEA (2009)
EF1	0.084	EEA (2009)
NO_X=(Fsn+Fon+Fprp)*EF2		
EF2	0.026	EEA (2009)

[1]EF: emission factor; [2]Fsn: annual amount of synthetic fertilizer N applied to soil; [3]Fon: annual amount of managed animal manure applied to soil; [4]Fprp: annual amount of urine and dung N deposited by grazing on pasture.

1.4.3. Eutrophication

Eutrophication is the build-up of a concentration of chemical nutrients, such as NH_3, nitrates (NO_3), NO_x and phosphorous (P), in an ecosystem which leads to abnormal productivity. This leads to an excessive plant growth like algae in rivers which causes severe reductions in water quality and animal populations (Acero *et al.*, 2014).

Eutrophication is a natural process in the ageing of lakes and some estuaries, but livestock and other agriculture activities can greatly accelerate eutrophication by increasing the rate of nutrients and organic substances that enter in the aquatic ecosystems (Steinfeld *et al.*, 2006). In the livestock sector, as acidification, even eutrophication is associated to manure management and mineral fertilizer. The last is more completely absorbed, depending of the fertilizer application rate and the type of mineral fertilizer. Most of N losses are not directly emitted to the atmosphere, but is lost to water by leaching and run off (Steinfeld *et al.*, 2006). In its inorganic form (NO_3), N is very mobile in soil solution, and can be easily be leached below the rooting zone to groundwater, or enter the subsurface flow. While, in its organic form, N can also be carried into water cycle through run off. High concentrations of nitrate in drinking water are considered a human-health problem because in the stomach nitrate is converted rapidly to nitrite, which can cause a reduction in the blood's oxygen-carrying capacity. The World Health Organization guide value for NO_3 concentration in drinking water is 45 mg/l (Steinfeld *et al.*, 2006).

P in water is not considered to be directly toxic to humans and animals health and, therefore, no drinking water standards have been established for this element. P contaminates water resources when manure is directly deposited or discharged into the water or when excessive levels of P are applied to the soil. Unlike N, P is held by soil particles and is less subject to leaching unless concentration levels are excessive. Erosion is in the fact the main source of phosphate ($PO^{3-}{}_4$) loss and P is transported in surface run off in soluble or particulate form (Steinfeld *et al.*, 2006). The livestock sector is the major cause of these increase, and in many countries animal production is directly or indirectly responsible for more than 50% of the mineral N and P applied on agricultural land (Steinfeld *et al.*, 2006).

This impact category is expressed using the reference unit, kg PO_4^{3-} equivalents (kg PO_4^{3-} eq). In this thesis N leaching at field level in the form of NO_3 was calculated on the basis of the IPCC (2006) equations while P loss in the form of PO^{3-}_4 was estimated as proposed by Nemecek and Kägi (2007). In Table 8 are reported equations and EF used.

Table 8. Equations and emission factors for the estimation of nitrogen (N) leaching at field level

Amount	EF[1]	References
Pollutant: NO_3		
NO_3=(Fsn[2]+Fon[3]+Fprp[4]+Fcr[5])*Frac_Leach[6]*62/14[7]		Eq. 11.10, IPCC (2006)
Frac_Leach	0.26	Bretscher (2010)
Pollutant: PO_4^{3-}		
Pro[8]=Prol[9]*Fro[10]		Nemecek and Kagi (2007)
Prol	arable land: 0.175 extensive permanent meadow: 0.15	Nemecek and Kagi (2007)
Fro=1+Fro_min[11]+Fro_man[12]		
Fro_min=0.2/80*P_2O_5 min[13]*95/31[14]		
Fro_man=0,4/80*P_2O_5 man[15]*95/31		

[1]EF: emission factor; [2]Fsn: annual amount of synthetic fertilizer N applied to soil; [3]Fon: annual amount of managed animal manure applied to soil; [4]Fprp: annual amount of urine and dung N deposited by grazing on pasture; [5]Fcr: annual amount of N in crop residues; [6]Frac_Leach: fraction of N added to managed soils lost through leaching and runoff; [7]62/14: conversion factor from NO_3-N to NO_3; [8]Pro: quantity of P lost throught run-off to rivers; [9]Prol: average quantity of P lost throught run-off for a land use category; [10]Fro: correction factor for fertilization; [11]Fro_min: correction factor for fertilization by mineral fertilizers; [12]Fro_man: correction factor for fertilization by manure; [13]P_2O_5min: quantity of P_2O_5 contained in the mineral fertilizer; [14]95/31: conversion factor from P to PO_4^{3-}; [15]P_2O_5man: quantity of P_2O_5 contained in the manure.

1.4.4. *Other impact categories of interest for milk production*

Land use and land use change (LUC) describe the environmental impacts of utilizing land for human purpose. This issue is highly relevant for dairy production, primarily related to feed production (both purchased feed and feed produced on farm) but also for utilization of raw materials. LUC can have both a positive impact, such as carbon sequestration in grasslands, and a negative impact, such as deforestation (Flysjö, 2012). Carbon sequestration in soils represent an important mitigation strategy for agriculture and despite the difficulties and uncertainties linked to its determination, many authors agree that carbon fluxes should be addressed in carbon footprint assessments (Flysiö, 2012; IPCC, 2006; Petersen *et al.*, 2013; Sousanna *et al.*, 2010). On the other hand, global environmental impact from LUC is responsible for about 9% of anthropogenic CO_2 emissions. These emissions derived from deforestation as a result of more land needed for the production of biofuels and food (mainly animal feed and livestock rearing). About one third of the GHG emissions related to livestock production is associated with LUC (Steinfeld *et al.*, 2006).

Livestock production plays an important role also in the current biodiversity crisis especially as a result of intensified agricultural practices, as it contributes directly or indirectly to all these drivers of biodiversity loss, at the local and global level. Livestock-related land use and LUC modify or destroy ecosystems that are the habitats for different species. Livestock contribute to climate change, which in turn has a modifying impact on ecosystems and species. Terrestrial and aquatic ecosystems are affected by emissions into the environment (acidification and eutrophication). The sector also directly affects biodiversity through invasive alien species and overexploitation, for example through overgrazing of pasture plants (Steinfeld *et al.*, 2006). However, biodiversity is an extremely complex concept that is difficult to summarize in a single indicator as other environmental concerns are. Researchers have identified and tested different indicators or tools to incorporate biodiversity impacts into dairy farms LCA, but no agreements have been yet reached on the most appropriate technique (Curran *et al.*, 2011; Penman *et al.*, 2010; Sizemore, 2015)

About toxicity, LCA methodology describes two impact categories: human toxicity and environmental one. The human toxicity is a calculated index that reflects the potential harm of a unit of chemical released into the environment, and it is based on both the inherent toxicity of a compound and its potential dose. There are different potentially dangerous chemicals to humans through inhalation, ingestion, and even contact. Cancer potency, for example, is an issue here. Environmental toxicity is measured as three separate impact categories that examine freshwater, marine and land. The emission of some substances, such as heavy metals, can have impacts on the different ecosystems. Assessment of environmental toxicity has been based on maximum tolerable concentrations in water for ecosystems (Acero *et al.*, 2014). These impact categories, not so easy to apply to a milk LCA, could be of great interest because strictly associated with the use of fertilizers and pesticides in animal feed production and with the use of medication and antibiotics in the rearing.

Another impact category that should be investigated in the case of dairy farms is the energy use. It consists in the direct use of fuels and electricity at farm level, and in the indirect energy linked with the production of off-farm equipment, feed and all materials derived or associated in some way with fossil fuels (Guerci, 2013).

1.5. Ecosystem services (ES)

The Millennium Ecosystem Assessment (MEA) was carried out between 2001 and 2005 to assess the consequences of ecosystem change for human societies and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being. It was a necessary response to government requests following four important international conventions: the Ramsar Convention on Wetlands (Ramsar, 1971), the Convention on Migratory Species (Bonn, 1979), the Convention on Biological Diversity (Rio de

Janeiro, 1992), and the United Nations Convention to Combat Desertification (Paris, 1994) (MEA, 2005).

MEA (2005) defines ecosystems as "dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit" and it deals with the full range of ecosystems from natural forests to landscapes with mixed patterns of human use, to ecosystems intensively managed and modified by humans' activities, such as agricultural land and urban areas.

Ecosystems, as defined above, offer to humans and to the surrounding environment a series of goods and services called ES. About this, the most important references were the work of Daily (1997) *Nature's services: societal dependence on natural ecosystem* and the paper of Constance *et al.* (1997) *The value of the world's ecosystem services and natural capital*. The definitions proposed by these authors were summarized in the documents of MEA and worldwide used, outlining ES as "the benefits that people obtain from ecosystems".

ES are classified by MEA into four main categories: (i) provisioning services consisting in all the goods that derive from ecosystems and of which humans need to live, such as food, water, timber, and fiber; (ii) regulating services that affect climate, floods, disease, wastes, and water quality; (iii) cultural services that provide recreational, aesthetic, and spiritual benefits; and (iv) supporting services that support and enable the provision of all the other ES such as soil formation, photosynthesis, and nutrient cycling. The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ES. In figure 4 are reported the strength of linkages between categories of ES and components of human well-being that are commonly encountered including also indications about the extent to which it is possible for socioeconomic factors to mediate the linkage.

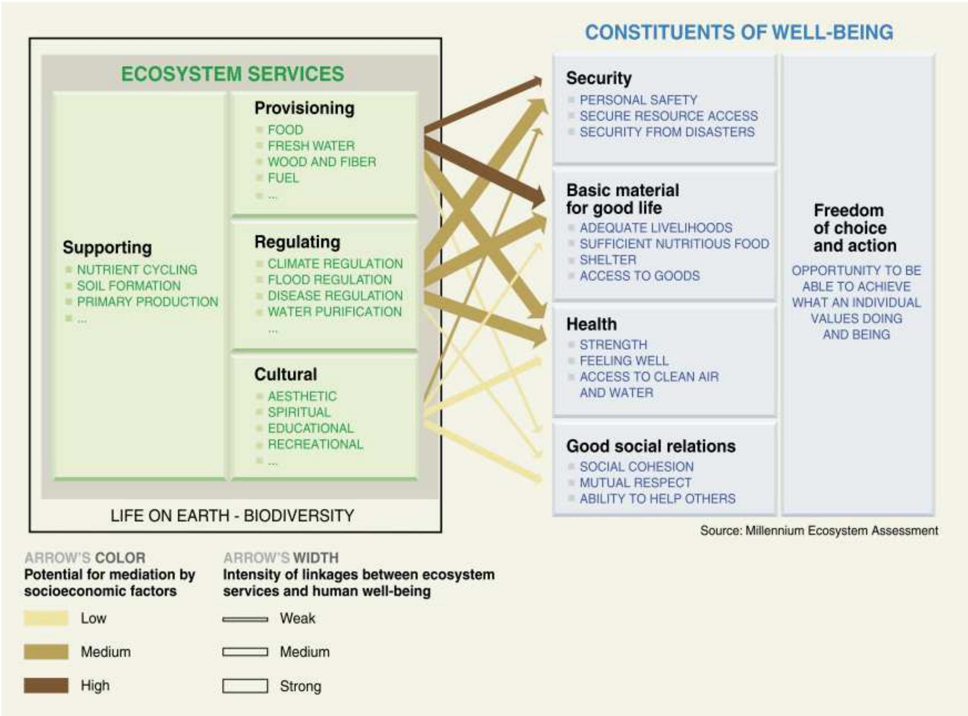

Figure 4. Ecosystem services and human well-being: strength of ties (MEA, 2005)

Nowadays, there is growing evidence that many ecosystems have been degraded to such an extent that they are nearing critical points, beyond which their capacity to provide useful services may be drastically reduced. The supply of food, fresh water, energy and materials for a growing population has been achieved at a considerable cost for the complex systems of plants, animals and biological processes that have made the planet habitable. Precaution is needed in order to maintain healthy ecosystems and the continued flow of ES over the long-term. This especially with the growth of human needs provided for the coming decades, when these systems will face even greater pressures, along with the risk of further weakening of the natural infrastructure on which all societies depend (MEA, 2005).

Modern technologies and knowledge today can significantly reduce the human impact on the ecosystem. However, it is unlikely that these instruments can be fully used until ES will be perceived as free and without limitations. In 2007, environment ministers from the governments of the G8+5 countries, meeting in Potsdam, Germany, agreed to "initiate the process of analysing the global economic benefit of biological diversity, the costs of the loss of biodiversity and the failure to take protective measures versus the costs of effective conservation" (TEEB, 2010).

1.5.1. Payment for ES (PES) and their quantification

The Economics of Ecosystems and Biodiversity (TEEB) study, which emerged from that decision, delivered a series of reports addressing the needs to apply economic thinking to the use of biodiversity and ES. This approach can help clarify two critical points: "why prosperity and poverty reduction depend on maintaining the flow of benefits from ecosystems; and why successful environmental protection needs to be grounded in sound economics, including explicit recognition, efficient allocation, and fair distribution of the costs and benefits of conservation and sustainable use of natural resources". The invisibility of ES has often encouraged inefficient use or even destruction of the natural capital that is the foundation of our economies (TEEB, 2010).

In recent years the interest of the researchers in environmental economics issues focused on tools designed to provide a market for goods and services that have none. These tools are called PES. In the international literature the main reference for a clear definition of PES is Wunder (2005) which lists the simple characteristics that identify a PES pattern. "A PES is: (i) a voluntary transaction where (ii) a well-defined ES (or a land-use likely to secure that service) (iii) is being 'bought' by a (minimum one) ES buyer (iv) from a (minimum one) ES provider (v) if and only if the ES provider secures ES provision (conditionality)". Engel *et al.* (2008) summarize the logic of PES as follows. Ecosystem managers (e.g., farmers) often receive higher benefits from land uses alternative to conservation and therefore choose the first form. However, those land uses often have negative effects on other people (for instance, downstream water users). The latter (the ES buyers) could therefore pay the ecosystem managers (the ES providers) to induce them to adopt practices that ensure the provision of the ES and the conservation of these important resources.

Finally, a fundamental issue is whether the ES can be measured. If measurement with a reasonable degree of accuracy is not possible, the extent of the externality cannot be assessed, and there would be no basis for negotiating (Tacconi, 2012). ES valuation is the process of assessing the contribution of ES to meeting a particular goal or goals (Liu *et al.*, 2010). There are at least three important goals that have been identified as important to managing ES within the context of the planet's ecological life support system: (i) sustainability: assessing and ensuring that human activities are ecologically sustainable; (ii) equity: distributing resources fairly, both within the current generation of humans and future generations, and also between humans and other species; and (iii) efficiency: efficiently allocating the resources to maximize utility or human welfare (Costanza, 2000; Liu *et al.*, 2010). In general, the monetary evaluation of ES 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). 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.

Europe's agricultural sector has received sustained public support under the Common Agricultural Policy (CAP) the last 50 years. This support has evolved alongside growing recognition and awareness of the strong links between agricultural production and the conservation of biodiversity. Consequently, CAP assistance has shifted from strict agricultural production support towards a broader focus including the inventory of public goods and ES provided by agriculture. Since the European Commission highlighted the importance of using the CAP to halt the decline of biodiversity, various efforts have been made to merge biodiversity conservation into agricultural policy. Agri-environment measures provide payments to farmers who subscribe, on a voluntary basis, to environmental commitments related to the preservation of the environment and the safeguarding of countryside (EEA, 2010b). This payments should provide compensation for additional costs and income foregone resulting from applying environmentally friendly farming practices. They are set on a regional basis by Rural Development Programmers and, considering the difficulties of estimating the values of ES, these payments can be seen as an indicator of dairy farms' ES (Kiefer *et al.*, 2015; Ripoll- Bosch *et al.*, 2012).

1.5.2. ES provided by alpine dairy farms

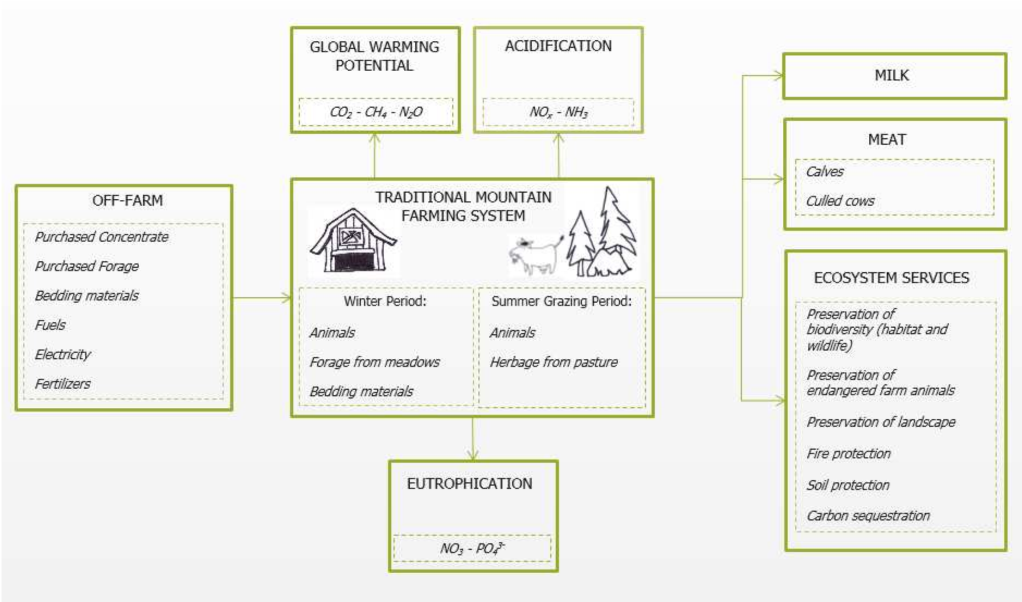

Figure 5. System boundaries diagram of Life Cycle Assessment applied to traditional dairy mountain farms which consider also the ecosystem services provided.

In recent decades, the livestock sector in alpine mountain areas, mainly represented by dairy cattle, has been affected by a dramatic reduction in the number of farms with important structural and management changes. Alpine farms increased in the number of animals, increased in indoor production systems, used more specialized non-indigenous cattle breeds and increased the utilization of extra-farm concentrates instead of forages from local meadows and pastures. (Ramanzin *et al.*, 2014). All this leads to the natural re-afforestation of abandoned meadows with the loss of a richer biodiversity (Marini *et al.* 2011). Along the bottoms of the main valleys, re-afforestation has been less pronounced, but many meadows have been converted into arable crops by modern farms, incurring in the risk of excessive nutrients outputs per unit of land. Both these processes have also been detrimental to landscape attractiveness (Sturaro *et al.*, 2013). Indeed, traditional dairy systems, largely based on the use of meadows and pastures, provide not only milk and meat, but also other fundamental positive externalities and ES, such as conservation of genetic resources, water flow regulation, carbon sequestration, pollination, climate regulation, landscape maintenance, recreation and ecotourism, and cultural heritage (EEAa, 2010).

LCA can be used to evaluate the environmental impact of livestock systems in mountain areas, and more and more authors (Beauchemin *et al.*, 2010; Haas *et al.*, 2001; Kiefer *et al.*, 2015; Ramanzin *et al.*, 2014; Ripoll-Bosch *et al.*, 2012) stress the importance of accounting for ES in LCA using a holistic approach. Figure 5 outlines the system boundaries of a LCA study applied to traditional dairy mountain farms: ES are considered as outputs of the system.

Once again, the deepening of these issues is postponed to the first paper reported in the thesis.

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2. Objective and structure of the thesis

The aim of the present research was to evaluate the environmental impacts of small-scale dairy farms in mountain areas, taking also into account their multi-functionality as these livestock systems provide a wide range of additional ecosystem services (ES). The structure of the thesis is presented in Figure 1.

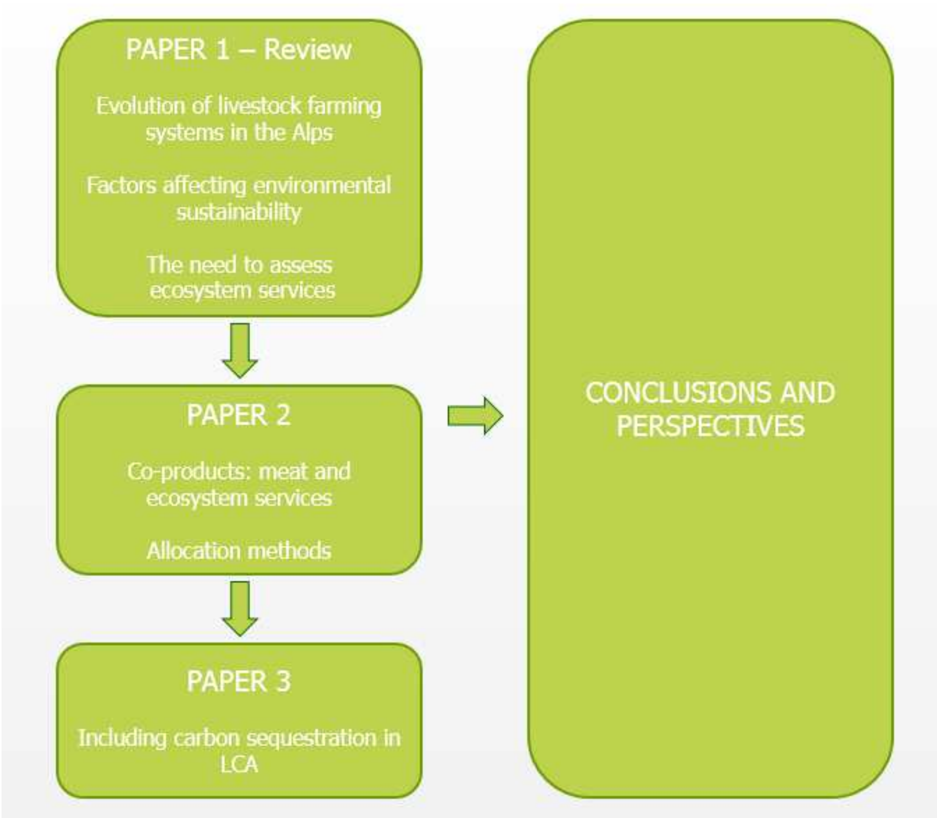

Figure 1. Structure of the present thesis.

The first paper is a review and it describes the evolution and characterization of livestock sector in the Italian Alps analyzing the most important factors affecting their environmental sustainability. This work has been shared with other researchers involved in alpine area studies to merge skills and to lay the foundations of a partnership that will create a common database to collect data of livestock alpine farms.

The review discusses the adoption of methods - like Life Cycle Assessment (LCA) - to evaluate the environmental impacts and the need to assess also the ES provided by foraged-based farms. In fact, only the traditional farms are able to use autochthonous breeds, to maintain grasslands and their biodiversity with extensive practices, to make full use of summer pastures, and conserve the traditional landscape. In addition, these farms are more often subjected to Nature 2000 regulations and exposed to increasing conflicts with wildlife. Therefore, the future of these grassland-based systems will depend not only on remuneration from high added value products, but also on regulation and compensation of ES.

The aim of the second paper is to estimate the environmental impact of organic and conventional small-scale dairy farms in Eastern Italian Alps. The farms object of this study were assessed for global warming potential (GWP), acidification and eutrophication impacts through a LCA approach in two scenario: Baseline Scenario, based on the real farm data, and Milk-Beef production system Scenario, assuming that calves exceeding the culling rate were fattened directly on-farm. Three different emissions allocation methods were considered: No allocation, Physical allocation that accounted also for the co-product beef, and Economic allocation that accounted also for the ES provided by the farms and estimated on the basis of agri-environment payments. Furthermore, two functional units were used: Fat and Protein Corrected Milk (FPCM) and Utilizable Agricultural Land.

The third paper, using the same LCA methodology as in the second work, takes into account the potential of soil carbon sequestration. In grassland based livestock systems, soil carbon sequestration might be a potential sink to mitigate greenhouse gas emissions. Nevertheless, it has not been included in the carbon footprint calculations and it lacks a methodology commonly shared.

Two groups of farms were identified on the basis of the Livestock Units (LU) reared: traditional small-scale farms (< 30 LU), and modern ones (> 30 LU) and two different emissions allocation methods were considered: No allocation and Physical allocation.

To point out how the presence of grasslands is crucial for small-scale farms carbon footprint, in this study was also applied a simulation for increasing forage self-sufficiency of farms.

3. Environmental sustainability of Alpine livestock farms

Original paper: Battaglini L., Bovolenta S., Gusmeroli F., Salvador S., Sturaro E., 2014. *Environmental sustainability of alpine livestock farms*. Italian Journal of Animal Science, (Page Press, Pavia, Italy), 13:3155, 431-443. (ISSN 1594-4077). (DOI: 10.4081/ijas.2014.3155).

3.1. 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.*, 2013). 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; Bernues *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 considers the key factors to be considered when evaluating the sustainability of these systems. The contribution of Alpine livestock to global greenhouses gas emissions (GHG) is also highlighted, taking into account the mitigating action of carbon sequestration. Finally, the need to incorporate ecosystem services (ES) offered in the evaluation of environmental sustainability with holistic methods, such as Life Cycle Assessment (LCA), is discussed.

3.2. Evolution and characterization 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 (northeastern 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 contain 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.

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 have 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 (Fig. 1). During the last two decades, the number of cows only increased in farms with more than 50 cows, decreasing in much smaller farms, which breed few animals but are able to effectively utilize 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).

Table 1. Livestock sector in the Italian Alps[1]

Year[2]	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

[1]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.
[2]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.

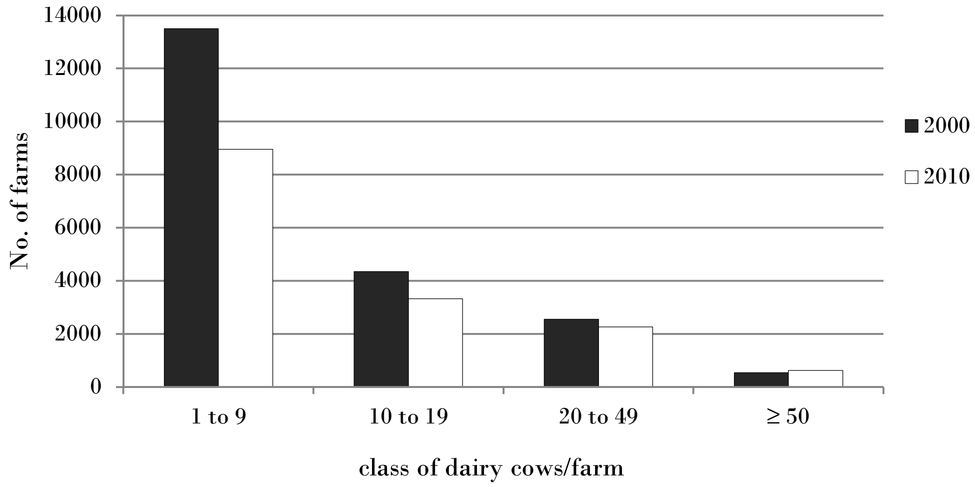

Figure 1. Number of dairy farms in the Italian Alps, by classes of heads/farm[1].

[1]On the basis of Italian agricultural censuses (ISTAT, 2013); mountainous areas in the province 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

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 breeds – 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 utilization during the summer, where milk is often processed in small farm dairy plants and the products are sold directly on the farm. The gradual utilization 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 or for meat production; however, 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.

Table 2. Classification of livestock systems in Italian alpine areas[1]

	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

[1] Modified from Bovolenta *et al.*, 2008.

3.3. 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 milk 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 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 standpoint. 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 is still 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 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 Common Agricultural Policy (CAP) (Bartolini *et al.*, 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).

Table 3. Factors affecting sustainability of livestock in alpine areas

Factors	Description	Contents
Technical and economic	- Specialization	level of intensification, management model, length of production chains, multifunctionality;
	- Production	production and milk quality, enhancement of meat production, traditional products, environmental labeling, 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.

3.4. GHG 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, extending 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).

CH_4 is the main component of GHG emissions in the ruminant livestock system and results from microbial anaerobic respiration in the rumen (87%) and, to a lesser extent

(13%), the intestine (Murray *et al.*, 1976; IPCC, 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; IPCC, 2006; Sommer *et al.*, 2009). The IPCC (2006) estimates 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).

N_2O 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; Vérge *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 50-100 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). 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 (Fig. 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 a 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 a 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 inflection 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.

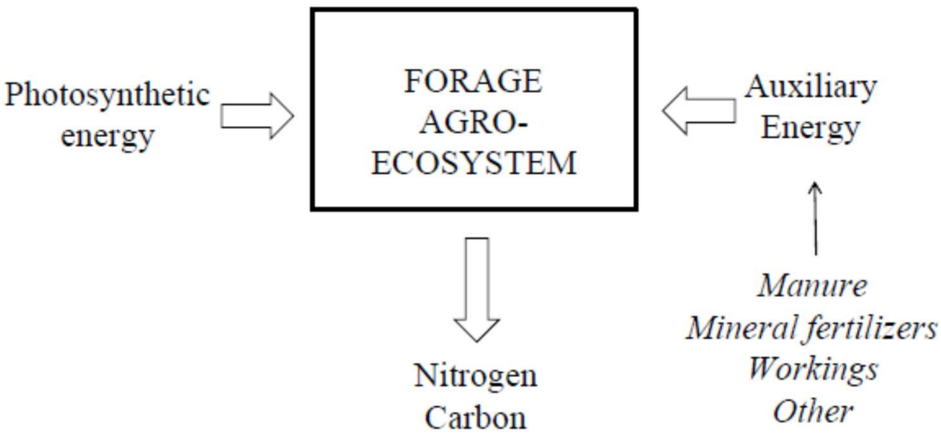

Figure 2. Input and output in forage agro-ecosystems

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

Table 4 summarizes the research state of 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 fertilizer 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.

Table 4. Environmental sustainability of livestock sector in the Alps: the state of 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: intensive, extensive and organic systems (farms=35)	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 (farms=31)	N and P farm gate balances	X					
Alig *et al.*, 2011	Switzerland Dairy farms: plain, hills *vs* mountain regions (farms=66)	LCA	X	X		X	X	
Bassanino *et al.*, 2011	Italy Dairy farms (farms=22)	N and P farm gate balances	X					
Schader *et al.*, 2012	Switzerland Organic dairy farm *vs* organic mixed farm (farms=2)	LCA		X		X		
Penati *et al.*, 2013	Italy Dairy farms (farms=28)	LCA	X	X	X	X		X
Guerci *et al.*, 2013b	Italy Dairy farms: summer grazing system *vs* no grazing system (farms=32)	LCA		X				

3.6. 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. LCA 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? LCA 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. LCA 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 ES 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 ES (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 ES 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 ES 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 viewpoint of a reversibility of the process viewpoint.

3.7. 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 CAP.

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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4. Environmental assessment of small-scale dairy farms with multifunctionality in mountain areas

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4.1. Introduction

The world's population has reached nearly 7 billion people and, according to several reliable projections, it is expected to reach 9 billion by 2050 (Lutz *et al.*, 2001; PRB, 2008). As the population grows, the demand for food will increase, and FAO (2009) forecasts a doubling of the consumption of animal products by 2050. This trend has an impact on several environmental emergencies and in particular global warming, eutrophication, acidification, and pollution (IPCC, 2013). Considering the environmental impact of animal products, especially due to the enteric emissions of methane (Gerber *et al.*, 2013), many authors explored the relationship between productivity and pollutant emissions, which are inversely related because increased efficiency allows the dilution of emissions across a larger volume of produced milk or meat (Capper *et al.* 2009, de Vries and de Boer, 2010; Gerber *et al.*, 2011).

Dairy farming in the Italian Alps has changed greatly in the last decades: between 1990 and 2010 (the last agricultural census available) farms decreased by 60%, while the number of animals decreased by 29%, with an increase of herd size by 76% (Battaglini *et al.*, 2014; ISTAT, 2013). However, this transition from small-scale, forage-based dairy farms towards larger and more specialized non-seasonal dairy systems, has resulted in a significant decrease of meadows and pastures (-27%), the abandonment of local dual-purpose breeds and a reduced ability to provide a wide range of the ecosystem services (ES) and cultural resources traditionally delivered by mountain dairy farms, as biodiversity and landscape conservation, soil protection, water quality and supply, carbon sequestration, avalanche and fire protection, agro-ecotourism, outdoor recreation, rural communities' and cultural heritage (Bernués *et al.*, 2005; EEA 2010a,b; Giupponi *et al.*, 2006; ISPRA, 2010; Mirazo-Ruiz, 2011; Parente and Bovolenta, 2012; Renting *et al.*, 2009; Schirpke *et al.*, 2012; Sturaro *et al.*, 2013).

The adoption of methods, such as Life Cycle Assessment (LCA) (ISO, 2006), to evaluate the environmental impacts that do not include these ES, may intensify this trend, which is considered defective by many scientists when applied to the mountains and, in general, to less favoured areas (Battaglini *et al.*, 2014; Bernués *et al.*, 2011; Kiefer *et al.*, 2015; Ramanzin *et al.*, 2014; Ripoll-Bosch *et al.*, 2013). In fact, also the Common Agricultural Policy (CAP) also recognizes the importance of livestock farming in mountain areas, and it has been directed its programmes toward the support of multi-functionality, with contributions and financial incentives and, in particular, with payments from agri-environmental measures of Rural Development Plans.

In this context of global demographic growth, environmental emergency, and economic crisis, the challenge for the future of mountain farming seems to be linked to the enhancement of products and services and the ability to achieve both "low input" and "high efficiency" (Nemecek *et al.*, 2011; Tilman *et al.*, 2011). Furthermore, organic systems should also be considered because they are commonly perceived by consumers as an eco-friendly method, which forbids the use of chemical substances and genetically modified organisms (Reg. UE 834/2007; Reg. UE 889/2008) and can increase the added value of animal products. LCA studies comparing organic and conventional livestock farming systems report a wide variation in the efficiency of milk production in the two systems. The studies show that the impacts per area of farmed land are usually less in organic systems, but are often higher when related to the quantity-produced impacts. (Meier *et al.*, 2015). Surveys of this kind carried out in mountainous areas and concerning small-scale farms are lacking in the literature.

The aim of this work was estimating, through an LCA approach, the environmental impact of small-scale farms in mountain areas comparing organic and conventional methods and using different functional units (FUs). The multi-functionality of these livestock farming methods was also considered, and the strudy explores how the environmental impact of these farms can change when accounting for ES through an economic allocation, as proposed by Ripoll-Bosh *et al.* (2013) and Kiefer *et al.* (2015).

4.2. Material and methods

4.2.1. Goal, scope definition, system boundaries and functional units of LCA

The goal of the LCA assessment was to assess how multi-functionality and the enhancement of co-produced beef could reduce the value of emissions attributable to milk.

The small-scale farms were analysed in a "cradle to farm-gate" LCA approach which implies that the emissions of greenhouse gases (GHGs) were assessed for all the processes involved up to the time when the milk leaves the farm and excludes the transport or processing of raw milk. All the processes related to the on-farm activity (*i.e.*, the animal's rations, manure storage, the cropping system and fuel consumption) and the related emissions were taken into account. The emissions from off-farm activities for the production of concentrate feed, fertilizers, bedding materials, electricity and fuel were also estimated. Figure 1 shows the flows considered in the study.

In this study, two FUs were considered: 1 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 1 m^2 of Utilizable Agricultural Land (UAL).

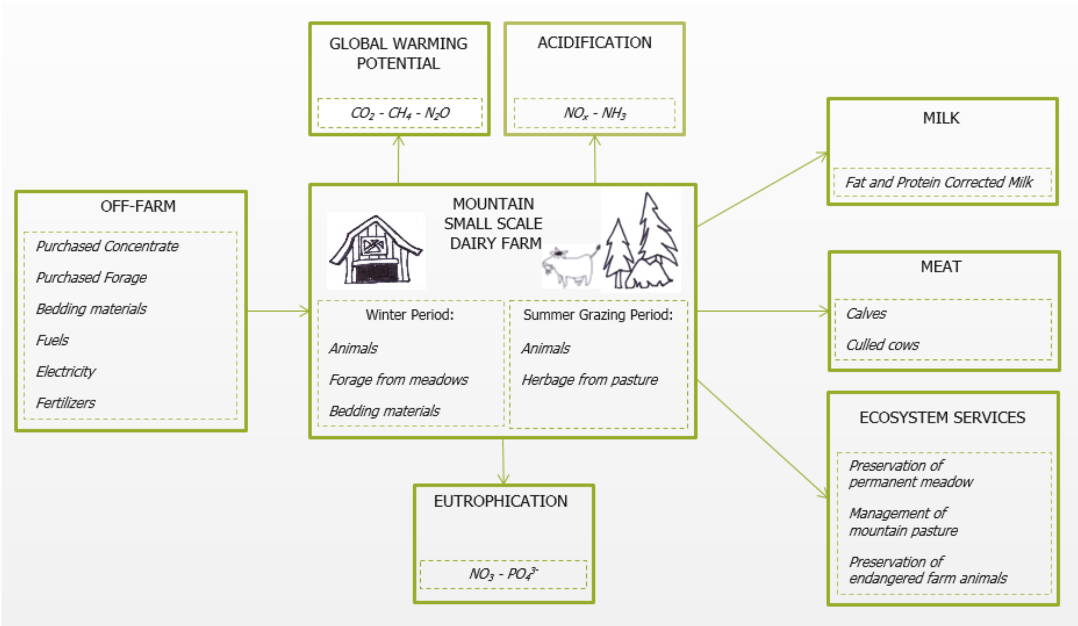

Figure 1. Small-scale farm system studied and emissions accounted for in the study.

4.2.2. Data collection and inventory analysis

The present study took place in the East Italian Alps (Rendena Valley, Autonomous Province of Trento). The area is entirely alpine and it is largely part of the Adamello Brenta National Park. The study involved 16 small-scale dairy farms (EFSA, 2015) that were selected to be representative of the area, and had the following particular characteristics: i) were handled by family members; ii) had a high forage self-sufficiency and use less than 800 kg of concentrate per cow per year; iii) held a local dual-purpose breed (all farms were registered in the Herd Book of Rendena breed); iv) used high-altitude pastures during summertime, following the traditional practices (min 90 days/year); v) hold the certifications of protected designation of origin (PDO) for *Spressa delle Giudicarie* cheese. Eight farms were certified organic (Reg. UE 834/2007), while the others were conventional. More details are reported in Table 1. The farms were analyzed in detail by a field investigation on the farm and through a farmer questionnaire, as well as by consultations with local associations and the Autonomous Province of Trento. The questionnaire covered the farm structure (buildings, machineries, equipment), the management (herd composition, housing system, manure management, ration composition), the summer grazing period (management of altitude pastures, duration of grazing period, characteristic of grassland area), and data on the input and output mass flow (forage, concentrate feed, milk, meat, fertilizer, pesticides) data. Information about the amount of milk and its protein and fat composition were provided by the dairy farms and by the Italian breeders association. Revenues and costs were obtained by consulting the farms balance sheets. The farm buildings and machineries, medicines, and other minor stable supplies were excluded from the assessment.

Table 1. Main characteristics of organic and conventional dairy farms.

	Organic		Conventional		Reference
	Mean	SE(1)	Mean	SE	
Total farm land, ha	79.5	31.90	70.9	32.96	PAT(2)
Highland pasture, ha	58.8	27.99	51.3	29.54	PAT
Permanent grassland, ha	20.3	5.08	19.5	4.16	PAT
LU(3) total, n	57.0	11.96	55.0	15.04	AIA(4)
Lactating cow, n	36.6	7.83	33.3	9.80	AIA
Milk yield, kg FPCM(5)/cow/year	4,491	436.8	5,092	260.2	AIA, DA(6), FA(7)
DMI lactating cows, kg DMI(8)/cow/day	17.3	0.22	18.8	0.23	FA
Concentrate feed, %	26.5	3.60	28.0	4.51	FA
Feed efficiency, kg FPCM/kg DMI/cow	0.71	0.06	0.74	0.03	-
Forage self-sufficiency, %	74.0	7.60	75.8	7.86	FA
Culling rate, %	16.9	1.65	21.3	1.98	AIA

(1)SE: Standard Error; (2)PAT: Autonomous Province of Trento; (3)LU: Livestock Units; (4)AIA: Italian Breeders Association; (5)FPCM: Fat and Protein Corrected Milk; (6)DA: Dairy Audit; (7)FA: Farm Audit; (8)DMI: Dry Matter Intake.

The methane (CH_4) emissions from enteric fermentation and manure management (including dung deposition during grazing time) were estimated according to Tier 2 of the Intergovernmental Panel on Climate Change, IPCC (2006a) guidelines. The CH_4 from enteric fermentation, based on the dry matter (DM) intake of the herd, was calculated by using an Y_m of 6% for lactating cows and 4% for young cattle (ISPRA, 2008; Pirlo and Carè, 2013); the digestible energy was calculated on the basis of the feed ration composition and expressed as a % of the gross energy (average values for the different animal categories: dairy cows 66%; heifers 62% and calves 59%). The CH_4 conversion factors (MCF) used for the manure emission in this study were 2% for solid storage and 1% for the pasture, with an annual average temperature of 10 °C (IPCC, 2006a). The proportion of manure handled in the two systems was calculated on the basis of each farm's grazing plan.

The direct nitrous oxide (N_2O) emissions at the storage level were estimated as proposed by Tier 2 of the IPCC (2006a): the count was based on the excretion of nitrogen (N), estimated as the DM intake and the N content of the diet. The protein of the indoor diet was calculated on the basis of the data provided by the commercial feed producers for the purchased concentrates and on the basis of the laboratory analysis for farm's concentrate and forage. The analyses to estimate the N content were performed according to the Kjeldahl method (AOAC, 2000) and the crude protein content was calculated as %N×6.25. The total contribution of grazing to the diet resulted from the nutrient requirements of the cattle (NRC, 2001) and on a database of the results of a series of studies on grazing dairy cows in the same geographical area and conditions (Bovolenta *et al.*, 2009, 2008, 2002; Malossini *et al.*, 1995). The resources grazed were included in the diet depending on the period spent in the high pastures.

The management of the manure in the farms object of analysis was made only through solid storage, and the emission factors used for direct N_2O was 0.005. Tier 1 (IPCC, 2006b) was applied to the estimation of the direct and indirect N_2O emissions at the field level (due to the application of manure and synthetic fertilizer, and to the dung and urine deposited by grazing animals), and for the N_2O emissions produced from leaching and runoff. The direct N_2O emissions at the field level were calculated applying the following emissions factors: 0.01 for the managed soils and 0.02 for the pastures (IPCC, 2006b). The direct deposition of dung and urine on the pasture was determined by computing the average time the animals spent outdoors. The indirect N_2O emissions at the field level were calculated by applying the following emissions factors: 0.01 N_2O-N/kg of N volatilized (IPCC, 2006b); 0.092 for 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 through leaching and runoff (IPCC, 2006b) with a fraction of the total N of 0.26 (Bretscher, 2010).

The fuel and electricity used for the agricultural operations (i.e., fuel consumption, milking, milk cooling, barn lighting) were estimated on the basis of the farm's invoices. The emission factors used for the 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 the ammonia (NH_3) emissions for farm's solid storage were calculated according to the IPCC (2006a) TIER 1, assuming that the fraction of N lost to volatilization is 29% out of the total amount excreted (ISPRA, 2008). The volatilization of N in the form of NH_3 and NO_x at the field level, due to the application of organic and mineral fertilizers, was estimated according the equations proposed by EEA (2009), and the emissions factors used were: 0.084 for NH_3, and 0.026 for NO_x.

For eutrophication, N leaching at field level in the form of NO_3 was calculated on the basis of the IPCC (2006b) equations with a FracLEACH value of 0.26 (Bretscher, 2010), and the phosphorus loss in the form of phosphate ($PO^{3-}{}_4$) was estimated as proposed by Nemecek and Kägi (2007). The manure phosphorus content was assumed to be 1.45 g/kg (Sommer and Hutchings, 2001).

4.2.3. Software, impact categories, and statistical analysis

The estimation of the off-farm emissions that occur throughout the production chain of commercial feed (from crop production to the final product delivered to the farm, including the transportation) was carried out with the assistance of SimaPro 7.3 (Pré Consultants, 2012) software and the Ecoinvent (2007) database and was assessed according to Nielsen (2003). The emissions related to the purchase forages and bedding materials were estimated according to the database of Nemecek (2007), while the database of Patyk and Reinhardt (1997) was used to assess the emissions for the production of chemical fertilizers. The data used for estimation of the diesel fuel and energy production were taken from Jungbluth (2007).

Additionally, the CML 2 (Centre for Environmental Studies, University of Leiden) baseline 2000 V2.02 method (Guinèe *et al.*, 2001) was used for the Life Cycle Impact Assessment analysis. The CML method is based on an internationally accepted approach. The selected impact categories and related measurement units for this study (IPCC, 2007) were as follows: Global Warming Potential (GWP), computed according to the CO_2-equivalent factors in a 100 year time horizon (1 kg CH_4 = 25 kg CO_2-eq, and 1 kg N_2O = 298 CO_2-eq), acidification (g SO_3-eq), and eutrophication (g PO_4^{3-}-eq).

The statistical analysis was performed using SPSS software version 17 (SPSS Inc., Illinois). The normality of the data distribution was tested with the Shapiro-Wilk test. The data were subjected to one-way analysis of variance (ANOVA) and the breeding method (organic vs. conventional) was treated as a fixed effect. When the assumption of normality was violated, the Mann Whitney U non parametric test was used. $P \leq 0.05$ level was established for statistical significance.

4.2.4. Impact assessment, sensitive analysis and allocation methods

Small-scale dairy farms in mountain areas provide not only milk, but also meat and ES. Moreover, these farms have the possibility to potentially fatten calves. From this point of view a sensitive analysis was performed in order to compare the actual farm situation with a scenario that was supposed to increase the production of the co-product meat. Then, the following two scenarios were taken into account:

- Baseline Scenario (BASE): the real farm data were analysed to assess the process of milk production;

- Milk-Beef production system Scenario (BEEF): it was assumed that calves exceeding the culling rate were fattened directly in the farm and sold for their usual commercial live weight for slaughtering according to the Italian market for the Rendena breed (560 and 480 kg for young bulls and heifers, respectively). For the fattening of young bulls, the animal performance, management, and diet characteristics (energy and protein concentration) were considered according to the studies of Corazzin *et al.* (2014) and Cozzi *et al.* (2009), which take into account the Rendena breed in organic and conventional breeding systems, respectively. The diets were hay-based and the ingredients that composed the concentrates were assumed to be the same as those that were actually used on the farms for the dairy cattle. For the fattening of the heifers and animal management, the diet characteristics and ingredients were considered to be the same as those used for fattening young bulls, while the performances were estimated according to the INRA (2010) standard for dual-purpose breeds.

Within the two scenarios, three allocation methods were considered to compare different methods to apportion emissions to milk:

- No allocation: the total emissions of the production system were apportioned to FPCM and to UAL;

- Physical allocation: the total emissions were apportioned not only to FPCM and UAL, but also to the culled dairy cows and calves produced, using the following formula: the allocation factor for milk=1-5.7717×(amount of beef/amount of milk) as proposed by the IDF (2010). In BEEF Scenario, the emissions resulting from the calves' fattening were deducted from the total emission of the dairy farm apportioning the remaining emissions to FPCM or UAL as in the BASE Scenario (Kiefer et al., 2015);

- Economic allocation: the economic allocation was performed considering the real farm income relative to the calves and milk sold at the farm gate, and the economic value of the ES. The ES were based on the CAP agri-environmental payments to farmers as proposed by Ripoll-Bosh *et al.* (2013) and Kiefer *et al.* (2015). The services recognized, and the payments to the farms that are the object of this study, were the maintenance of a local breed (Rendena) and the management of pastures (Table 2). The difference in the price paid for organic milk was considered as an added value for the product, and we included it in the ES payments (0.46 *vs.* 0.40 €/kg milk, VAT excluded, for organic and conventional farms, respectively). In BEEF Scenario, the usual market prices of live animals at the farm gate was considered, which was 35% higher, on average (Bioreport, 2012), for organic than for conventional animals.

Table 2. Agri-environmental measures from the local (Autonomous Province of Trento, Italy) Rural Development Program (2007-2013) including payments relevant for LCA allocation.

Agri-environmental measure	Compensation payment
Management of grasslands - preservation of permanent meadows	
farms with land above 900 m a.s.l.	340 €/ha
farms with land up to 900 m a.s.l.	
organic farms	340 €/ha
conventional farms up to 2 LU[1]/ha	260 €/ha
conventional farms from 2 to 2.5 LU/ha	200 €/ha
Management of grasslands - mountain pastures	
farms with at least 15 dairy cows	90 €/ha
farms with less than 15 dairy cows	72 €/ha
Preservation of endangered farm animals (Rendena breed)	200 €/LU

[1]LU: Livestock Unit.

4.3. Results and discussion

4.3.1. Environmental sustainability and allocations in the BASE Scenario

Table 3 presents the results for the three impact categories considered for the two groups of small-scale farms comparing different allocation methods within the BASE Scenario.

Considering the CO_2-eq emission per kg of FPCM without any allocation (No allocation), and in contrast to what has been presented in other works (Kristensen *et al.*, 2011; Thomassen *et al.*, 2008), the organic farms appear rather similar to the conventional ones; on the other hand, when using the UAL as the FU, although the difference was not significant, the emissions were lower for the organic farms. When beef is considered as a co-product (Physical allocation), the values obtained for GWP related to the production of 1 kg of FPCM were similar in both groups of small-scale farms (on average 1.19 kg CO_2-eq). This result is lower than the GWP estimated by Guerci *et al.* (2014) in the central Italian Alps on traditional dairy farms (1.60 kg CO_2-eq/kg FPCM), and the value registered 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 those obtained in our study (1.14 kg CO_2-eq/kg FPCM, Penati *et al.*, 2013; 1.08 kg CO_2-eq/kg FPCM, Schader *et al.*, 2014). In agreement with Guerci *et al.* (2014), on average 84.1% of the total emissions were addressed to milk. This percentage was lower in the organic than in the conventional farms (81.6 *vs.* 86.5%; data not reported in Tables), although it was not significant. This result was probably affected by the culling rate, which can be considered an indicator of longevity. In fact, longevity is an important trait in the Rendena breed, which shows an average age from birth of almost 6 years (Gilmozzi, 2012), and in this study, as shown in Table 1, the organic farms reported lower culling rates than conventional ones (16.9% *vs.* 21.3%). The two groups of farms did not show any significant difference within the GWP impact category performing Economic allocation to beef and ES. However, considering the kilogram of FPCM as the FU, the reduction of the GHG emissions from No allocation to Economic allocation was 39.0 to 29.3%, and from Physical allocation to Economic allocation was 25.2 and 17.5% for organic and conventional farms, respectively. These results are comparable with the study of Kiefer *et al.*, (2015), who performed an Economic allocation and found that more extensive German pasture-based farms with a low production of milk (3,263 kg/cow/year) registered the highest percentage variation (-46.2 and -18.7%, respectively, between No allocation and Physical allocation), highlighting the important role ES may play in computing GHG emissions. On the contrary, the permanent indoor housing systems characterized by higher amounts of concentrated feed and milk yield optimizers, registered, with the same allocation, a low percentage variation, and in this case the beef co-produced was more relevant than the ES for emissions apportionment (-19.1 and +10.9%, respectively from No allocation and Physical allocation).

The average on-farm contribution to the GWP was 80.6% (data not reported in Tables) while the contributions of the different emissions sources are shown in Figure 2. The enteric emissions and manure storage together represented, on average, the 59.2% of the total GHG emissions. The enteric emission (mainly CH_4) was the largest contributor to the GWP, and it was significantly higher in the organic than in conventional farms (52.8 *vs.* 48.6%; Table 1). Jiao *et al.* (2014) and Knapp *et al.* (2014) observed a reduction of the CH_4 emissions when increasing the amount of concentrate in the animals' diet. The other main contribution to GWP is the utilization of commercial feed; the respective values for the organic and conventional farms were 14.4 and 20.4%. This difference was not significant because of the slightly different amount of concentrate purchased in the two groups of farms (26.5 *vs.* 28.0%, Table 1). Indeed, small-scale farms in the Italian Alps, both organic and conventional, are mainly based on local forage and pasture. Crop production does not have a strong impact on the GWP because these values were related to the emissions from the processing required by the crops and the variation in the soil carbon stock. The small-scale farms considered in this work managed a large proportion of grasslands and highland pastures, while arable crops were absent or insignificant.

Table 3. The Baseline Scenario (BASE): environmental impacts (global warming, acidification and eutrophication) of the organic and the conventional farms considering different allocations (none, physical and economic).

BASE	Organic		Conventional	
	Mean	SE[1]	Mean	SE
Global warming				
No allocation				
kg CO_2-eq/kg FPCM[2]	1.46	0.067	1.40	0.056
kg CO_2-eq/m^2	0.69	0.173	0.91	0.324
Physical allocation				
kg CO_2-eq/kg FPCM	1.19	0.067	1.20	0.050
Economic allocation				
kg CO_2-eq/kg FPCM	0.89	0.026	0.99	0.057
Acidification				
No allocation				
g SO_2-eq/kg FPCM	27.24	2.026	24.44	1.492
g SO_2-eq/m^2	12.40	2.904	16.16	6.392
Physical allocation				
g SO_2-eq/kg FPCM	22.27	1.807	21.19	1.453
Economic allocation				
g SO_2-eq/kg FPCM	16.64	0.937	17.36	1.258
Eutrophication				
No allocation				
g PO_4^{3-}-eq/kg FPCM	3.60^{α}	0.343	4.39^{β}	0.307
g PO_4^{3-}-eq/m^2	1.58	0.351	3.06	1.178
Physical allocation				
g PO_4^{3-}-eq/kg FPCM	2.95^{α}	0.300	3.79^{β}	0.265
Economic allocation				
g PO_4^{3-}-eq/kg FPCM	2.20^{a}	0.182	3.16^{b}	0.322

[1]SE: Standard error; [2]FPCM: Fat and Protein Corrected Milk.
^{a,b}: different letters within impact categories differ for $P \leq 0.05$
$^{\alpha,\beta}$: different letters within impact categories differ for $P \leq 0.10$

With regard to acidification, the total average estimated value in relation to 1 kg of FPCM without any allocation was 25.84 g SO_2-eq, while in Physical allocation the value found was 21.73 g SO_2-eq. this data were higher than the average of 10.15 g SO_2-eq found by Thomassen *et al.* (2008) in more intensive farms of The Netherlands, but they confirm what it was registered in more extensive and lower efficient Italian farms (22.9 g SO_2-eq/kg FPCM, Penati *et al.*, 2013). In this case, only in relation to the UAL and in the Economic allocation were the numeric results for organic farms more sustainable than those for conventional farms.

On average, the contribution of on-farm emission was 79.9% (data not reported in Tables). As shown in Figure 3, acidification is strongly influenced by manure storage and enteric emissions (66.68 *vs.* 66.14% for organic and conventional farms, respectively), followed by the emissions from purchased feed (on average 19.9%) and crops (12.9%). The contribution of energy use and fuel, as well as purchased fertilizer, was very low.

Because of the lack of arable crops in the considered small-scale farms, we generally registered lower eutrophication values in comparison to other studies (Guerci *et al.*, 2013; Penati *et al.*, 2013). In the case of No allocations we obtained 3.60 and 4.39 g PO_4^{3-}-eq/kg FPCM for the organic and conventional farms, respectively. The organic farms' emissions were numerically lower than those of the conventional one by using UAL as the FU (Table 3). When we estimated emissions in relation to 1 kg of FPCM, eutrophication was lower ($P \leq 0.10$) for No allocation and Physical allocation, and was significantly lower for Economic allocation in the organic than conventional farms, in agreement with the findings of other authors (Haas *et al.*, 2001; Thomassen *et al.*, 2008). This is likely related to the fact that eutrophication in this work was influenced more by off-farm emissions (25.2% of total emissions, data not reported in Tables) than by the other two impact categories, being important the roles of leaching of nitrate, phosphate, and volatilized ammonia during the application of fertilizer for the production of concentrates. As shown in Figure 4, the purchased feed weighed more for the conventional (32.9%) than for organic farms (14.2%). Moreover, the emissions that strongly contributed to eutrophication were mainly linked to manure and enteric fermentation.

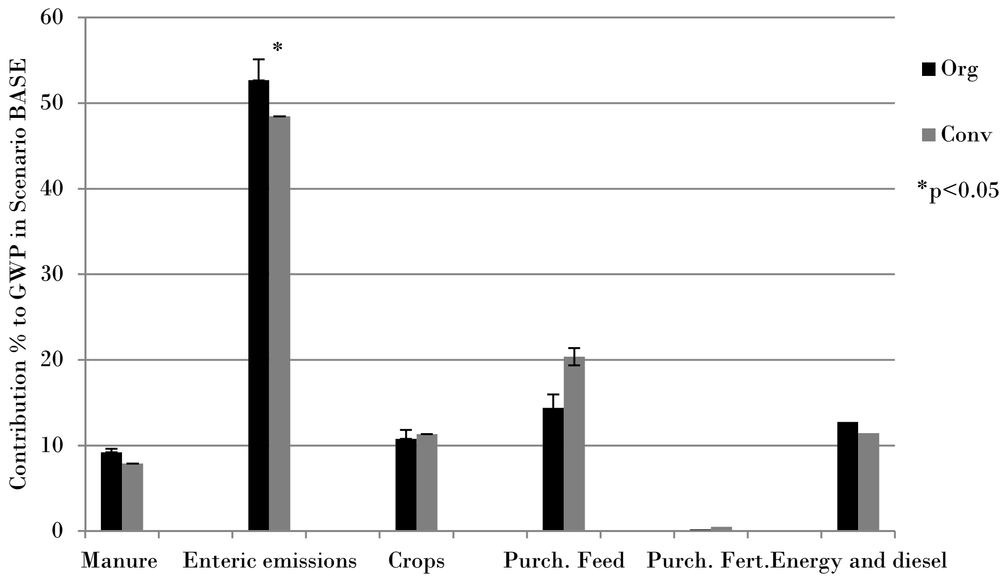

Figure 2. Contribution to global warming potential (GWP) of different sources in the BASE Scenario for the two groups of farms: organic (Org) and conventional (Conv). Vertical bars report standard errors (*: $P \leq 0.05$).

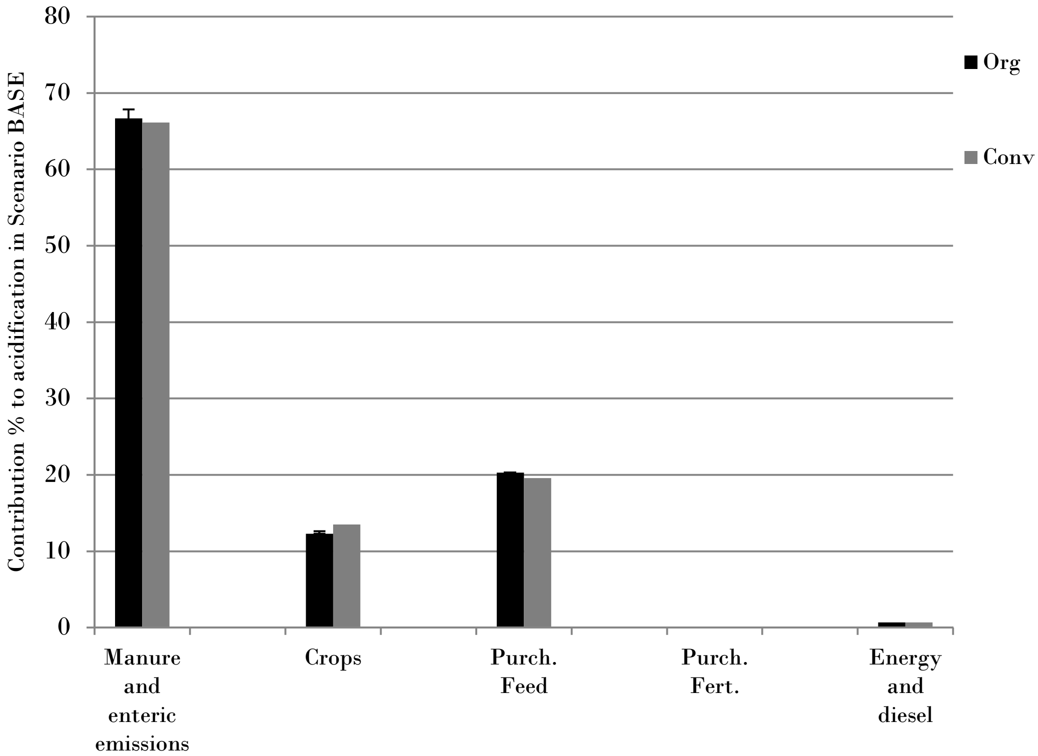

Figure 3. Contribution to acidification of different sources in the BASE Scenario for the two groups of farms: organic (Org) and conventional (Conv). Vertical bars report standard errors.

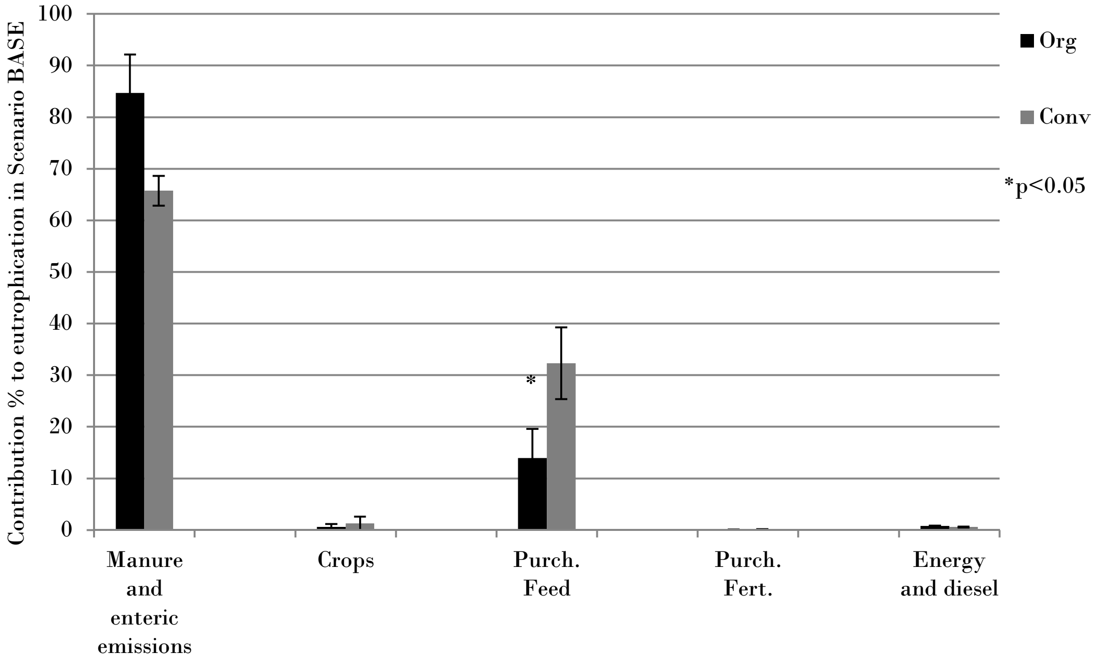

Figure 4. Contribution to eutrophication of different sources in the BASE Scenario for the two groups of farms: organic (Org) and conventional (Conv). Vertical bars report standard errors (*: $P \leq 0.05$).

4.3.2. Environmental sustainability and allocations in the BEEF Scenario

As expected, when the GHG emissions were distributed only on milk (No allocation), the BEEF Scenario had higher emissions compared to the BASE Scenario (1.64 *vs.* 1.43 kg CO_2-eq/kg FPCM; Table 3 and 4). In the BEEF Scenario, considering Physical allocation and the kilogram of FPCM as the FU, the GHG emissions were reduced by 8.4% in comparison with the BASE Scenario because of fattening calves. Kiefer *et al.*, (2015) hypothesizing a similar system expansion in dairy farms, explained that beef production could be a suitable tool in order to reduce the GHG emissions per kg of FPCM. Flysjö *et al.* (2012) noted that cows in organic farming systems have more lactations, on average, delivering in this way more beef than conventional dairy systems. The increased milk production per cow did not necessarily reduce the GWP of milk when the alternative production of the co-product beef is considered. Moreover, within the BEEF Scenario, from No allocation to Economic allocation, a reduction of 44.0% of the GHG emissions per kg of FPCM was calculated. This value falls outside of the 46-77% range proposed by Zehetmeier *et al.* (2014), likely because of the different attitude to meat production for the breeds considered. The results of this study highlight that increased multi-functionality can be environmentally rewarding also in systems that are already facing eco-friendly methods.

When milk production was the FU, there were significant differences between the two groups of farms in Economic allocation for all the three emission categories. In particular, despite the lower performance for fattening calves, the higher value for meat and the lower culling rate could explain the lower emission values recorded in the organic farms compared to the conventional farms.

Table 4. The Milk-Beef production system Scenario (BEEF): environmental impacts (global warming, acidification and eutrophication) of the organic and the conventional farms considering different allocations (none, physical and economic).

BEEF	Organic		Conventional	
	Mean	SE[(1)]	Mean	SE
Global warming				
No allocation				
kg CO_2-eq/kg FPCM[(2)]	1.70	0.092	1.57	0.049
kg CO_2-eq/m^2	0.80	0.196	1.03	0.367
Physical allocation				
kg CO_2-eq/kg FPCM	1.12	0.042	1.07	0.036
Economic allocation				
kg CO_2-eq/kg FPCM	0.82^{A}	0.016	1.01^{B}	0.042
Acidification				
No allocation				
g SO_2-eq/kg FPCM	31.52	2.443	27.82	1.685
g SO_2-eq/m^2	14.33	3.389	18.74	7.311
Physical allocation				
g SO_2-eq/kg FPCM	20.84	1.365	19.63	1.125
Economic allocation				
g SO_2-eq/kg FPCM	15.16^{a}	0.555	17.82^{b}	1.131
Eutrophication				
No allocation				
g PO_4^{3-}-eq/kg FPCM	4.20	0.388	3.99	0.298
g PO_4^{3-}-eq/m^2	1.85	0.419	2.85	1.103
Physical allocation				
g PO_4^{3-}-eq/kg FPCM	3.05	0.256	3.10	0.239
Economic allocation				
g PO_4^{3-}-eq/kg FPCM	2.01^{a}	0.113	2.57^{b}	0.217

(1)SE: Standard error; (2)FPCM: Fat and Protein Corrected Milk.
^{A,B}: different letters within impact categories differ for $P \leq 0.01$
^{a,b}: different letters within impact categories differ for $P \leq 0.05$

4.4. Conclusions

This study has taken into account small-scale conventional, but in fact traditional, and organic farms located within a Natural Park and holding a local cattle breed, Rendena. Within the scenarios considered, the differences between the two groups of farms were limited, likely because of the very similar farm management. Greater differences could emerge if the impact category of ecotoxicity of the conventional and organic feed was also assessed in the analysis. However, the enhancement of the co-product beef in small-scale farms that already hold dual-purpose breeds could be a good way to reduce emissions. This is especially true in mountain livestock systems such as those studied, which cannot turn to precision agriculture to ensure efficiency in production. Small-scale farms, located in less favoured areas, should rather focus on the provision of ES and on multi-functionality. Indeed, increasing the production of meat with high added value, such as in organic beef, can lead to the reduction of the emissions apportioned to milk.

The quantification of ES based on the payments from the agri-environmental measures of Rural Development Plans and their inclusion in the Economic allocation adopted in this paper, is only an example, and the evaluation criteria of the services offered by small-scale farms in mountain areas are still largely to be defined. Although the carbon sequestration capacity of meadows and pastures is difficult to evaluate, it should be considered in greater detail in future analyses. Our study confirmed that the choice of the FUs and the allocation methods for handling co-products and services had an important impacts on the results of the LCA in dairy farms. This leads to the need to harmonize not only the emission factors, but also the LCA approach and the allocation methods for the Alps in order to produce comparable data and create common databases.

4.5. References

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5. How do grasslands influence the environmental impact of small-scale dairy farms in Italian Alps?

Original paper: Salvador S., Corazzin M., Romanzin A, Bovolenta S. *How do grasslands influence the environmental impact of dairy small-scale farms in Italian Alps?* Submitted to Journal of Environmental Management.

5.1. Introduction

About production of milk, recent scientific literature focuses very often on the theme of carbon footprint analyzed using Life Cycle Assessment (LCA) approach. LCA is an objective method of evaluation and quantification of environment impacts associated with a product/process/activity along the whole life cycle, from raw material to end of life ("from the cradle to the grave"). Internationally, the LCA methodology is governed by ISO 14040-3 and the evaluation study of the life cycle includes: the definition of objective and scope of the analysis, the compilation of an inventory of inputs and output of the system, the evaluation of the environmental impacts associated with inputs and outputs, and finally the interpretation of results. However, the application of LCA to dairy farms is still controversial (Flysjö *et al.*, 2012; Pirlo, 2012) and there is no a commonly accepted approach for accounting the soil carbon sequestration (Batalla *et al.*, 2015). Carbon sequestration is the process of removing carbon from the atmosphere depositing it temporarily in a reservoir such as the soil. The time of carbon store in agricultural soil depends by 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 feedbacks on the climate system (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 take into account 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 the global warm potential (GWP), the mountain small-scale dairy farms are in disadvantaged position respect to the intensive farms because of their limited productivity (Gerber *et al.*, 2011). However, on the other hand, small-scale dairy farms are characterized by high presence of grassland, by low presence of arable crops, by low extra-farm inputs, and by a lower density of animals per hectare (Battaglini *et al.*, 2014). The presence of grassland has also a positive effect on energy consumption because it increases self-sufficiency in feed, reducing the impact of production and transport of purchased feed (Guerci *et al.*, 2013), and reduces field operations required for tillage, planting, and harvesting in comparisons with arable crops (Belflower *et al.*, 2012). Moreover, the small-scale dairy farms should be considered a multifunctional system (OECD, 2001) that produce milk and meat, and, especially in less favored areas, contribute positively to other control functions providing a wide range of ecosystem services (ES) (Battaglini *et al.*, 2014; Bernués *et al.*, 2014; 2005; Kiefer *et al.*, 2015). In particular they are often associated with high biodiversity (Belfrage *et al.*, 2005; EEA, 2004; Marini *et al.*, 2011; Tscharntke *et al.*, 2005) and with the preservation of landscape from reforestation (Cocca *et al.*, 2012; Tasser *et al.*, 2007). They also play a key role in the prevention of fire risk and soil erosion by maintaining meadows and pasture (Höchtl *et al.*, 2005; Newesely *et al.*, 2000; Tasser *et al.*, 2003) and, last but not least, they increase the touristic vocation of mountainous areas and the economic and social development of rural communities (Iorio and Corsale, 2010; Scarpa *et al.*, 2010; Valdivia and Barbieri, 2014), guarantying the survival of local products. Despite their social role, the number of small-scale dairy farms is gradually decreasing because of the abandoning and intensification processes that affect the Alpine agriculture during last decades (Ramanzin *et al.*, 2014). However, within the small-scale dairy farms in Alps, the meadows and pasture available per farm are extremely different (Sturaro *et al.*, 2013).

In our knowledge, very few studies about the assessment of GWP in small-scale dairy farms are available, and no one focused on the role of grassland.

Aim of this study is to assess the effect of grassland carbon sequestration accounting on the environmental impact of small-scale dairy farms in Italian Alps.

5.2. Material and methods

5.2.1. Data collection and sample description

For this study, thirty-four small-scale dairy farms (EFSA, 2015) representative of the Italian Alpine region were considered. In particular these farms were handled by family members, had a high forage self-sufficiency (min 46.3%), held dual-purpose breeds (mainly Rendena and Italian Simmental), and used high altitude pastures during summertime (at least for heifers, min 60 days/year). The size of herd varied considerably and the average Livestock Units (LU) reared are 38.8, while the total farm land was on average 50.2 ha. All farms did not manage arable crop and used permanent grasslands for the production of hay, they are located over 600 meters above sea level and had a high degree of seasonality in parts. More details are reported in Table 1.

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

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

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

	Mean	SE(1)
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(2)	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(3)/cow/year	4,621	181.3
Animals sold, kg LW(4)/farm/year	3,708	577.6

(1)SE: Standard Error; (2)LU: Livestock Units; (3)FPCM: Fat and Protein Corrected Milk; (4)LW: Live Weight.

5.2.2. Carbon footprint: functional unit and system boundaries

Carbon footprint of the sampled farms were calculated using the LCA approach according to CML 2 (Centre for Environmental Studies, University of Leiden) baseline 2000 V2.02 method (Guinèe *et al.*, 2001).

In this study, two functional units were used: 1 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 1 m^2 of Utilizable Agricultural Land (UAL).

Small-scale farms were analysed in a "cradle to farm-gate" LCA approach, which implies that emissions of greenhouse gas (GHG) were assessed for all processes involved up to when milk leave the farm and excluding transport or processing of raw milk. 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 estimated too. Farm buildings and machineries, medicines, and other minor stables supplies were excluded from the assessment. Figure 1 illustrates the system boundaries of this study.

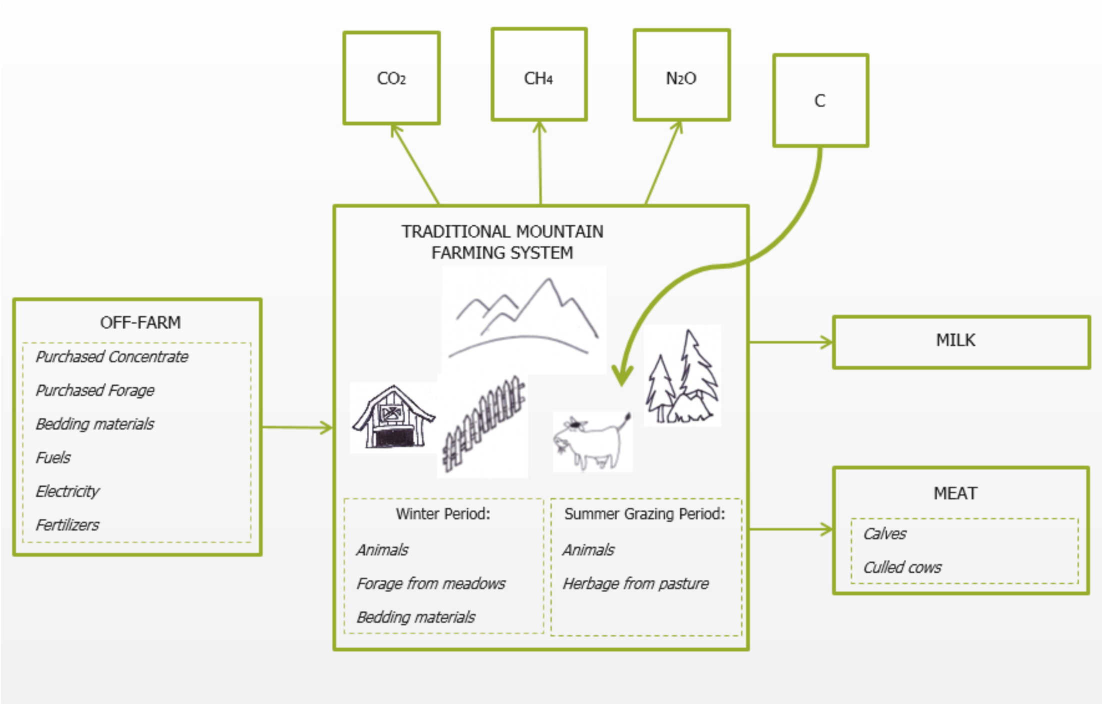

Figure 1. System boundaries diagram of Life Cycle Assessment applied to traditional dairy mountain farms which consider also the carbon sequestration capacity of meadows and pasture.

5.2.3. Carbon footprint: calculation of emissions

Methane (CH_4) emissions from enteric fermentation and manure management were estimated according to Tier 2 of the Intergovernmental Panel on Climate Change, IPCC (2006a) guidelines. CH_4 from enteric fermentation, based on dry matter (DM) intake of the herd, was calculated by using an 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 in high pastures. Emission factors used for direct N_2O was 0.005. The Tier 1 (IPCC, 2006b) was applied to the estimation of 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 and 0.02 for pastures (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 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 production to the final product delivered to the farm including the transportation) 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).

5.2.4. Carbon footprint: impact categories, software and statistical analysis

The selected impact category and related measure units for this study was the GWP, computed according to the CO_2 equivalent factors in a 100 year time horizon (1 kg CH_4 = 25 kg CO_2-eq and 1 kg N_2O = 298 CO_2-eq) (IPCC, 2007a).

A specially programmed Microsoft Excel spreadsheet was used for determining the carbon footprint in accordance to IDF (2010) and IPCC (2006a; 2006b).

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 (TRADITIONAL *vs.* MODERN) 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 GWP including carbon sequestration 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).

5.2.5. Carbon footprint: allocation method

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). In the physical allocation, the emissions attributable to beef were deducted from total emissions according to the formula proposed by IDF (2010) and based on animal weight.

5.2.6. Role of grassland in environmental impact: including carbon sequestration in LCA

As in literature there is no a commonly accepted approach for accounting soil carbon sequestration in LCA, in this work it was applied the methodology suggested by Petersen *et al.* (2013), based on a 100 years perspective, when will be sequester the 10% of total carbon added to the soil. Annual carbon input in grassland were calculated considering crop residues and manure.

Biomass production of grasslands is subject of fluctuations on a spatial and temporal scale. The spatial variability depends essentially on flora characteristics, elevation and soil fertility. The temporal one is linked to production variability within the seasonal cycle, and the annual weather patterns (Gusmeroli *et al.*, 2002). In Alpine mountain, the productivity variation is represented by the range of 500-6,500 kg DM/ha (Cavallero *et al.*, 1992). For this work meadows total crop yields were based on the farmer questionnaire, while for pasture productivity was used the average values of 2,973 kg DM/ha, calculated on the basis of a database obtained from studies carried out in different pasture of Italians Alps (Amato *et al.*, 1989). Crop residues were calculated according to Batalla *et al.* (2015) (40% and 16% of total crop yield respectively for above e below ground residues) assuming a carbon content of 45% of DM.

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

5.2.7. Role of grassland in environmental impact: forage self-sufficiency

With the aim of investigating how forage self-sufficiency can affect environmental impact of small-scale farms, two scenarios were taken into account. In the first, the real data were considered, while in the second it was assumed that all the farms object of this study were self-sufficient in terms of forage. Consequently, the purchased forage was supposed to be entirely substituted by forage produced in additional permanent grasslands per each farm (Amato *et al.*, 1989).

Also within the simulated scenario, it was considered physical allocation method to apportion emissions to milk and it was also included carbon sequestration.

5.3. Results and discussion

5.3.1. Farms

TRADITIONAL small-scale farms (n=17) were characterized by tie stalls housing and traditional feeding (mainly hay and few concentrates). All this farms move the whole herd, including lactating cows, to highland pasture during the summer period and they avoid calvings before and during the use of summer pasture. Conversely, considering the MODERN small-scale farms (n=17), three of them transferred to summer pasture only the replacement heifers, while the others moved the whole herd to highland pasture during the summer period. Also these farms feed animals mainly with hay and concentrates, but they have calvings all year long. Sturaro *et al.* (2013) discuss how survived dairy farms in Italian Alps can be classified into a variety of systems that represent different steps in the shift from the original, seasonally transhumant system, based on the use of local forage resources with autochthonous breeds to a modern, more intensive system with highly specialized breeds, total mixed rations and concentrates. The characteristic of the two groups of farms are reported in Table 2. TRADITIONAL farms identified in the present work were significantly smaller than MODERN ones in term of lactating cows (8.7 *vs.* 40.6 cows, $P \leq 0.01$). About milk productivity, TRADITIONAL farms tended to produce less than the other group (4,300 *vs.* 4,942 FPCM/cow/years; $P \leq 0.10$). The average total value of 4,621 FPCM/cow/years was lower than productions registered by others 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 which use highland pasture (Guerci *et al.* 2014). The DM intake of cows, was significantly higher in traditional than in modern farms (22.1 *vs.* 18.7 kg DM/cow/day, $P \leq 0.01$), and the average value was higher than those reported by Bovolenta *et al.* (2008, 2009). Moreover, while in traditional farms concentrate feed was 16.8%, in the modern farms this percentage reached the 28.9% ($P \leq 0.01$). Consequently to the limited amount of concentrate used, also feed efficiency of farms was low and significantly different between farms group (0.54 *vs.* 0.72 kg FPCM/kg DM intake for TRADITIONAL and MODERN farms, respectively, $P \leq 0.01$), and it was lower than that reported by Guerci *et al.* (2014), 1.09 kg FPCM/kg DM intake. TRADITIONAL small-scale farms managed smaller agricultural surface, both as grasslands and as highland pasture, than MODERN ones (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 TRADITIONAL and MODERN, respectively). The local climate, the elevation and the slope exposure could explain the high variability of the grassland crop yield with TRADITIONAL that showed lower value than MODERN farm (4,112 *vs.* 7,390, respectively, $P \leq 0.01$). The stocking rate was lower for TRADITIONAL than MODERN farms (0.8 *vs.* 1.9 LU/ha, respectively, $P \leq$

0.05) and the average value recorded was lower than that observed by others authors (Sturaro *et al.*, 2013; Guerci *et al.* 2014). Despite the low production of the meadows, TRADITIONAL small-scale farms succeed better than MODERN ones to support their animal stocks: forage self-sufficiency is higher in TRADITIONAL farms than in the second group (84.8 *vs.* 71.8%, $P \leq 0.05$). In general, comparing the two farms groups, MODERN farms were more efficient in terms of production, and the higher level of concentrate in the rations, indicates that these farms are going into a process of intensification (Sturaro *et al.*, 2013).

Table 2. Characteristics of the two groups of small-scale dairy farms identified on the basis of Livestock Units (LU): traditional and modern small-scale farms, rearing under and above 30 LU respectively.

	Traditional < 30 LU		Modern > 30 LU	
	Mean	SE[1]	Mean	SE
Lactating cow, n	8.7^{A}	1.02	40.6^{B}	7.60
Milk yield, kg FPCM[2]/cow/year	$4{,}300^{\alpha}$	207.7	$4{,}942^{\beta}$	282.0
DM[3] 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
Grasslands crop yield, kg DM/ha	$4{,}112^{A}$	335.5	$7{,}390^{B}$	1,084.9
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

[1]SE: Standard Error; [2]FPCM: Fat and Protein Corrected Milk; [3]DM: Dry Matter.
^{A,B}: $P \leq 0.01$; ^{a,b}: $P \leq 0.05$; $^{\alpha,\beta}$: $P \leq 0.10$

5.3.2. Environmental impact

Performing no allocation, and using FPCM as functional unit, slightly significant differences were found between the two groups of farms and the value registered for TRADITIONAL ones tended to be higher than the other group (1.94 *vs.* 1.59 kg CO_2-eq/kg FPCM, $P \leq 0.10$, Table 3). This is in line with other works which highlight how more extensive farms, less productive and less efficient from an environmental point of view, impact more 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). TRADITIONAL farms sold on average more beef respect to MODERN ones, stressing more the dual-purpose character of alpine livestock systems and the co-product meat. In this way, the percentage of total emissions addressed to milk (rather than to the beef) is much lower in TRADITIONAL than in MODERN farms (64.0 *vs.* 81.5%, $P \leq 0.05$; data not reported in Tables). On average 72.8% of total emissions were addressed to milk and this result is lower than the 85.0% registered by Guerci *et al.* (2014) and respect the default allocation value of 85.6% suggested by 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 GWP estimated by Guerci *et al.* (2014) in central Italian Alps on traditional dairy farms (1.60 kg CO_2-eq/kg FPCM), and also in comparison to the value registered by Kiefer *et al.* (2015) in grassland-based areas of southern Germany (1.53 kg CO_2-eq/kg FPCM). Other authors reported in alpine dairy farms lower values than those 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 result to be significantly different, and TRADITIONAL farms registered lower values than MODERN ones without any allocation ($P \leq 0.05$, Table 3).

Table 3. Global Warming Potential of traditional (LU[(1)] < 30) and modern (LU > 30) small-scale farms. Emissions are expressed as CO_2-eq per kg of Fat Protein Corrected Milk (FPCM) and per m² of Utilizable Agricultural Land, before and after including the contribution of soil carbon sequestration (Petersen *et al.*, 2013).

	Traditional		Modern	
	Mean	SE[(2)]	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/m²	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/m²	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

[(1)]LU: Livestock Units; [(2)]SE: Standard Error.
^{A,B}: $P \leq 0.01$; ^{a,b}: $P \leq 0.05$; $^{\alpha,\beta}$: $P \leq 0.10$

As showed in Table 4, TRADITIONAL farms have higher GHG contribution from manure storage ($P \leq 0.05$) and lower GHG contribution from purchased feeds ($P \leq 0.01$) than MODERN farms. Since the management of manure was the same, these results were probably linked to bedding materials utilization. TRADITIONAL small-scale farms, characterized by tie stalls, used more wheat straw or sawdust respect the farms managed with free animals that have access to rubber mattresses. In this way, for TRADITIONAL farms, increase not only manure quantity, but also the contribution of off-farm emissions due to the purchased bedding materials. The different contribution from feed purchased to GHG is mainly linked to the different level of concentrates included in the animals' diet. In percentage terms (data not reported in Tables), the average on-farm contribution to GWP was 81.5%. Enteric emissions and manure storage together represented on average the 62.2% of total GHG emissions (showed graphically in Figure 2). Enteric emission (mainly CH_4) was the largest contributor to GWP (46.3% on average). The other main contribution to GWP was represented by electricity and diesel consumption (13.6% on average), while crop production has not a strong impact on GWP because small-scale farms considered in this work managed a large proportion of grasslands and highland pastures while arable crops were absent or insignificant.

Table 4. GHG[(1)] contribution (kg CO_2-eq) per kg of Fat Protein Corrected Milk from different sources in traditional (LU[(2)] < 30) and modern (LU > 30) small-scale farms.

	Traditional		Modern	
	Mean	SE[(3)]	Mean	SE
Manure	0.42^{b}	0.097	0.21^{a}	0.055
Enteric emission	0.82	0.062	0.72	0.025
Crops	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

[(1)]GHG: Greenhouse Gas; [(2)]LU: Livestock Units; [(3)]SE: Standard Error.
^{A,B}: $P \leq 0.01$; ^{a,b}: $P \leq 0.05$; $^{\alpha,\beta}$: $P \leq 0.10$

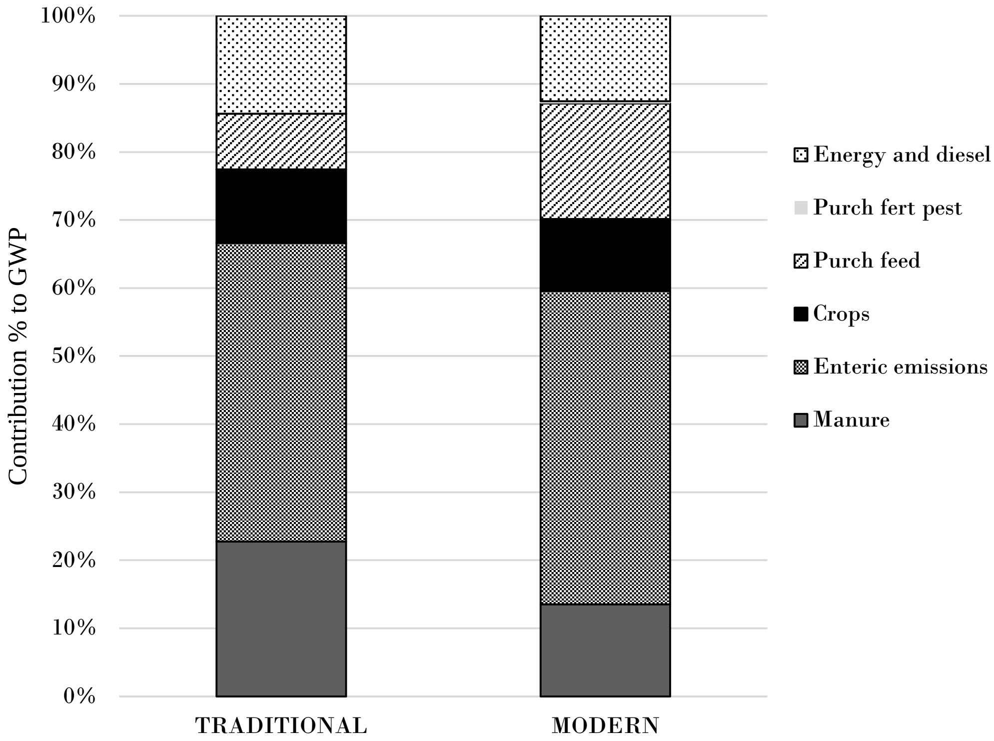

Figure 2. Contribution of different emissions sources to Global Warming Potential (GWP) of milk for the two group of small-scale farms: traditional and modern.

5.3.3. Including soil carbon sequestration in GWP estimation

As showed in Table 3, performing no allocation, TRADITIONAL farms registered higher values per kg of FPCM than the other group (1.38 *vs.* 1.10 kg CO_2-eq/kg FPCM, $P \leq 0.05$), and the situation overturned considering the m^2 of UAL as 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 ($P > 0.05$; Table 3).

Performing no allocation, when the contribution from soil carbon sequestration was included in the LCA, the GWP was reduced on average by 29.7% (by 28.9 and 30.8%

for TRADITIONAL and MODERN farms, respectively). Considering the beef as a co-product of the farm, the percentage of reduction was on average 43.0% (48.3 and 38.3% for TRADITIONAL and MODERN farms respectively), and GWP per kg of FPCM in some cases can be even negative: a minimum value of -0.19 kg CO_2-eq/kg FPCM was registered among TRADITIONAL small-scale farms.

Figure 3 shows the principal component analysis (PCA) performed on farm characteristics and GWP per kg of FPCM. In particular, GWP calculated with physical allocation is separated by GWP calculated with no allocation method along the first component, that explains the 35.5% of variability. The first dimension is positively correlated with feed efficiency, milk yield, concentrate level in the diet, stocking rate and GWP calculated with physical allocation method. Conversely, the second dimension, that explains the 22.2% of variability, is positively correlated with GWP calculated with both the allocation methods, and with stocking density, and negatively correlated with forage self-sufficiency.

In literature, few works include carbon sequestration in milk LCA, and lack of consensus also exists on how to correctly assess it in 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 consider it in LCA as 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 it resulted that grass-based and confinement dairy systems have similar GWP. In a recent study, Battini *et al.* (2016), registered a modest contribution of carbon sequestration to GHG. They found a higher amount of carbon sequestration in farming systems of smaller size and lower efficiency, located in hilly and mountain areas and partially based on grassland crops, than the one registered in intensive farm.

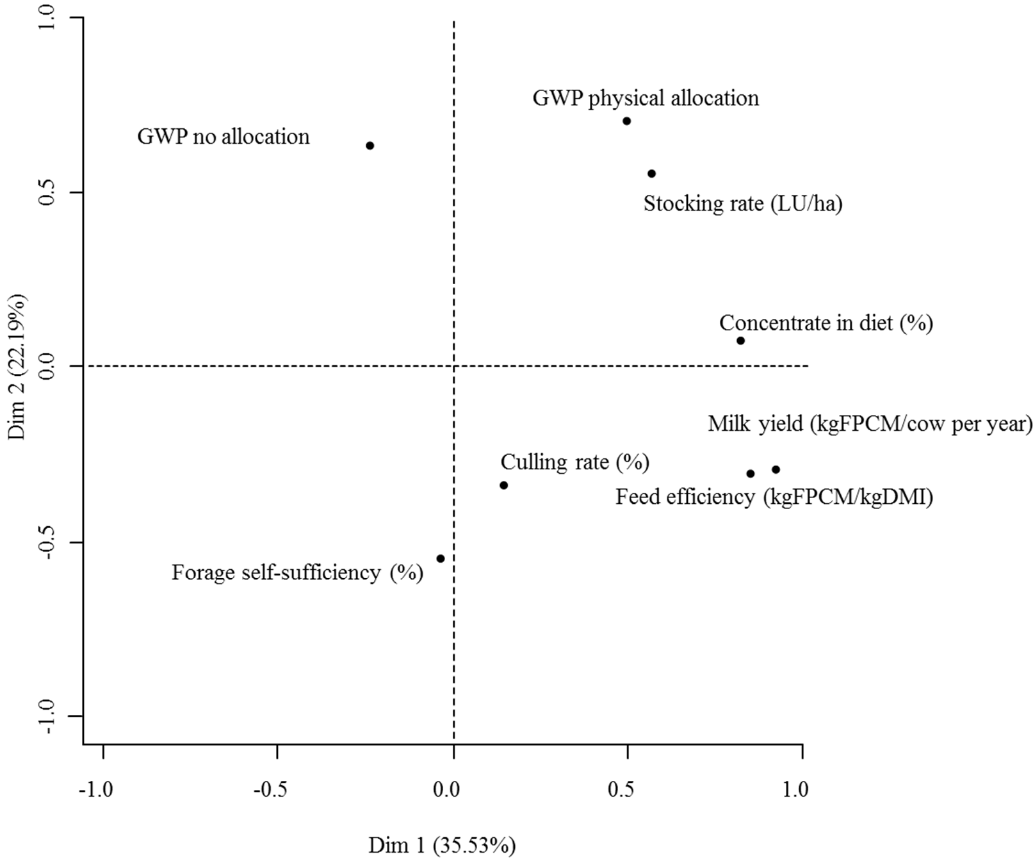

Figure 3. Principal component analysis of farm characteristics and Global Warming Potential (GWP) expressed as CO_2-eq per kg of Fat Protein Corrected Milk (FPCM) including carbon sequestration with no allocation (GWP no allocation) and physical allocation method (GWP physical allocation).

5.3.4. Increasing forage self-sufficiency to 100%

In the case where the forage self-sufficiency is increased to 100% for all the farms, and the carbon sequestration included in LCA methods, GWP per kg of FPCM was similar between MODERN and TRADITIONAL farms both considering no allocation and physical allocation ($P > 0.05$; Table 5). Taking into account also the real data showed in Table 3, these results highlighted the importance of forage self-sufficiency in the GWP calculation and reduction. In particular, if the soil carbon sequestration was not taken into account, the percentage of GWP reduction was on average 2.5% (1.7 *vs.* 3.1% for TRADITIONAL and MODERN farms respectively). As expected, the reduction becomes more important when also the carbon sequestration was considered: -26.1 and -28.2% with no allocation was performed, and -40.0 and -20.3% considering the co-product beef for TRADITIONAL and MODERN farms respectively. Penati *et al.* (2013) argued that enhancing feed self-sufficiency, through the increasing of mountain pasture exploitation, can be a suitable strategy in order 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 manage more land. Indeed, in this simulation, permanent grasslands increase on average of 3.64 ha: 1.59 and 5.70 ha per farm for TRADITIONAL and MODERN farms, respectively.

Table 5. Global Warming Potential of traditional (LU[(1)] < 30) and modern (LU > 30) small-scale farms considering 100% of 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 (Petersen *et al.*, 2013).

	Traditional		Modern	
	Mean	SE[(2)]	Mean	SE
NO SOIL CARBON INCLUDED				
No allocation				
kg CO_2-eq/kg FPCM	1.92^{α}	0.176	1.54^{β}	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

[(1)]LU: Livestock Units; [(2)]SE: Standard Error.

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

5.4. Conclusions

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

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6. Conclusions and perspectives

Dairy farming systems in mountain areas play an essential role from the economic, social and environmental point of view. However, extensive mountain farms, due to many different constraints, appear rather unsustainable from an environmental perspective when pollutants emissions are allocated on the quantity of milk produced. On the other hands, an analysis on the product, rather than on the agricultural surface, mainly reflects the perspective of the citizens/consumers. Many works carried out using Life Cycle Assessment (LCA) approach and the kilogram of milk as functional unit (FU), led indeed to this misleading result. It is necessary to consider that these multifunctional farms deliver, in addition to the co-product meat, also important services to the community - such as agro-biodiversity protection, meadows and pastures maintenance, fires and hydrogeological instability prevention - to which is important recognizing a cost in terms of emissions. This thesis demonstrates that, even adopting LCA approaches, when taking into account both the products and the services, the impact values registered for the multifunctional mountain farm for the produced quantities, are entirely comparable to those obtained with more intensive systems.

The first paper reported in the thesis points out how, over the last several decades, the Alps experienced a general abandonment of traditional farms and this evolution resulted into an important reforestation of permanent meadows and pastures, which host a rich plant and animal biodiversity. This review shows in particular the obvious conflict between the intensification of animal husbandry, which aims to optimize the resource use per unit of output, limiting its impact, and the preservation of pastoral systems. Grassland-based livestock systems are characterized by a low productivity and in disadvantaged areas, such as the mountain, they cannot be supported by technology to ensure efficiency in production. Anyway, small-scale farms are the only type of livestock system still present in a number of semi-natural habitats in Europe, they are the only systems capable of ensuring animal production in marginal areas and they provide a wide range of ES.

The second paper shows how, performing LCA, the choice of FUs and allocation methods for handling co-products and services have an important influence on the results. Environmental impact of organic and conventional small-scale dairy farms located within a Natural Park and holding a local breed were assessed for global warming potential (GWP), acidification and eutrophication impacts. Two scenarios were considered: Baseline Scenario, based on the real farm data, and Milk-Beef production system Scenario, assuming that calves exceeding the culling rate were fattened directly on-farm. Three different allocation methods were considered: no allocation, physical allocation that accounted also for the co-product beef, and economic allocation that accounted also for the ES provided by the farms and estimated on the basis of agri-environment payments. Furthermore, two functional units were used: Fat and Protein Corrected Milk (FPCM) and Utilizable Agricultural Land (UAL).

This study provides a double-folded advice: first, through its Milk-Beef production system Scenario is suggesting to strengthen beef production in dual-purpose breeds in order to reduce emissions apportioned to milk. Second, through its economic allocation it is suggesting an approach to acknowledge multi-functionality considering some ES provided by the farms. Further, distributing the emissions on the UAL, these appear to be very low.

The third paper takes into account the potential of soil carbon sequestration. In grassland based livestock systems, soil carbon sequestration might be a potential sink to mitigate greenhouse gas emissions. Nevertheless, it has not been included in the carbon footprint calculations, and it lacks a methodology commonly shared. In this work, the GWP of mountain small-scale dairy farms was assessed considering two allocation methods (no allocation and physical allocation) and two functional units (kg of FPCM and UAL). The work highlights how, considering the carbon sequestration capacity of meadows and pastures, farms emissions will considerably shoot down.

To point out how the presence of grasslands is crucial for small-scale farms carbon footprint, in this study was also applied a simulation for increasing forage self-sufficiency of farms. To be able to produce enough forage for all animals reared, farms need to increase the surface of permanent grasslands. This has important implications not only on reducing environmental emissions, but also on the maintenance of landscape and biodiversity.

A comprehensive evaluation of livestock farms sustainability in mountainous areas should take into account the provisioning of co-products and ES, and the carbon sequestration capacity of meadows and pastures. This leads to the need to harmonize LCA approach and the allocation methods for the Alps in order to produce comparable data and create common databases. The important impact categories of biodiversity, ecotoxicity and land use would also be assessed in the LCA analysis. Nevertheless, it is important to develop methods to measure and quantify ES by means indices.

In this scenario where the animal production sector stresses more and more the importance of sustainability-related issues, as it has already pointed out, small-scale farms in mountain areas unlikely will be able to focus on mitigation strategies desirable by precision agriculture. In this way, mountain farms may be disadvantaged in the market if a environmental certification became mandatory. In these perspectives, it is necessary to work and bring to light these issues so that small-scale farms and their productions could be protected to avoid their gradual disappearance which would have important and negative consequences on the supply of ES.

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