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ENVIRONMENTAL FOOTPRINT OF BEEF PRODUCTION: INTEGRATED INTENSIVE AND EXTENSIVE SYSTEMS

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Abstract

The environmental footprint of the food supply chain has emerged as one of the most important issues in public debate. Livestock systems have an important role in the food supply chain, contributing to nearly 40 percent of the global value of agricultural output. The livestock systems characteristics at regional level depend on the regional eco-climatic conditions and their interactions with the socio-economic features of the regional anthropic society. The output derived from the different livestock systems and its consequences on anthropic and natural systems depend on how all these elements interact. Focusing on beef production systems, the extensive grazing ruminant systems rely on fibrous and human-inedible feedstuffs and on low resource intensity and quality, providing various multi-functional valuable goods and services. At the same time, unbalances among productive systems, environment and society could emerge, leading to disruptive effects such as overgrazing, soil degradation, biodiversity losses due to natural ecosystems clearance as well as threats for food security and poverty level. Conversely, the intensive beef systems rely on great amount of energetic and protein feedstuffs, most of them imported through national and international trade, and on improved production efficiency to obtain the greatest amount of food output per one unit of input. The specialization, aggregation and decoupling from local eco-climatic conditions, while affording to cover the increasing demand of animal-derived food, have led to notable alterations in the biogeochemical cycles related to greenhouse gases (GHG) emissions and to nutrients such as nitrogen and phosphorus. Different indicators and methods were developed in order to cope with the increasing awareness about the livestock systems environmental footprint, and Life Cycle Assessment (LCA) has arisen as one the most suitable methodologies to evaluate the positive and negative outputs due to a product throughout its life cycle. The procedure is composed of goal and scope definition (definition

of the aims and the structure of the LCA model), life cycle inventory (collection of all the inputs and outputs of the system, inventorying the resources used, the emissions produced and the wastes generated), life cycle impact assessment (classification and characterization of the impacts) and interpretation. An increasing number of studies has been published on the environmental footprint of livestock sector using a LCA procedure in the last decade, mainly concerning GHG emissions. The application of LCA method to livestock systems needs to take into account the peculiarities of each regional livestock system. This is the case of the integrated France-Italy beef production system, a particular system that integrates the suckler cow-calf system located in the Massif Central semi-mountainous area (central France), and based on extensive pasture system, with the intensive fattening system located in north-eastern Italy, where beef calves are imported and reared using total mixed rations based on maize silage and concentrates. The aim of this PhD thesis was the assessment of the environmental footprint of the north-eastern Italy beef production system through a multi-indicator approach based on LCA, considering also the whole supply chain obtained with the integration of the French suckler cow-calf system as well as investigating some sources of variation of the environmental footprint of the beef fattening phase.

This PhD thesis is composed by three chapters. The first chapter aimed at evaluating the environmental impact of the north-eastern Italy beef fattening system through a partial LCA method. The study involved 342 fattening batches (i.e., a group of animals homogenous for genetic type, sex, origin, fattening farms and finishing period) reared in 16 fattening farms during 2013. Data on animal performance were recorded for each batch. Diet composition and feed intake were collected for each beef category (combination of genotype and sex) within farms. On- and off-farm feed production data and materials used were recorded for each farm. Impact categories regarded (mean values and standard deviation per kg BW gain are provided between brackets): global warming potential (GWP, 8.4±1.6 kg CO_2-eq), acidification potential (AP, 197±32 g SO_2-eq), eutrophication potential (EP, 65±12 g PO_4-eq), cumulative energy demand (CED, 62±16 MJ), and land occupation (LO, 8.9±1.7 m^2/year). The contribution to GWP, AP and EP was greater for the on-farm than off-farm stages, whereas the opposite pattern was found for CED and LO. This contribution gave a preliminary analysis of the north-eastern Italy beef production system, developing a methodological framework that was used in the following chapters for assessing the environmental footprint of the whole beef supply chain (chapter 2) and for evaluating some factors affecting the environmental footprint of the Italian beef fattening system (chapter 3).

The second chapter considered the whole beef production supply chain, with a cradle-to-farm-gate LCA approach. The aim of this chapter was to evaluate the environmental footprint of the integrated France-Italy beef system (extensive grassland-based suckler cow-calf farms in France with intensive cereal-based fattening farms in north-eastern Italy) using a multi-indicator approach, which combines environmental impact categories computed with a cradle-to-farm gate LCA, and food-related indicators based on the conversion of gross energy and protein of feedstuffs into raw boneless beef. The study involved 73 Charolais batches kept at 14 Italian farms. Data from 40 farms originating from the Charolais Network database (INRA) were used to characterize the French farm types, which were matched to the fattening batches according to the results of a cluster analysis. The impact categories assessed were as follows (mean ± SD per kg BW): GWP (13.0±0.7 kg CO_2-eq, reduced to 9.9±0.7 kg CO_2-eq when considering the carbon sequestration due to French permanent grassland), AP (193±13 g SO_2-eq), EP (57±4 g PO_4-eq), CED (36±5 MJ) and LO (18.7±0.8 m^2/year). The on-farm impacts outweighed those of the off-farm stages, except in the case of CED. On average, 41 MJ and 16.7 kg of dietary feed gross energy and protein were required to provide 1 MJ or 1 kg of protein of raw boneless beef, respectively, but nearly 85% and 80%, respectively, were derived from feedstuffs not suitable for human consumption. Emission-related (GWP, AP, EP) and resource utilization categories (CED, LO) were positively correlated. Food-related indicators showed positive correlations with emission-related categories when the overall feedstuffs of the diet were considered but were negatively correlated when only the human-edible portions of the beef diets were considered.

The third chapter aimed at investigating the effect of some diet-related factors and of the beef category (genotype x sex) on the environmental impact of the north-eastern Italy beef fattening system computed according to a partial LCA method. The study involved 245 batches reared in 17 fattening farms in 2014. Data on animal performance and farm input were collected for each batch and farm, respectively. Data on feed allowance, ingredients composition of the diets as well as diet sample for the chemical analysis were monthly collected for each batch. Impact categories assessed (mean ± SD per kg BW gain into brackets) were: GWP (8.8±1.6 kg CO_2-eq), AP (142±22 g SO_2-eq), EP (55±8 g PO_4-eq), CED (53±18 MJ) and LO (7.9±1.2 m^2/year). Impact values were analysed with a linear mixed model including farm (random effect) and the fixed effect of beef category, season of arrival and classes of initial BW, self-sufficiency rate diet (SELF), crude protein (CPI) and phosphorus (PI) daily intake. Beef category and classes of SELF, CPI and PI significantly affected the impact categories values. Impact mitigation was observed with enhancing SELF and reducing CPI and PI values, with no detrimental effects on farm economic profitability expressed as income over feeds cost.

The results of this PhD thesis give interesting insights about the environmental footprint of the France-Italy beef production system. The assessment at the batch level allowed to investigate the factors, such as beef category and diet characteristics, that may influence the environmental footprint of the beef fattening phase, allowing the implementation of mitigation strategies. Moreover, the necessity to use indicators related to different issues not only regarding to the environmental impact, in a multi-indicator approach within LCA, should be considered in order to obtain a more consistent and accurate evaluation of the environmental footprint of livestock systems.

General introduction

The livestock sector has an important role in the food supply chain, contributing to nearly 40 percent of the global value of agricultural output (FAO, 2009). The increase in the economic status in both developed and developing countries as well as the population growth has led to a dramatic growth of the animal-derived food consumption and a similar trend is expected to continue in the developing countries during the next decades (FAO, 2009; FAO, 2011).

The livestock systems characteristics at regional level are based on the regional eco-climatic conditions and their interactions with the socio-economic features (Steinfeld et al., 2006; Gerber et al., 2015). The climatic conditions determine the type and the source of the feedstuffs available and the animals which could be managed with those resources. In general, harsh environments have led to extensive grazing systems based on grassland, whereas more favourable environments has led to more intensive systems based on feeding animals with diets enriched with pulses and cereals (Sere and Steinfeld, 1996; Gerber et al., 2013). The overall output observed in each regional livestock system is the result of how the productive, social, economic and environmental spheres interact. Focusing on beef production, grassland-based systems are less productive in terms of food supply than intensive systems, but its multi-functionality gives a great contribution in terms of leather, fertilizers, labour, insurance and banking services supply (FAO, 2009; Gerber et al., 2015). Although extensive grazing beef systems rely on fibrous feedstuffs not suitable for direct human consumption, so decoupling the beef production issue from the cereals and pulses production, broad land extension is necessary to their production. Indeed, grasslands are estimated to occupy a quarter of the emerged land (Steinfeld et al., 2006) and their management could result in overgrazing and soil degradation phenomena, with consequent effects on soil quality and lower capacity to cope with desertification (Buringh and Dudal, 1987; Suttie et al., 2005; Steinfeld et al., 2006). Moreover, the clearance of the natural ecosystems to obtain new areas for livestock production, especially in the tropical area, implies the disruption of the original ecosystems, with dramatic negative effects on the biodiversity (Sala et al., 2000; Foley et al., 2005), although grasslands themselves can sustain high level of biodiversity, especially in those areas such as semi-natural grasslands in Europe, where the biological communities had time to adapt (Bignal and McCracken, 1996).

The intensive beef systems are observed particularly in the industrialized regions and are dedicated to and specialised for food production. These systems are based on great amount of inputs more qualitative than those used in the grazing and extensive mixed systems, and on more productive animals fed with diets rich in energetic and protein concentrates (Steinfeld et al., 2006; Gerber et al., 2015), which could exacerbate the competition between feed and food production (Godfray et al., 2010). Moreover, the intensive beef systems rely on great amount of purchased input, in order to decouple the production level and the carrying capacity of the territory to produce feedstuffs (related to its eco-climatic conditions), enabling to sustain great herds and satisfy the high demand in animal-derived food (FAO, 2009). The disconnection between production capacity and carrying capacity of the territory has led to alter the dynamics in the nutrient flows and emission patterns (Steinfeld et al., 2006). Although improved procedures at crop level and improved diets and management at animal level could enhance the productive efficiency of livestock systems, the efficiency to use input has remained low: only nearly 50% of the nitrogen (N) input to soil is incorporated into the harvested final products (Smil 2000; Galloway et al., 2003) and beef efficiency to convert feedstuffs into valuable output hardly achieved 15% (Steinfeld et al., 2006; Cassidy et al., 2013). The consequences are related to the loss of N and phosphorus (P) into natural ecosystems, with acidification effects due to ammonia volatilisation and following deposition on soil and watersheds, eutrophication effects on the surface watersheds, contamination with toxic compounds (e.g., nitrate) of groundwater bodies and alteration of food webs and related biodiversity (Correl, 1998; Bennett et al., 2001; Galloway et al., 2003; Steinfeld et al., 2006). These phenomena have been enhanced by the segregation of crop and livestock systems due to the productive specialization, which lowered the capacity of agro-livestock systems to recycle nutrients (Peyraud et al., 2014). Furthermore, the livestock systems intensification and specialisation have led to alter not only the biogeochemical cycles related to the nutrients flow but also those concerning greenhouse gases (GHG): the share related to livestock sector has been estimated at 14.5% (nearly 6% due to beef systems), although with great differences at regional level (Gerber et al., 2013). Livestock systems mostly contribute to methane (CH_4) and nitrous oxide (N_2O), whereas its contribution to the emission of CO_2 is lower (Steinfeld et al., 2006). Methane is mainly derived from the enteric fermentation processes observed into the bovine rumen and secondly from the anaerobic fermentation during the storage phase of manure (Monteny et al., 2001), whereas N_2O is mainly emitted from the nitrogen-fertilized soils (Galloway et al., 2003) and from manure (Monteny et al., 2001).

The livestock sustainability has recently emerged as an important issue in tackling the human influence on the Earth system (Steinfeld et al., 2006; Rockstrom et al., 2009; Gerber et al., 2013) Since livestock systems have complex interactions with social-economic and environmental spheres, with specific trends and patterns in each region and territory, the necessity of evaluating their sustainability through various indicators has arisen, resulting in a series of indicators which have been applied to livestock systems (van der Werf and Petit, 2002; Halberg, 2005; Lebacq et al., 2013). These indicators spaced from the consideration of the environmental indicators (farm practices, input management and quality of natural resources), including the excretion of N and P (e.g., nutrient balance in Xiccato et al., 2005) to economic (profitability, autonomy, diversification and durability) and social aspects (Lebacq et al., 2013), to productive efficiency and competition about human-edible feedstuffs between feed and food destination (Gill et al., 2010; Wilkinson, 2011).

Regarding the environmental footprint of the livestock production systems, the increasing necessity to consider at the same time various indicators related to different issues has conducted to apply methods such as Life Cycle Assessment (LCA) (ISO, 2006) and the Ecosystem Services Framework (ESF) (MEA, 2005). While both methodologies take into account the peculiarities of the regional livestock systems, ESF is more related to the evaluation of the services that natural ecosystems provide to human society, to how the human activity can alter them and how to shape human activities in order to maintain and enhance these services, whereas LCA methodology is more focussed on the production aspect, evaluating how much an anthropic supply chain contributes to specific environmental phenomena of concern.

Life Cycle Assessment is a standardised methodology that aims to evaluate the overall environmental impact of a product, taking into account all the varying interactions with the natural environment that can exist along its life cycle (ISO, 2006). Consequently, the LCA approach allows to encompass both the direct pressures on the environment caused by the production, use and waste disposal of the targeted product and the indirect pressures caused by the production, use and disposal of background inputs implied in its life cycle. Moreover, according the International Reference Life Cycle Data (ILCD) Handbook (European Commission, 2010) the LCA approach is an elastic and multi-scaling methodology, which allows to consider only the life-cycle stages and the type of environmental burden that are consistent with the prearranged purpose.

The consideration of the entire life-cycle of a product could resolve a main problem that arises when the reduction of the environmental impact is assessed: the implementation of a mitigation strategy concerning a single stage of the product life-cycle can result in a reduction of the environmental impact observed in this single stage while increasing the same type of impact observable in another life-cycle stage or increasing the impacts related to other environmental phenomena (Finnveden et al. 2009).

The standard procedure is composed of goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), interpretation (ISO, 2006). The goal and scope definition targets the definition of the aims and the structure of the LCA model; the characteristics of the LCA model set in this phase alter the type of data to be collected, the results and the degree of the implications. Firstly, the model can be set to have a description of the environmentally relevant physical flows from and to the life cycle of the product (attributional LCA) or to study how these environmentally relevant physical flows change if the life cycle is modified in one or more points (consequential LCA). Secondly, the boundaries of the LCA model implemented (i.e., system boundaries) are set in order to include those production stages of the whole life cycle of the product, their related inputs and those typologies of impact that are consistent with the aim previously chosen. Thirdly, a key point of the LCA model is the expression of the overall impact per functional unit (i.e., unit of product, see Schau et al., 2008), which can be based on quantitative functions (e.g., mass or on volume) or qualitative ones (e.g., taking into account animal products: protein content) (De Vries and De Boer, 2010). Finally, many products are obtained from multifunctional systems, which are characterised by the production of more than one valuable product, creating the problem of how to allocate the global impact to the different co-products (Cederberg and Stadig, 2003; ISO, 2006; Schau et al., 2008; Finnveden et al., 2009). Different methods to resolve the allocation problem exist and their alternative use can alter the final results, implying an important source of uncertainty. For this reason, ISO standard (ISO, 2006) recommends a rank of allocation methods to be followed, from avoiding the allocation problem, whenever possible, by dividing the multifunctional process into sub-processes, one for each co-product, to the system expansion, to methods based on a main common characteristic of the co-products (mass, protein, energy or economic value) to the no-allocation method, for which the whole impact is allocated to the targeted co-product.

The LCI aims at collecting all the inputs and outputs of the system, inventorying the resources used, the emissions produced and the wastes generated for producing a precise amount of targeted product. Two different types of data can be collected: foreground data are personally collected in the studied unit (e.g., the farm), and consider each activity directly performed and the resources used within it, whereas the background data are obtained from existing datasets and scientific literature and usually regard activities indirectly connected with the targeted system (i.e., the output of these activities is used as input in the targeted system).

The following LCA step (LCIA) aims to identify and evaluate the magnitude of the potential impacts on the environment caused by the system analysed. The potential impacts are included into specific impact categories. Each impact category concerns a particular environmental modification or phenomenon which could be caused by different substances or agents (i.e, environmental-damaging outputs produced by the system analysed) and has to be stated in the goal and scope definition. As an example, the global warming potential could be considered an impact category, and CO_2, CH_4 and N_2O are single substances contributing to the global warming. In the LCIA step, the different agents are aggregated, connecting each of them to the impact category it could contribute to (Classification) and expressing them in the common unit of the impact category itself (Characterisation). The Characterisation is based on a set of conversion factors that allows to express each pollutant in the common unit of the impact category, since each agent unit contributes to the related impact category with a different weight (ISO, 2006; Finnveden et al., 2009). In the last LCA step, the interpretation, the results of previous steps are gathered and evaluated in order to obtain conclusions and recommendations consistent with the initial parameters (Hertwich et al., 2001; Rebitzer et al., 2004; Finnveden et al., 2009).

The application of the LCA method, born and developed in the industrial sector in order to improve the resource efficiency of the production (Finnveden et al. 2009), to the livestock sector needs some arrangements that have to be taken into account. Firstly, the agro-livestock production chains are biologically-based, implying a range of uncertainty in the assessment of the impacts derived (Brentrup et al., 2004; Finnveden et al., 2009; Gerber et al., 2013). Secondly, the application of the LCA method to production systems that are widespread in the regional territory such as livestock production systems implies that the climatic, soil and ecosystems variation within the territory, and its consequence on the factors to be applied, has to be take into account, in particular if local-based phenomena, such as acidification and eutrophication, are evaluated (Potting and Hauschild, 2006).

An increasing number of studies has been published on the environmental footprint of livestock sector using a LCA procedure (Figure 1). Using "livestock" and "Life Cycle Assessment" key-words in Scopus database, in 2003 only three studies were published, whereas this number was increased from three to more than 30 in 2015, most of them concerning GHG emissions (de Vries and de Boer, 2010; Desjardins et al., 2012). The most studied livestock sectors are beef and dairy systems, whereas only few studies have investigated the environmental impact of meat or milk derived from small ruminant systems (Weiss and Leip, 2012; Opio et al., 2013; Ripoll-Bosch et al., 2013). In general, livestock edible outputs such as milk and eggs show a lower impact per functional unit compared to meat (either form monogastric or ruminant systems), even if evidences of similar impact per 1 kg of protein for milk, chicken, pork or eggs are reported (de Vries and de Boer, 2010). Among meat production systems, beef systems have been reported producing a greater environmental burden than poultry or pig meat production systems, because of the enteric methane emission and the lower feed conversion efficiency observed in ruminant animals, and beef originated from suckler cow-calf system has been reported to produce greater impacts than beef originated from dairy systems, because of the allocation of the total emission between milk and meat characterizing the latter (de Vries and de Boer, 2010; de Vries et al., 2015).

The diversity of the livestock regional systems implies that environmental footprint results found in literature for a livestock system could not simply apply to another livestock system. This is the case of the integrated France-Italy beef production system, a particular system that integrates the suckler cow-calf system located in the Massif Central semi-mountainous area (central France) and based on extensive pasture system (Brouard et al., 2014) with the intensive fattening system located in north-eastern Italy, where beef calves are imported and reared as batch (i.e., a group of animals homogenous for genetic type, sex, origin, fattening farm, finishing period and diet) using total mixed rations based on maize silage and concentrates (Gallo et al., 2014). Therefore, the general aim of the research conducted during my PhD was the assessment of the environmental footprint of the north-eastern Italy beef production system through a multi-approach methodology based on LCA, considering the whole supply chain obtained with the integration of the French suckler cow-calf system, and including the evaluation of the factors that may affect the environmental footprint of the Italian beef fattening phase.

This thesis is composed by 3 chapters:

In the first chapter, the environmental impact of the north-eastern Italy beef fattening system is assessed through a partial LCA method. The study involved 342 fattening batches (reared in 16 fattening farms during 2013. Data on animal performance were recorded for each batch. Diet composition and feed intake were collected for each beef category (combination of genotype and sex) within farms. On- and off-farm feed production data and materials used for animal management were recorded for each farm. This chapter gave a preliminary analysis of the environmental impact of the north-eastern Italy beef production system, developing a methodological framework that has been used in the following chapters for assessing the environmental footprint of the whole beef supply chain (chapter 2) and for evaluating some factors affecting the environmental footprint of the Italian beef fattening system (chapter 3).

The second chapter aimed at evaluating the environmental footprint of the integrated France-Italy beef production system (extensive grassland-based suckler cow-calf farms in France with intensive cereal-based fattening farms in north-eastern Italy) using a multi-indicator approach, which combines environmental impact categories computed with a cradle-to-farm gate Life Cycle Assessment, and food-related indicators based on the conversion of gross energy and protein of feedstuffs into raw boneless beef. The study involved 73 Charolais batches kept at 14 Italian farms. Data from 40 farms originating from the Charolais Network database (INRA) were used to characterize the French farm types, which were matched to the fattening batches according to the results of a cluster analysis.

The third chapter aimed at investigating the effect of the origin of the feedstuffs of the beef diets, the crude protein and phosphorus daily intake and of the beef category (genetic type x sex) on the environmental impact of the north-eastern Italy beef fattening system computed according to a partial LCA method. The study involved 245 batches reared in 17 fattening farms in 2014. Data on animal performance and farm input were collected for each batch and farm, respectively. Data on feed allowance, ingredients composition of the diet as well as diet sample for the chemical analysis were monthly collected for each batch.

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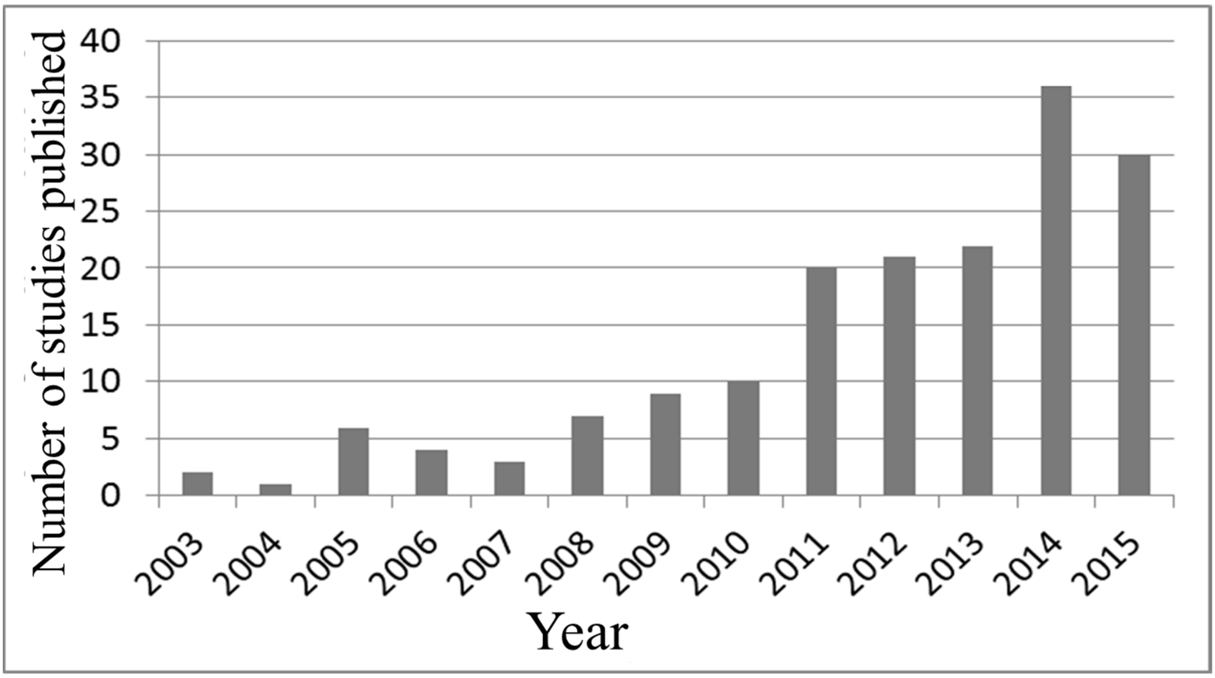
Figure 1. Number of studies published in Scopus database from 2003 to 2015 that present "livestock" and "Life Cycle Assessment" as key-words.



Chapter 1

Environmental impact of a cereal-based intensive beef fattening system according to a partial Life Cycle Assessment approach

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Abstract

This study investigated the environmental impact of the intensive beef fattening sector in North-Eastern Italy. A partial Life Cycle Assessment method was used with the boundaries of the system set from the arrival of stock calves, mainly born and raised in French suckler cow-calf systems, to the sale of finished young bulls and heifers to the slaughterhouses. One kg of body weight gained (BWG) was taken as the functional unit. This study examined 327 batches (groups of animals homogeneous for sex, genotype, origin, fattening farm and finishing period, 63±32 heads of average size) fattened by 16 farms. Data on animal performance were recorded for each batch. Diet composition and feed intake were collected for each beef category (combination of genotype and sex) within farms. On- and off-farm feed production data and materials used were recorded for each farm. Impact categories regarded (mean values and standard deviation per kg BWG are provided between brackets): global warming potential (8.4 ± 1.6 kg CO_2-eq), acidification potential (197 ± 32 g SO_2-eq), eutrophication potential (65 ± 12 g PO_4-eq), cumulative energy demand (62 ± 16 MJ), and land occupation (8.9 ± 1.7 m^2/year). The contribution to global warming, acidification, and eutrophication potentials was greater for the on-farm than off-farm activities, whereas the opposite pattern was found for cumulative energy demand and land occupation. When referred to the whole production system, adding the global warming potential of French suckler cow-calf systems taken from the literature to those found in the present study for the fattening period, the resulting GHG emission was comparable to those reported for other suckler cow-based beef chain systems. The impact category values obtained for each batch were analysed with a linear mixed model which included the effects of farm (random effect), beef category, season of arrival in the fattening farm, and body weight class at the start of the fattening period within beef category. Beef category greatly affected all impact categories and variation across farms was notable. In conclusion, the beef fattening system taken into account was characterized by an overall global warming potential similar to, or slightly lower than those reported for other beef systems, due to its productive efficiency, but showed a high energy demand, due to the relevance of off-farm activities. Different impact categories evidenced notable variation among farms, suggesting that there is potential for decreasing impacts through appropriate and specific management procedures of herds and farms.

Keywords: Environmental impact; Beef fattening; Life Cycle Assessment

Introduction

Livestock production accounts for nearly 14% of total greenhouse gases (GHG) emissions of anthropogenic origin, and beef supply chains are estimated to account for nearly 40% of all livestock emissions (Gerber et al., 2013). Several studies have recently addressed the environmental impact of different beef production systems (Desjardins et al., 2012; de Vries et al., 2015) through Life Cycle Assessment (LCA) approach (Finnveden et al., 2009), but there is still a gap in knowledge regarding the contribution of specific regional systems. One of these is the intensive beef fattening sector in North-Eastern Italy, a very specialised farming system which produces nearly 24% of beef bulls reared by fatteners in the European Union (European Commission, 2011). This system traditionally integrates the extensive suckler cow-calf herds, mostly located in France, which provide stock calves, with the intensive fattening herds of the Po valley in northern Italy, where beef calves are raised and finished using total mixed rations based on maize silage and concentrates (Gallo et al., 2014). Despite the economic relevance, the large number of animals produced, and the involvement of different countries in this beef chain, only few studies considered the environmental aspects of this system, focussing on nitrogen pollution at regional level (Xiccato et al., 2005) or providing just some general insights of the global warming potential within the European scenario (Leip et al., 2010). This study aims to assess the environmental impact of the intensive beef fattening sector in North-Eastern Italy through a partial LCA approach (European Commission, 2010) considering as systems boundaries the whole finishing period, from the arrival of the calves at the fattening farm to their sale to the slaughterhouse.

Materials and methods

Origin of the data, goal and scope definition

The goal of the study was to survey the environmental impact of the specialised intensive beef production system of North-Eastern Italy. Given the diversity of suckler cow-calf systems that supply the beef sector in this geographical area (ISTAT, 2014), the system boundaries were set at farm gate, i.e. from the arrival of the calves at the fattening farm to their sale to the slaughterhouse, without any consideration about the previous suckler cow-calf. Therefore, this study took into account the production and use of on-farm feeds, the production and transport of off-farm feeds, the materials used and the herd management procedures, whereas the stock calves production, their transport from suckler cow-calf farms, the slaughterhouse operations, and the inputs, operations and facilities related to other farms outputs (crops for market) were excluded, according to the indications of the International Standardisation Organisation sub-division procedure (ISO, 2006). For multifunctional products for which sub-division was not possible (e.g. soybean meal as a co-product of soybean oil production), an economic allocation method was used, since this is the most common method in livestock sector (de Vries and de Boer, 2010). Within these boundaries, the reference unit was the batch, defined as a group of animals homogeneous for genotype, sex, origin, fattening farm and finishing period (Gallo et al., 2014). This approach allowed to take into account the variation of the impact among and within farms. The following impact categories were assessed: global warming potential (without land use change consideration), acidification potential, eutrophication potential, cumulative energy demand and land occupation, using 1 kg of body weight gained (BWG) as the functional unit.

The study considered 327 batches (20,598 animals, 63±32 heads of average size) herded in 16 beef fattening farms whose geographical location, ownership type, and herd structure and management were typical of this specialized beef sector (Gallo et al., 2014). The reference year was 2013. The batches were composed by the following beef genetic type and sex: Charolais bulls (196 batches), Limousin bulls (48 batches), Irish crosses bulls (35), Limousin beef heifers (30), French cross-bred bulls (5), Salers bulls (5), Charolais x Salers bulls (4) and Charolais beef heifers (4). Nearly 90% of calves were born in France.

Life Cycle Inventory

The Life Cycle Inventory accounts for all the system's inputs and outputs and records all emissions, energy use and occupied land related to the system itself. For this reason, each farm was visited by a unique operator in order to collect general data for the description of facilities, organization, and manure management systems of each farm (Supplementary Table S1). Thereafter, data on animals, crop production and materials used were recorded monthly at farm level by the same operator.

Batches characteristics, diets and on-farm feed production

Information regarding the number of animals, breed, sex, arrival and sale dates, BW at start and at sale (BWI and BWF respectively, kg), and the number of deaths were recorded for each batch. Average daily gain (ADG, kg/d) was calculated as the difference between total BWF and total BWI, at batch level, divided by the total animal presence (heads x days) in order to take into account death records. Fattening duration was obtained as the difference between the date of purchase and that of sale. Diet composition and dry matter intake (DMI) were collected for each genotype and sex within each farm. Dry matter intake was computed using the average composition of the diets fed to each beef category (a combination of genotype and sex) within each farm, taking into account the daily composition of total mixed rations, collected from farm documents, and the mean beef category daily animal number (heads/day), collected from animal flows recorded by farmers (see Supplementary Table S2).

Self-sufficiency was computed for each diet as the ratio of dry matter produced on farm to total DMI. For each diet, chemical composition and gross energy intake, digestibility, digestible energy (MJ/day and MJ/kg DM), and metabolisable energy (MJ/day and MJ/kg DM) were calculated using data from the literature, according to values proposed by Martillotti et al. (1996) for silage feedstuffs and by INRA (2007) for all other feedstuffs. Protein and mineral supplements were analysed to determine dry matter (AOAC method 934.01, 2003), crude protein (Kjeldahl, AOAC method 976.05, 2003), ash (AOAC method 942.05, 2003), neutral detergent fibre (Van Soest et al., 1991), starch (HPLC method; Bouchard et al., 1988), and phosphorus (P) content (AOAC 999.10, 2000 and ICP-OES). Gross energy, digestibility, digestible energy and metabolisable energy for protein and mineral supplements were calculated using INRA (2007) procedure.

For each batch, nitrogen (N) input-output flows were estimated using the procedure suggested by Environmental Resource Management (ERM, 2002) as follows: N excretion as the difference between N intake (DMI x duration cycle x (N diet/100)) and N retention ((BWF – BWI) x 0.027 kg N/kg BW). Phosphorous input-output flows were calculated according to the same procedure, using P diet content and a retention factor of 0.0075 kg P/kg BW (Whiters et al., 2001).

In order to estimate the environmental impact of feeds originating on-farm, farms documents and invoices and farmers' indications were used for each crop used for feeding beef to record all production inputs (fuel, mineral and organic fertilizers, pesticides, seeds), extent of land use and yields. Drying processes were taken into account when appropriate (e.g. grain or alfalfa hay). Emission factors (EF), energy use and land occupation for fertilizers were derived from Ecoinvent 3.1 (Ecoinvent Centre, 2014) database, whereas those for pesticides and seed production are reported in Supplementary Table S3. Inputs used per on-farm crop are reported in Supplementary Table S4. Agricultural machines (construction and delivery) were not taken into consideration, but lubricants were considered and allocated accordingly.

Off-farm activities and materials

Off-farm inputs used for herd management were assessed, with the exception of stock calves. Feeds originating off-farm and background production were accounted for on the basis of farms' records and from suppliers. Soybean meal was assumed to come from Brazil and be transported by ship to the Rotterdam harbour (The Netherlands), then by lorry to Italy, whereas maize grain, maize by-products, and dried sugar beet pulp were assumed to come from the Ukraine (as mean start point) by lorry. Fuel, electricity, lubricant, plastic and bedding materials were recorded from official invoices (see Supplementary Table S5). Emission factors, energy use, and land occupation for off-farm feedstuffs, plastic, lubricant, and bedding materials and transports were derived by Ecoinvent 3.1 (Ecoinvent Centre, 2014) and Agri-footprint 1.0 databases (Blonk Agri-footprint, 2014) implemented in the Simapro software 8.0.5. Impact factors for ammonia due to mineral fertilizers at soil level and fuel were derived from the European Environmental Agency report (EEA, 2013), whereas the global warming potential EF proposed by O'Brien et al. (2010) was used for fuel refinement. Regarding electricity production, proportion of each electricity source was derived from the Italian electricity network handling company and the Italian Environmental Agency (ISPRA, 2015); global warming potential EF was derived by ISPRA (2015), and impact factors for acidification, eutrophication, energy demand and land occupation were derived from Ecoinvent database.

Emissions calculation

The complete set of equations used for calculating emissions is shown in Tables 1 and 2. Greenhouse gas emissions were first computed following the International Panel on Climate Change (IPCC) Tier 2 procedure (IPCC, 2006). As variation in enteric methane (CH_4) estimation is high (Cederberg et al., 2013) and the IPCC procedure for enteric CH_4 is based on a fixed CH_4 conversion factor (fraction of energy intake loss by CH_4 emission), which does not account for the chemical composition of diets, two alternative methods were also used and compared (Table 1). These were the equation proposed by Ellis et al. (2007), in which CH_4 emission is a function of metabolisable energy intake, neutral detergent fibre (NDF, kg/kg DM) and the percentage of forage in the diets; and the equation proposed by Moraes et al. (2014), in which rumen CH_4 production depends on gross energy intake. Methane and nitrous oxide (N_2O) emissions from manure management and N_2O emissions from crop production were calculated according to IPCC procedures (IPCC, 2006).

Acidifying pollutants were also assessed. Because of the importance of spatial variability in the emission rate for non-global impact categories, such as acidification potential (Potting, 2000), three methods for calculating ammonia (NH_3), nitrogen oxides (NO_x) and sulphur dioxide (SO_2) volatilisation from barns, storage, and the spreading of manure and fertilizers on the soil were used and compared: IPCC (2006) and ISPRA (2011), which are based on N excreted and organic and mineral N spread on the soil, and EEA (2013), which is based on total ammoniacal N. The international method of IPCC is based on regionalised parameters, whereas EEA and ISPRA have been developed for European and Italian assessments, respectively. Leaching losses and N deposited after volatilisation were computed for eutrophication potential category. Leaching losses were considered for N (as nitrate, NO_3) and P. Potential N leaching was calculated as the difference between N inputs and N outputs (N removed by harvested crops and N loss to air), taking soil N content to be in steady state. Phosphorus loss was calculated following the procedure described in Nemecek and Kägi (2007).

Life Cycle Impact Assessment

Impacts were classified according to the following impact categories: global warming potential (kg CO_2-eq), acidification potential (g SO_2-eq), eutrophication potential (g PO_4-eq), cumulate energy demand (MJ) and land occupation (m^2/year).

Pollutants were aggregated into impact categories as follows: global warming potential included carbon dioxide (CO_2), CH_4 and N_2O emissions; conversion to common unit CO_2 equivalent (eq) was calculated according to the 100-year global warming potential factors of each gas, CO_2: 1, CH_4 biogenic: 28, CH_4 fossil: 30, N_2O: 265 (Myhre et al., 2013). Acidification potential included SO_2, NH_3, and NO_x, eutrophication potential NO_3, NH_3 and P. Conversion factors in SO_2-eq, (SO_2: 1, NH_3: 1.88, NO_x: 0.7) and in PO_4-eq (NO_x: 0.13, NH_3: 0.35, NO_3: 0.1, P: 3.06) were used for acidification and eutrophication potential, respectively (Guinée et al., 2002). Cumulative energy demand accounted for the renewable and non-renewable energy to produce and use inputs for on-farm feed production and animal fattening. Land occupation included the agricultural land needed to produce the feeds and other materials.

Ecoinvent and Agri-footprint databases, implemented in Simapro software, were used to assess the impact due the off-farm input with the following methods: 100-years GWP method (global warming), CML 2001 method (acidification and eutrophication potentials, as well as land occupation) and Cumulative Energy Demand version 1.09 (cumulative energy demand).

Global warming potential category for cradle-to-farm gate assessment

As in the intensive fattening system analysed in this paper calves originate mainly from French suckler cow-calf systems, the global warming potential of the whole production cycle (cradle-to-farm gate) was calculated for the French batches only (292 batches). The suckler cow-calf GHG emission, calculated by multiplying the mean carbon footprint value (17.5 kg CO_2-eq/kg BW sold) reported by Nguyen et al. (2012) for total BWI of each batch, was added to the GHG emission obtained for the fattening period of each batch.

Statistical analysis

Charolais and Limousin females were grouped into a single beef category (beef heifers), Salers, Charolais x Salers, and other French crossbreds were included in a single class (other French breeds and crosses). Months of arrival were grouped into seasons: winter (December, January and February), spring (March, April, May), summer (June, July, August) and autumn (September, October, November). The statistical unit was the batch. The distribution of impact category variables was tested using Shapiro Wilk test (PROC UNIVARIATE, SAS, 2012).

Data were analysed using a mixed linear model (PROC MIXED, SAS, 2012) which included the random effect of farm and the fixed effects of beef category (Charolais, Limousin, other French breeds and crosses, Irish crosses, beef heifers), season of arrival, and class of BWI (3 classes: low, including batches with BWI lower than the mean - 0.5 SD, medium, including batches with BWI comprised within mean ± 0.5 SD, high, including batches with BWI greater than the mean + 0.5 SD; and each mean and SD computed within beef category). The differences among LS means were tested by adjustment through Bonferroni method.

Results

Growth performance and feed intake

Descriptive statistics for growth performance and feed intake are given in Table 3. Body weight at the start and at the end of the fattening period averaged 365 and 682 kg, respectively. As the duration of the fattening period approached 7 months, ADG was close to 1.4 kg/d. Dry matter intake averaged nearly 10 kg/d and exhibited a 11% coefficient of variation. Maize silage was the main feed used for preparing total mixed rations, and it accounted on average for nearly one third of the total DMI. On average, feedstuffs originated for nearly half from farm production, but the rate of feed self-sufficiency was quite variable among farms.

Impact categories

Global warming potential ranged from 7.9 to 9.0 kg CO_2-eq/kg BWG, according to the method used to compute CH_4 emissions (Table 4). Variation within the same method was of similar extent, irrespective of computation method. Mean acidification potential ranged between 141 and 197 g SO_2-eq/kg BWG, with increasing values from ISPRA (2011), to EEA (2013), and to IPCC (2006) methods. There was also variation within each method, as coefficient of variation ranged between 16 and 19%. Eutrophication potential averaged 65 g PO_4-eq/kg BWG, and exhibited a coefficient of variability comparable to those observed for global warming and acidification potential. Conversely, cumulative energy demand, which approached on average 62 MJ/kg BWG, showed the greatest coefficient of variation among the impact categories considered. On average, the production of 1 kg BW required nearly 9 m^2/year, with a range comprised between 5.5 to 13 m^2/year.

On- and off-farm contribution to each impact category is shown in Table 5. The on-farm category represents the impact due to herd management (enteric fermentation, manure management and fuel for feeding) and on-farm feed production procedures (direct impacts at soil plus emissions due to production of fuel, fertilizers, pesticides and seeds). Impact derived from off-farm activities includes off-farm feed production and transport, production and use of industrial materials (fuel refinement, plastic, lubricant) and production of bedding materials. For global warming and acidification potential categories, only results from the IPCC method are shown. In general, the contribution of on-farm activities to the overall impact was largely predominant for acidification (75%), prevalent for eutrophication (60%) and slightly greater than that due to off-farm contribution for global warming (56%). Conversely, on-farm activities had a minor contribution to impact due to land occupation (28%) and cumulative energy demand (16%) when compared to the role of off-farm procedures. In particular, global warming and acidification potentials were originated mainly by on-farm herd management (47% and 61%, respectively), due to enteric or manure emissions, followed by off-farm feed production (27% and 22%, respectively). Eutrophication potential was mainly due to feed production, with off-farm and on-farm contributing 37% and 26%, respectively. However, on-farm herd management also gave a considerable contribution to eutrophication, accounting for more than one third of this impact category. Cumulative energy demand and land occupation derived predominantly from off-farm stages, mainly because of off-farm feed production (48% and 67%, respectively) and from transport, which accounted for 31% of cumulative energy demand.

Correlations between impact categories were positive and significant ($P < 0.01$), and Pearson's correlation values ranged from 0.62 to 0.99 (Supplementary Table S6). Impact categories followed a normal distribution (Shapiro-Wilk test> 0.95, $P <0.001$) and were all influenced by beef category ($P < 0.001$, Table 6), and season of arrival ($P < 0.05$, data not shown in table). Variance due to farm effect was nearly 3.4 to 12 times greater than residual, according to the impact category taken into account, suggesting that farm is a considerable source of variation of environmental impact (data not shown in table). The least squares means of farm effect on global warming potential computed with a GLM which included farm as fixed effect are given in Supplementary Table S7. Charolais and Irish crosses beef bulls provided the lowest values for all impact categories (Table 6), whereas beef heifers showed the greatest values. Limousin and other French breeds and crosses bulls had intermediate values, with the exception of energy demand, for which Limousin bulls and beef heifers showed similar results. Effects of beef category on global warming and acidification potential reported in Table 6 refer to the impact categories computed according to the IPCC method only. The influence of beef category on the same impact categories computed with the other methods followed a similar trend (see Supplementary Table S8).

When the system boundaries were enlarged in order to include the suckler cow-calf phase, relatively to the 292 fattening batches arrived from France, the global warming potential was on average 13.6 ± 1.4, 13.9 ± 1.4 and 14.1 ± 1.4 kg CO_2/kg BW, using the IPCC (2006), Ellis et al. (2007) and Moraes et al. (2014) methods for enteric CH_4 emission in the fattening period, respectively.

Discussion

Comparison with impacts of other beef systems

Most studies dealing with the environmental impact of beef production used a cradle-to-gate approach, as usually beef production system integrates within the same regional or national chains the step of production of stock calves with that of finishing of beef cattle (de Vries and de Boer, 2010, de Vries et al., 2015). In the present study a partial LCA approach focussed on the fattening period only was used to investigate the environmental impact of intensive beef cattle farms in North-Eastern Italy, as finishing according to standardised management and feeding practices related to specific beef categories is the only step of beef production performed in these intensive and specialized beef herds (Cozzi, 2007; Gallo et al., 2014). Only few papers investigated the environmental impact of the beef fattening phase using diets based on maize (Nguyen et al., 2012; Pelletier et al., 2010). Estimates about the global warming potential found in the present study are comparable with those reported by Nguyen et al. (2012) for a standard maize silage-based fattening herd and by Pelletier et al. (2010) for the feedlot system – 8,6 and 8,3 kg CO_2-eq/kg BWG respectively – even if the computation of the emissions were not methodologically identical. In particular, the study of Nguyen et al. (2012) differs in the computation of the enteric methane (derived from Vermorel et al., 2008), whereas Pelletier et al. (2010), although using the IPCC (2006) framework as this study, adopted an allocation method based on the gross chemical energy content of the co-products.

Land occupation result obtained in this study was similar to that found by Nguyen et al. (2012). Conversely, acidification potential was nearly three times greater, and eutrophication and energy use nearly two times greater than the estimates reported in that study, respectively. These differences can be at least partly explained considering: i) the different methods of calculation used to account for the assessment of acidification potential; ii) the differences in distances needed for the transport of off-farm feedstuffs for the assessment of cumulative energy demand; and iii) the greater amount of P used for the fertilization of maize in the present study with respect to data of Nguyen et al. (2012) (48 vs 30 kg P_2O_5/ha, respectively), for the assessment of eutrophication potential.

On the other hand, the comparison of the results found in this study other than global warming potential with those of Pelletier et al. (2010) was possible only for cumulative energy demand because of the absence (acidification potential) or the use of different methodologies (eutrophication potential) or of different impact categories (ecological footprint). The result found in this study for the cumulative energy demand was nearly three times greater than that of Pelletier et al. (2010) for the feedlot step, probably due to differences in the distance for the transport of off-farm inputs and the notable share of off-farm feeds in the beef diets.

In order to compare the results of the present study with data from the literature dealing with the impact of beef production using a cradle–to-gate approach, the impact due to the production of calves should be considered. The GHG emission calculated for the France-Italy beef system in this study is similar or slightly lower than those found in the literature for suckler cow-based beef chain systems: 15.3 – 15.9 kg CO_2/kg BW (Nguyen et al., 2012) and 14.3 - 18.3 kg CO_2/kg BW (Veysset et al., 2010) in France; 14.8 - 19.2 kg CO_2/kg BW (Pelletier et al., 2010) in the USA; 13.04 kg CO_2/kg BW (Beauchemin et al., 2010) in Canada. The contribution derived from the suckler cow-calf phase outweighed that of the fattening phase; consequently, the increment of the share of BW gain obtained during the fattening phase (BW_ITA), purchasing young bulls with low BWI and their sale at high BWF, could have a mitigation effect on the France-Italy beef production system diluting the GHG emission due to the suckler cow-calf phase (r factor from -0,48 to -0,71, P<0,001, between BW_ITA and the cradle-to-farm gate global warming potential, within beef category).

Sources of variation in emission factors

The intensive beef fattening sector of North-Eastern Italy is greatly standardised for what concern facilities, management and feeding strategies (Cozzi, 2007). Nevertheless, beef farms considered in the present study showed a wide variation for all impact categories, and the differences between the least and the most impacting farm were in the order of two to three times (Supplementary Table S9).

The results of the mixed model analysis clearly indicated that the beef category is a main factor in explaining the variation of the impact category values. Production performances are strongly affected by breed and beef categories (Gallo et al., 2014). The ranking of beef categories for environmental impact can be explained taking into account differences in ADG, which clearly affects the denominator of total burden/total BWG ratio. Charolais and Irish crosses beef bulls had the lowest impact values per kg of BWG, despite their greater feed intake and CO_2-eq/head/day emission (+ 8% and +12%, respectively, when compared to beef heifers, the category which exhibited the lowest values for the traits of concern). Improving growth traits could be therefore a way for decreasing the impact per kg of functional unit in beef. (Crosson et al., 2011). However, an increase of ADG within beef category is associated with higher share of off-farm feedstuffs into the beef diet ($r=0.45$, $P<0.001$).

The large variation among farms observed suggests that there is potential for decreasing emissions through appropriate and specific management procedures of herds and farms. Strategies able to mitigate the environmental impact of the on-farm component, are known by the literature. Among others, a better matching between feed protein intake and protein requirements (Rotz, 2004), and the improvement of on-farm feed production procedures (Johnson et al., 2007) may support the decrease of environmental impact of beef herds. The off-farm component was predominant for cumulative energy demand and land occupation. It can be reduced increasing the rate of self-sufficiency of the diet, expressed as the total on-farm feed to the total feed intake ratio (Guerci et al., 2013). In fact, it could cut off-farm feed transport, which exerted a strong influence on cumulative energy demand.

Also the computation methods affected EF estimation. The use of different methods in the estimation of global warming and acidification potential resulted in a notable variation of the impact values computed. With respect to global warming potential, using the equations in Ellis et al. (2007) and Moraes et al. (2004) to compute enteric CH_4 emission from the chemical composition of the diet yielded values 6% and 11% greater, respectively, than those obtained using IPCC. Variability between the methods used was even larger for acidification potential. The minimum value, with ISPRA (2011), was 28% lower than the maximum, with IPCC (2006). These differences are mainly due to the variable EF for N volatilisation in the manure management stage, as herd management is the main contributor to acidification potential (61%, Table 5). The use of N-excreted (IPCC, 2006; ISPRA, 2011) instead of total ammoniacal-N (EEA, 2013) is not a main difference factor, since the minimum and maximum values found were calculated with the N-excreted method. Therefore, from a methodological point of view, the use of data collected on-farm instead of those derived from the literature databases improves accuracy in estimating the "animal component" of the impact. In any case, the different impact calculation methods did not interact with beef category, since ranking of beef category did not change for either global warming potential or acidification potential (Supplementary Table S8).

Conclusion

The results obtained in this study showed that the cereal-based intensive beef farms specialised in the fattening phase are characterised by a large variability in terms of environmental impacts, suggesting the possibility to improve the sustainability of this beef system. The batch-based approach used in this research allowed to investigate the sources of variation of environmental burden, such as the beef category, and can be used in perspective to address strategies aimed to mitigate environmental impacts. The association between suckler cow-calf herds, located mainly in France but also in other European countries, and the Italian fattening farms integrates and gives value to systems and areas characterized by different ecological and economic features. As this integrated beef system is important for the European beef production, a better quantification of its overall impact is needed, together with further investigations about mitigation strategies aimed at improving the efficiency of this integrated beef chain.

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Table 1.

Equations used to calculate emissions from enteric fermentation (at batch level, 327 batches) and manure management (at farm level, 16 farms) in beef fattening farms.

Pollutant	Equation	Reference
Enteric fermentation		
CH_4 (kg/head per day)	$= (\text{GEI\_IPCC}^{1} \times 0.04^{2})/55.65^{3}$	IPCC (2006) Tier 2
	$= (0.183 + 0.0433 \times (\text{ME}^{4} \times \text{DMI}^{5}/100) + 0.647 \times (\%\text{NDF}^{6} \times \text{DMI}^{5}/100) + 0.0372 \times \%\text{forage}^{7})/55.65^{3}$	Ellis *et al.* (2007)
	$= (0.743 + 0.054 \times \text{GEI\_DIET}^{8})/55.65^{3}$	Moraes *et al.* (2014)
Manure Management		
CH_4 (kg)	$= (\text{VS}^{9} \times \text{duration cycle (day)}) \times (\text{Bo}_{(T)}{}^{10} \times 0.67 \times \sum (\text{MCF}_{(S,k)}{}^{11}/100) \times \text{MS}_{(S,k)}{}^{12}$	
	$\text{VS} = (\text{GEI\_DIET}^{13} \times (1 - \text{DE}\%^{14}/100) + (\text{UE}^{15} \times \text{GE\_DIET}^{16})) \times ((1 - \text{ASH}^{17})/\text{GE\_DIET})$	
N_2O direct (kg)	$= \sum (\text{Heads} \times \text{N excreted} \times \text{MS}_{(S,k)}) \times \text{EF}_{S}{}^{18}) \times 44/28^{19}$	IPCC (2006) Tier 2
NH_3 housing + storage (kg)	$= (\text{N slurry (kg)} \times \text{Frac}_{\text{GasSLURRY}}{}^{20} + \text{N solid manure (kg)} \times \text{Frac}_{\text{GasMANURE}}{}^{21}) \times 17/14^{22}$	
N_2O indirect (kg)	$= NH_3 \text{ (kg)} \times 14/17 \times 0.01 \text{ (kg N-}N_2O\text{/(kg N-}NH_3 + \text{kg N-}NO_x)) \times 44/28$	
NH_3 housing (kg)	$= \sum (\text{TAN}_{\text{housing, S}}{}^{23} \times \text{EF}_{\text{housing}}{}^{24}) \times 17/14$	EEA (2013)
NH_3 storage (kg)	$= \sum (\text{TAN}_{\text{storage, S}}{}^{25} \times \text{EF}_{\text{Storage}}{}^{26}) \times 17/14$	
NH_3 housing + storage (kg)	$= \text{Heads} \times \text{N excreted} \times 0.271 \text{ (kg N-}NH_3\text{/kg N excreted)} \times 17/14$	ISPRA (2011)

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[1] GEI_IPCC: Gross Energy Intake (MJ/day per head) calculated with IPCC procedure.

[2] Fraction of GEI (MJ) lost as methane (ISPRA, 2008).

[3] Energy content (MJ) of 1 kg of methane (IPCC, 2006).

[4] ME: Metabolisable Energy (MJ/kg DM).

[5] DMI: Dry Matter Intake (kg DM/day per head).

[6] NDF: neutral detergent fibre (%).

[7] %forage: percentage of forages in the diet (%).

[8] GEI_DIET: gross Energy Intake (MJ/day per head) calculated with INRA (2007).

[9] VS: daily volatile solid excreted (kg DM/head per day).

[10] $Bo_{(T)}$: maximum methane producing capacity for manure produced ($m^3 CH_4$/kg VS).

[11] $MCF_{(S,k)}$: methane conversion factor for manure management system (MCF slurry = 0.14, MCF solid manure = 0.02).

[12] $MS_{(S,k)}$: fraction of animals handled using manure management S.

[13] GEI_DIET: gross Energy Intake (MJ/day).

[14] DE%: Diet Energy Digestibility (%).

[15] UE: urinary energy fraction.

[16] GE_DIET: gross energy of diet (MJ/kg DM).

[17] ASH: 0.08 kg DM ash/kg DM.

[18] EF_S : emission factor for manure management system (EF slurry = 0.005, EF solid manure = 0.005).

[19] kg N_2O/kg N-N_2O ratio.

[20] $Frac_{GasSLURRY}$: 0.40 kg N-NH_3/kg N excreted.

[21] $Frac_{Gas\ MANURE}$: 0.45 kg N-NH_3/kg N excreted.

[22] kg NH_3/kg N-NH_3 ratio.

[23] $TAN_{housing,\ S}$: Total Ammoniacal Nitrogen (kg) for manure management system S; (TAN = 0.6 x N excreted).

[24] $EF_{housing}$: emission factor for housing (EF slurry = 0.20 kg N-NH_3/kg TAN, EF solid manure = 0.19 kg N-NH_3/kg TAN).

[25] $TAN_{storage,\ S}$: TAN (kg) for storage stage (= kg $TAN_{housing}$ – kg N-NH_3 Housing).

[26] $EF_{Storage}$: emission factor for storage (EF slurry = 0.20 kg N-NH_3/kg TAN, EF solid manure = 0.27 kg N-NH_3/kg TAN).

Table 2.

Equations used to calculate emissions from crop production in the sample of 16 beef fattening farms.

Pollutant	Equation	Reference
N_2O direct (kg)	= (mineral N (kg) + manure N (kg) + crop residues N[1] (kg)) x 0.01 (kg N-N_2O/kg N applied) x 44/28[2]	IPCC (2006) Tier 1
NH_3 spreading (kg)	= (mineral N (kg) x 0.1 (kg N volatilised/kg N mineral) + manure N (kg) x 0.2 (kg N volatilised/kg N manure)) x17/14[3]	IPCC (2006) Tier 1
N_2O volatilisation (kg)	= NH_3 (kg) x14/17 x 0.01 (kg N-N_2O/(kg N-NH_3 + kg N-NO_x)) x44/28[2]	IPCC (2006) Tier 1
NH_3 spreading (kg)	= ((TAN $_{spreading,S}$ [4] x EF_S [5]) + (N mineral (kg) x $EF_{min,spr}$ [6])) x 17/14[3]	EEA (2013)
NH_3 spreading (kg)	= (mineral N (kg) + manure N (kg)) x 0.1299 (kg N-NH_3/kg N applied) x 17/14[3]	ISPRA (2011)
NO_x spreading (kg)	= (mineral N (kg) + manure N (kg)) x 0.026 (kg N-NO_x/kg N applied)	EEA (2013)
NO_3 potential leaching (kg)	= ((mineral N (kg) + manure N (kg)) – N harvested - N loss (N-N_2O (kg), N-NH_3 (kg))) x 62/14 (kg NO_3/kg N-NO_3)	
N_2O leaching (kg)	= $NO_{3\ potential\ leaching}$ (kg) x 14/62 x 0.0075 (kg N-N_2O/N-NO_3 leach) x 44/28[2]	IPCC (2006) Tier 1
P leaching ground (kg)	= ha[7] x 0.07 (kg/ha per year) x (1+(0.2/80) x P_2O_5 slurry (kg))	Nemecek and Kägi (2007)
P run off surface (kg)	= ha[7] x 0.175 (kg/ha per year) x [1+((0.2/80) x P_2O_5 slurry (kg) +(0.7/80) x P_2O_5 mineral (kg) + (0.4/80) x P_2O_5 manure (kg))]	Nemecek and Kägi (2007)

[1] Crop residue N: Equation 11.6, chapter 11, IPCC (2006).

[2] kg N_2O/kg N-N_2O ratio.

[3] kg NH_3/kg N-NH_3 ratio.

[4] TAN $_{spreading,\ S}$: Total Ammoniacal Nitrogen (kg) for livestock manure (= manure N (kg) x 0.6).

[5] EF_S: emission factor for manure N volatilisation (EF slurry = 0.55 kg N/kg N-NH_3, EF solid manure = 0.79 kg N/kg N-NH_3).

[6] $EF_{min,spr}$: emission factors for mineral N volatilisation (Table 3-2, chapter. 3.3.2.1 in EEA (2013)).

[7] Extent of land (hectare).

Table 3.

Descriptive statistics (mean ± SD) for growth performance (for 327 batches) and feed intake (for 37 farm x beef category combinations) for each beef category.

Variable	Overall statistics	Beef category				
		CH[7]	IRE[8]	IF[9]	HEI[10]	LIM[11]
BWI[1] (kg)	365 ± 47	392±25	369±30	387±13	289±16	300±15
BWF[2](kg)	682 ± 83	730±22	712±28	711±19	503±21	582±28
Heads/batch (N)	63 ± 32	66±31	65±30	49±18	27±14	79±31
Length of the finishing period (day)	226 ± 17	224±17	234±13	233±15	234±13	216±18
ADG[3] (kg/d)	1.41 ± 0.20	1.51±0.09	1.47±0.10	1.39±0.07	0.92±0.07	1.30±0.06
DMI[4] (kg DM/ head/day)	9.8 ± 1.1	10.3±0.7	9.9±1.0	10.2±0.7	8.2±0.2	8.7±0.9
% maize silage[5]	34 ± 9	33±8	32±9	42±7	42±2	33±12
% self-sufficiency[6]	46 ± 12	45±10	43±8	52±13	66±6	39±11

[1] BWI: initial body weight,

[2] BWF: final body weight

[3] ADG: Average Daily Gain.

[4] DMI: Dry Matter Intake.

[5] % maize silage: maize silage (kg DM)/total dry matter intake (kg DM).

[6] % self-sufficiency: total on-farm feed intake (kg DM)/total dry matter intake (kg DM).

[7] CH = Charolais bulls; [8] IRE = Irish crosses bulls; [9] IF = Other French breeds and crosses, [10]HEI: Charolais or Limousin beef heifers, [11] LIM = Limousin bulls.

Table 4.

Descriptive statistics for impact categories, expressed per kg body weight gained (BWG) (N = 327 batches).

Impact category	Unit	Reference	Mean	SD	Min[1]	Max[2]
Global warming potential	kg CO_2-eq	IPCC (2006)	7.9	1.3	4.9	11.2
		Ellis et al. (2007)	8.4	1.6	4.9	12.9
		Moraes et al. (2014)	9.0	1.6	5.5	13.3
Acidification potential	g SO_2-eq	IPCC (2006)	197	32	136	297
		EEA (2013)	154	30	90	239
		ISPRA (2011)	141	26	85	204
Eutrophication potential	g PO_4-eq	IPCC (2006), Nemecek and Kägi (2007)	65	12	40	96
Cumulative energy demand	MJ		62	16	27	94
Land occupation	m^2/year		8.9	1.7	5.5	13.1

[1] Min = minimum.

[2] Max = maximum

Table 5.

On and off-farm contribution (expressed as % at batch level, 327 batches) for each impact category.

	GW[1]	AC[2]	EU[3]	CED[4]	LO[5]
On-farm					
Herd management[6]	47 ± 8	61 ± 5	35 ± 5	7 ± 4	< 1
Feed on-farm[7]	10 ± 4	14 ± 4	25 ± 7	10 ± 8	28 ± 11
Total	57 ± 10	75 ± 6	60 ± 9	17 ± 11	28 ± 11
Off-farm					
Feed off-farm[8]	25 ± 7	22 ± 6	37 ± 8	47 ± 9	67 ± 12
Transport off-farm feed[9]	15 ± 3	< 1	< 1	32 ± 4	< 1
Industrial materials[10]	1 ± 1	1 ± 1	3 ± 4	< 1	1 ± 1
Bedding materials[11]	2 ± 2	2 ± 2	< 1	4 ± 4	4 ± 4
Total	43 ± 10	25 ± 6	40 ± 9	83 ± 11	72 ± 11

[1] GW = global warming potential, IPCC (2006) method.

[2] AC = Acidification potential, IPCC (2006) method.

[3] EU = Eutrophication potential.

[4] CED = Cumulative Energy Demand.

[5] LO = Land Occupation.

[6] Herd management: emissions due to enteric methane, manure management and fuel used for herd management.

[7] Feed on-farm: emissions due to manure spreading and to production and use of fertilizers, pesticides, seeds and fuel used for crop production and post-crop production steps and transport from regional warehouse.

[8] Feed off-farm: emissions due to production of off-farm feed production.

[9] Transport off-farm feed: emissions due to transport of off-farm feed.

[10] Industrial materials: emissions due to production and use of plastic and lubricant used.

[11] Bedding materials: emissions due to production of various bedding materials.

Table 6.

Least squares means of beef category for environmental impact of 1 kg body weight gained (BWG) (N = 327 batches).

Impact category	Unit	Beef category					RMSE	P-value
		CH [1]	IRE [2]	IF [3]	HEI[4]	LIM [5]		
Global warming potential	kg CO_2-eq	7.9 ^{a}	7.9 ^{a}	8.3 ^{b}	9.3 ^{c}	8.6 ^{b}	0.4	***
Acidification potential	g SO_2-eq	190 ^{a}	195 ^{a}	207 ^{b}	248 ^{c}	214 ^{b}	14	***
Eutrophication potential	g PO_4-eq	64 ^{a}	65 ^{a}	70 ^{b}	82 ^{c}	71 ^{b}	4	***
Cumulative energy demand	MJ	62 ^{a}	63 ^{a}	65 ^{a}	72 ^{b}	72 ^{b}	4	***
Land occupation	m^2/year	8.9 ^{a}	9.2 ^{a}	9.5 ^{b}	11.1 ^{c}	10.0 ^{b}	0.6	***

[1] CH = Charolais bulls; [2] IRE = Irish crosses bulls; [3] IF = Other French breeds and crosses, [4]HEI: Charolais or Limousin beef heifers, [5] LIM = Limousin bulls.

Level of significance (P-value): *** P<0.001.

^{a,b} Values within a row with different superscripts differ significantly at P<0.05

Appendix to Chapter 1

Supplementary Tables to the Chapter 1

Supplementary Table S1.

Manure management systems (values in percentage) per beef category (N = 327 batches).

Beef category	Manure management	
	MS[1] (S,k) slurry (%)	MS (S,k) solid manure (%)
CH [2]	0.53 ± 0.21	0.47 ± 0.21
IRE [3]	0.58 ± 0.20	0.42 ± 0.20
IF [4]	0.56 ± 0.11	0.44 ± 0.11
HEI [5]	0.51 ± 0.03	0.49 ± 0.03
LIM [6]	0.50 ± 0.08	0.50 ± 0.08
Total	0.53 ± 0.18	0.47 ± 0.18

[1] $MS(_{S,k})$: fraction of animals handled using manure management S

[2] CH = Charolais bulls; [3] IRE = Irish crosses bulls; [4] IF = Other French breeds and crosses, [5] HEI: Charolais or Limousin beef heifers, [6] LIM = Limousin bulls.

Supplementary Table S2.

Diet composition (mean ± SD) per beef category calculated for the sample of 327 batches reared in intensive beef fattening farms (expressed as kg DM/head/day).

Beef category	CH[1]	IRE[2]	IF[3]	HEI[4]	LIM[5]
Maize silage	3.33 ± 0.87	2.87 ± 0.85	4.12 ± 0.71	3.33 ± 0.22	2.50 ± 0.82
Triticale silage	0.06 ± 0.15	0.04 ± 0.11	0.10 ± 0.22	0.59 ± 1.02	0.03 ± 0.06
Sorghum silage	0.04 ± 0.15	0.07 ± 0.19	0	0.34 ± 0.32	0.09 ± 0.20
Maize ears silage	0.17 ± 0.45	0.14 ± 0.39	0	0	0
Maize grain silage	0.73 ± 0.89	0.64 ± 0.66	0.28 ± 0.38	1.29 ± 1.15	1.09 ± 1.00
Sugar beet pulp dried	0.74 ± 0.56	0.66 ± 0.70	0.65 ± 0.50	0.16 ± 0.07	0.63 ± 0.77
Sugar beet pulp pressed	0.30 ± 0.48	0.30 ± 0.33	0.17 ± 0.87	0.16 ± 0.27	0.23 ± 0.40
Maize grain	1.75 ± 0.95	1.97 ± 1.05	1.84 ± 0.73	0.53 ± 0.92	1.01 ± 1.20
Hay	0.06 ± 0.14	0.03 ± 0.07	0.11 ± 0.24	0.03 ± 0.04	0.06 ± 0.07
Straw	0.35 ± 0.21	0.43 ± 0.32	0.29 ± 0.27	0.39 ± 0.23	0.39 ± 0.18
Alfalfa hay	0.44 ± 0.37	0.41 ± 0.29	0.40 ± 0.39	0.32 ± 0.32	0.33 ± 0.34
Soybean meal	0.24 ± 0.29	0.31 ± 0.39	0.40 ± 0.65	0.39 ± 0.32	0.23 ± 0.29
Sunflower meal	0.04 ± 0.15	0	0	0	0
Wheat bran	0.05 ± 0.11	0.01 ± 0.04	0.01 ± 0.03	0.06 ± 0.06	0.04 ± 0.05
Barley flour	0.04 ± 0.12	0.05 ± 0.16	0	0	0
Maize distiller	0.17 ± 0.39	0.12 ± 0.23	0.37 ± 0.60	0.24 ± 0.42	0.12 ± 0.27
Maize gluten meal	0.62 ± 0.47	0.78 ± 0.39	0.46 ± 0.48	0.28 ± 0.48	0.74 ± 0.46
Fat	0.05 ± 0.05	0.07 ± 0.09	0.03 ± 0.04	0	0.14 ± 0.15
Cotton seed	0.04 ± 0.17	0	0	0.19 ± 0.33	0.15 ± 0.34
Protein mineral supplement	1.01 ± 0.47	1.13 ± 0.66	0.94 ± 0.46	0.31 ± 0.29	1.44 ± 0.75

[1] CH = Charolais bulls; [2] IRE = Irish crosses bulls; [3] IF = Other French breeds and crosses, [4] HEI: Charolais or Limousin beef heifers, [5] LIM = Limousin bulls.

Supplementary Table S3.

Greenhouse gases emission and energy use factors for agricultural inputs (pesticides and seeds production) used for crop production in the sample of 16 beef fattening farms.

Product	EF[1]	Unit	Reference
Pesticides			
Pesticides	22.0	Kg CO_2-eq / kg	2
Herbicides	22.8	MJ / kg	3
Insecticides and fungicides	24.5	MJ / kg	3
Seeds			
Seeds	0.3	Kg CO_2-eq / kg	2

1 EF= Emission factor.

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Supplementary Table S4.

Agricultural inputs (kg/ha) and yield (t DM/ha) per on-farm crop for the 16 North-Eastern beef fattening farms, expressed as mean ± SD.

Crop[1]	Sugar beet	Alfalfa hay	Wheat[2]	Maize	Barley[2]	Sorghum	Triticale
Farms	2	1	5	15	1	3	2
N slurry	69 ± 98	0	82 ± 75	79 ± 82	170	0	29 ± 40
N solid manure	73 ± 103	0	7 ± 15	98 ± 49	0	126 ± 46	98 ± 40
P_2O_5 slurry	12 ± 17	0	15 ± 13	15 ± 14	31	0	5 ± 7
P_2O_5 solid manure	12 ± 13	0	1 ± 2	20 ± 16	0	21 ± 7	17 ± 8
N mineral	90 ± 42	0	80 ± 91	142 ± 5	56	131 ± 21	200
P_2O_5 mineral	10 ± 14	0	9 ± 12	11 ± 25	0	5 ± 5	35 ± 1
K_2O mineral	0	0	0	10 ± 26	0	0	2 ± 3
Pesticides	39	0	5 ± 3	8 ± 7	11	0	4
Herbicides	10	0	2 ± 2	6 ± 3	9	0	3
Fuel	105	145	106	151	106	106	106
Seed	30 ± 1	15	27	20 ± 1	27	22 ± 8	27 ± 1
Yield	14 ± 5	10.9	4 ± 1	17 ± 5	4.3	12 ± 2	19 ± 1

[1] A nitrogen deposition rate of 20 kg N/ha/year was applied to all types of crop.

[2] Wheat straw, barley grain. Economic allocation between grain and straw: 40% and 44% of impacts allocated to straw (wheat and barley respectively). Economic prices derived from farms data.

Supplementary Table S5.

Industrial and bedding materials used by the 16 North-Eastern beef fattening farms.

Farm	Heads/day[1]	Plastic	Lubricant	Fuel	Electricity	Bedding materials		
						Straw	Maize stover	Sawdust
		kg/year	kg/year	kg/year	kWh/year	kg/year	kg/year	kg/year
1	1009	786	411	22033	83561			
2	239	1030	180	9898	15213	47500		40000
3	803	801	324	30535	14783	50000		
4	699	1200	720	43375	11049	105000	105000	
5	581	206	210	17000	40729	88382		
6	1039	920	302	42338	76320	241900	38700	
7	245	200	120	10180	7700	85102		
8	441	118	252	21771	4875	178310	138500	
9	902	1060	108	17910	15796	204123		
10	815	1600	200	9928	39885	120000		
11	497	400	258	22755	4339	60000		
12	921	506	400	36118	19562	547200		
13	241	147	152	4822	3618	92275		
14	852	248	325	17612	31769	75000		61880
15	544	440	317	10200	17574	164250		
16	300	3520	606	12488	9712	403200		

[1] Heads/day: average number of young bulls presented into the farm per day

Supplementary Table S6.

Pearson's correlation factors for impact categories calculated for the sample of 327 batches reared in intensive beef fattening farms(all statistically significant with $P<0.001$).

	GW [1] IPCC (2006)	GW [1] Ellis *et al.* (2007)	GW [1] Moraes *et al.* (2014)	AC [2] IPCC, (2006)	AC [2] EEA, (2013)	AC [2] ISPRA (2011)	EU [3]	CED [4]	LO [5]
GW [1] $_{\text{IPCC}}$									
GW [1] $_{\text{ELLIS}}$	0.99								
GW [1] $_{\text{MORAES}}$	0.99	0.99							
AC[2] $_{\text{IPCC}}$	0.87	0.90	0.90						
AC [2] $_{\text{EEA}}$	0.90	0.92	0.92	0.97					
AC [2] $_{\text{ISPRA}}$	0.93	0.92	0.93	0.95	0.96				
EU [3]	0.90	0.91	0.92	0.95	0.97	0.96			
CED [4]	0.89	0.82	0.84	0.62	0.67	0.76	0.68		
LO [5]	0.87	0.86	0.88	0.83	0.83	0.87	0.90	0.70	

[1] GW = Global warming.

[2] AC = Acidification.

[3] EU = Eutrophication.

[4] CED = Cumulative Energy Demand.

[5] LO = Land Occupation.

Supplementary Table S7.

Effect of farm on global warming impact category (kg CO_2 –eq/kg body weight gained; Least squares means and RMSE from GLM model), for 327 batches reared in intensive beef fattening farms.

Farm	GW [1] IPCC (2006)	Farm	GW [1] Ellis *et al* (2007)	Farm	GW [1] Moraes *et al* (2014)
1	5.2 ^{a}	1	5.5 ^{a}	1	6.0 ^{a}
2	7.7 ^{b}	3	8.2 ^{b}	3	8.8 ^{b}
3	7.7 ^{b}	5	8.2 ^{b}	5	8.8 ^{b}
4	7.9 ^{b}	2	8.4 ^{bc}	2	8.9 ^{bc}
5	7.9 ^{b}	7	8.7 ^{bc}	7	9.3 ^{c}
6	8.1 ^{bc}	6	8.9 ^{c}	4	9.4 ^{c}
7	8.3 ^{bc}	4	8.9 ^{c}	9	9.5 ^{c}
8	8.4 ^{c}	9	9.0 ^{c}	6	9.5 ^{c}
9	8.5 ^{c}	8	9.3 ^{cd}	11	9.6 ^{cd}
10	8.6 ^{cd}	10	9.3 ^{cd}	10	9.9 ^{cd}
11	8.7 ^{cd}	11	9.3 ^{cd}	8	9.9 ^{cd}
12	8.9 ^{d}	12	9.5 ^{d}	12	10.3 ^{d}
13	9.3 ^{de}	13	10.1 ^{de}	14	11.0 ^{de}
14	9.4 ^{de}	14	10.3 ^{de}	13	11.0 ^{de}
15	9.8 ^{e}	16	10.6 ^{e}	16	11.2 ^{e}
16	9.9 ^{e}	15	10.6 ^{e}	15	11.4 ^{e}
RMSE	0.4		0.5		0.5
P-value	***		***		***

[1] GW: Global warming potential

Level of significance (P-value): *, P<0.05; **, P<0.01; ***, P<0.001.

^{a,b} Values within a row with different superscripts differ significantly at *P*<0.05.

Supplementary Table S8.

Effect of beef category on global warming and acidification impact categories, expressed per kg body weight gained (Least squares means and RMSE from mixed model), at batch level (327 batches), for different computation methods.

Impact categories	Unit	Beef category					RMSE	P-value
		CH [1]	IRE [2]	IF [3]	HEI[4]	LIM [5]		
GW [6], IPCC (2006)	kg CO_2-eq	7.9 ^{a}	7.9 ^{a}	8.3 ^{b}	9.3 ^{c}	8.6 ^{b}	0.4	***
GW [6], Ellis et al (2007)	kg CO_2-eq	8.3 ^{a}	8.3 ^{a}	8.8 ^{b}	10.6 ^{c}	9.3 ^{b}	0.5	***
GW [6], Moraes et al (2014)	kg CO_2-eq	8.8 ^{a}	8.9 ^{a}	9.5 ^{b}	11.2 ^{c}	9.9 ^{b}	0.5	***
AC [7], IPCC (2006)	g SO_2-eq	190 ^{a}	195 ^{a}	207 ^{b}	248 ^{c}	214 ^{b}	14	***
AC [7], EEA (2013)	g SO_2-eq	149 ^{a}	152 ^{a}	163 ^{b}	191 ^{c}	164 ^{b}	10	***
AC [7], ISPRA (2011)	g SO_2-eq	137 ^{a}	141 ^{a}	149 ^{b}	174 ^{c}	156 ^{b}	10	***

[1] CH = Charolais bulls; [2] IRE = Irish crosses bulls; [3] IF = Other French breeds and crosses, [4] HEI: Charolais or Limousin beef heifers, [5] LIM = Limousin bulls.

[6] GW: Global warming potential

[7] AC: Acidification potential

Level of significance (P-value): *, P<0.05; **, P<0.01; ***, P<0.001.

[a,b] Values within a row with different superscripts differ significantly at *P*<0.05.

Supplementary Table S9.

Impact categories results expressed per kg body weight gained (BWG), at farm level (16 farms).

Farm	GW [1]	AC [2]	EU [3]	CED [4]	LO [5]
	kg CO_2-eq	g SO_2-eq	g PO_4-eq	MJ	m^2/y
1	5.3 ± 0.4	156 ± 17	46 ± 5	31 ± 3	6.3 ± 0.6
2	7.3 ± 0.3	166 ± 9	51 ± 3	61 ± 3	7.6 ± 0.4
3	7.3 ± 0.3	176 ± 15	61 ± 4	53 ± 3	9.0 ± 0.7
4	7.5 ± 0.4	183 ± 14	64 ± 5	45 ± 2	8.1 ± 0.6
5	7.4 ± 0.2	160 ± 7	52 ± 2	63 ± 3	7.2 ± 0.3
6	7.8 ± 0.7	211 ± 23	72 ± 7	52 ± 9	9.8 ± 0.9
7	7.8 ± 0.3	194 ± 11	69 ± 4	67 ± 3	12.4 ± 0.6
8	7.9 ± 0.3	211 ± 10	72 ± 3	63 ± 3	8.5 ± 0.4
9	8.1 ± 0.4	201 ± 12	64 ± 4	68 ± 4	8.1 ± 0.4
10	8.4 ± 0.9	183 ± 21	63 ± 7	67 ± 9	9.7 ± 1.1
11	9.6 ± 0.7	248 ± 20	79 ± 7	65 ± 5	10.9 ± 0.8
12	8.8 ± 0.4	227 ± 14	74 ± 4	82 ± 7	9.3 ± 0.6
13	8.9 ± 1.2	229 ± 44	76 ± 15	74 ± 15	10.0 ± 1.9
14	8.9 ± 0.3	207 ± 9	68 ± 3	76 ± 3	9.9 ± 0.4
15	9.3 ± 0.3	208 ± 8	74 ± 3	83 ± 3	10.8 ± 0.4
16	9.4 ± 0.4	226 ± 11	84 ± 4	83 ± 4	11.5 ± 0.5

[1] GW = global warming potential, IPCC (2006) method.
[2] AC = Acidification potential, IPCC (2006) method.
[3] EU = Eutrophication potential.
[4] CED = Cumulative Energy Demand.
[5] LO = Land Occupation.

Chapter 2

Environmental footprint of the integrated France-Italy beef production system assessed through a multi-indicator approach

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Abstract

This study aims to evaluate the environmental footprint of the integrated France-Italy beef production system (extensive grassland-based suckler cow-calf farms in France with intensive cereal-based fattening farm in northeastern Italy) using a multi-indicator approach, which combines environmental impact categories computed with a cradle-to-farm gate Life Cycle Assessment, and food-related indicators based on the conversion of gross energy and protein of feedstuffs into raw boneless beef. The system boundaries were set from the calves' birth to their sale to the slaughterhouse, including the herd management, on- and off-farm feed production and materials used on the farms. One kilogram of body weight (BW) sold was used as the functional unit. The study involved 73 Charolais batches (i.e., a group of animals homogenous for age, finishing period and fattening farm), kept at 14 Italian farms. Data from 40 farms originating from the Charolais Network database (INRA) were used to characterize the French farm types, which were matched to the fattening batches according to the results of a cluster analysis. The impact categories assessed were as follows (mean ± SD per kg BW): global warming potential (GWP, 13.0±0.7 kg CO_2-eq, reduced to 9.9±0.7 kg CO_2-eq when considering the carbon sequestration due to French suckler cow-calf system permanent grassland), acidification potential (AP, 193±13 g SO_2-eq), eutrophication potential (EP, 57±4 g PO_4-eq), cumulative energy demand (CED, 36±5 MJ), and land occupation (LO, 18.7±0.8 m^2/year). The on-farm impacts outweighed those of the off-farm activities, except in the case of CED. On average, 41 MJ and 16.7 kg of dietary feed gross energy and protein were required to provide 1 MJ or 1 kg of protein of raw boneless beef, respectively, but nearly 85% and 80%, respectively, were derived from feedstuffs not suitable for human consumption. Emission-related (GWP, AP, EP) and resource utilization categories (CED, LO) were positively correlated. Food-related indicators showed positive correlations with emission-related indicators when the overall feedstuffs of the diet were considered but negative correlations when only the human-edible portions of the beef diets were considered. In conclusion, the integration of the pasture-based France suckler cow-calf system with the cereal-based Italian fattening farms allows for the exploitation of the resources available, increasing the share of non-human-edible feedstuffs while maintaining good livestock productive efficiency. Combining indicators of impact categories with indicators of feed net supply may improve the assessment of the environmental footprint of livestock systems.

Keywords livestock farming system, multi-indicator approach, environmental impact, conversion efficiency, Life Cycle Assessment

Introduction

Several studies have recognized beef production systems as important contributors to agricultural emissions of climate-altering, acidifying and eutrophying compounds, as well as to the exploitation of natural resources (Steinfeld et al., 2006; de Vries and de Boer, 2010, Gerber et al., 2013). At the same time, beef production systems produce a variety of positive outputs, contribute to food security and to the recycling of nutrients contained in feeds non-edible by humans into high-protein food of valuable nutritional quality (Oltjen and Beckett, 1996; Schiere et al., 2002; FAO, 2007; Ertl et al., 2016).

Different methods have been developed to evaluate the sustainability of the livestock sector, ranging from farm characteristics predictors to effect-based indicators (Lebacq et al., 2013). Among these, Life Cycle Assessment (LCA; ISO, 2006; Finnveden et al., 2009) has emerged as one of the most suited methodologies for evaluating the environmental impact of livestock systems (De Vries and de Boer, 2010; Lebacq et a., 2013). However, the LCA methodology usually does not account for some essential benefits of the beef production systems, such as the contribution to food security and the diverting of non-human-edible foodstuffs to animal feeding (Gill et al., 2010; Wilkinson, 2011). Therefore, approaches based on the use of different indicators could improve the assessment of livestock systems, particularly when different agro-ecosystems are involved in the production cycle (Cucek et al., 2012; Röös et al., 2013). This is the case in the integrated France-Italy beef production system. This system is characterized by a geographical separation of the grassland-based suckler cow-calf phase, mainly located in the French Massif Central semi-mountainous area (Brouard et al., 2014), and the intensive, cereal-based fattening phase, located in northeastern Italy, where intensive beef fatteners import the young bulls and rear them using total mixed rations based on maize silage and concentrates (Gallo et al., 2014). Different surveys have described various aspects of the system (Xiccato et al., 2005; Sturaro et al., 2009; Brouard et al., 2014; Gallo et al., 2014), but a comprehensive assessment of its environmental footprint is still lacking.

The aim of this study was to evaluate the environmental footprint of the integrated France-Italy beef production system using a multi-indicator approach, which combines emission-related - global warming (GWP), acidification (AP) and eutrophication (EP) potentials - and resource utilization - cumulative energy demand (CED) and land occupation (LO) - impact categories computed using a cradle-to-farm gate LCA methodology with food-related indicators (gross energy and protein conversion ratio and competition with direct human use of human-edible feedstuffs).

Materials and Methods

Goal and scope definition

The parameters of the LCA model for assessing the environmental footprint of the integrated France-Italy beef production system were set as follows. A cradle-to-farm gate LCA model was considered, taking into account the fattening batch as reference unit. The batch is defined as a group of stock calves, homogeneous for genetic type, origin, finishing herd, fattening period and characteristics of the diet. The time period of each batch consisted of the whole productive cycle, from the birth of the calves to the sale of beef bulls to the slaughterhouse. Therefore, the system boundaries included the French suckler cow-calf herd, the Italian fattening phase and the transport from France to Italy. The impacts due to the herd management, the production of on- and off-farm feedstuffs, the production and use of industrial (fuel, plastic, lubricant) and bedding materials and the transport of inputs and animals (Figure 1) were taken into account for both the French suckler cow-calf and the Italian fattening phases. The impact categories assessed were GWP, AP, EP, CED and LO and their magnitude was reported to 1 kg of body weight (BW) sold, which was taken as the functional unit. Land occupation was partitioned according to the agronomic destination: land surface area maintained as grassland (LO grass), land surface area cultivated for producing feedstuffs directly used for feeding animals (LO cropland), and the share of land surface area economically allocated to the production of agricultural by-products used in the beef diets (LO by-products).

Being the suckler cow-calf phase a multi-functional system producing more than one product, such as weaned male and female calves and cull cows, the allocation problem was resolved applying a mass allocation method. As the results of the LCA approach could be influenced by the allocation method chosen (ISO, 2006), a sensitivity analysis was performed by also considering an allocation of the impacts based on a protein method (relative importance of the protein in BW sold) and an economic method (relative importance of the revenue obtained by the sale of animals). For details, see Supplementary Table 1.

Life Cycle Inventory and Life Cycle Impact Assessment

Data collection and editing for the northeastern Italy fattening sector

The starting Italian dataset included 137 Charolais young bull batches. As the usual calving period in the French suckler cow-calf system is concentrated between November and April (Brouard, 2014), for this study, only the Italian batches of young bulls born in these months were retained. This editing provided 73 batches involving 4882 animals herded in 14 intensive beef fattening farms in northeastern Italy. For each farm, the land surface area used for the production of feedstuffs and the spreading of manure, the herd size, the use of chemical fertilizers and concentrates, and the amount of bedding materials, fuel, plastic and electricity consumed were collected by a unique operator through farm visits. The allocation of the different inputs to each batch within the farm was based on the utilization of each on-farm feed into the diet (agricultural inputs) and on the average amount of input per animal and per day (bedding and industrial inputs). Information collected for each batch included the number of animals, the purchase and sale dates and BW at the purchase in France (BWS), at the arrival to the Italian fattening farm (BWI) and at the end of the finishing period (BWF). The average daily gain (ADG, kg/day) was calculated as the difference between BWF and BWI divided by the total animal presence (animals x days).

Diet formulation and feed allowance, assumed equal to feed intake, were collected monthly for each diet used within each farm. All diets were sampled at the manger for the chemical composition analysis. Crude protein, ether extracts, crude fiber, ash, starch, neutral detergent fiber and non-starch carbohydrate content were assessed using the near-infrared spectroscopy method, whereas phosphorus (P) content was assessed according to the AOAC procedure (AOAC 999.10, 2000 and ICP-OES). Total monthly feed intake was calculated for each batch as the mean of two subsequent recorded daily feed intakes multiplied by the number of days between the two recordings. The feed intake in the period following the arrival of the batch at the farm was assumed equal to that of the first record, and that in the period preceding the sale of the batch to the slaughterhouse was assumed equal to the last recorded. The total feed intake for each batch (kg DM) was calculated as the sum of the monthly feed intakes and referred to the entire fattening period (sale date – arrival date), and the daily dry matter intake (DMI, kg DM/animal/day) was computed as the total feed intake divided by the length of the fattening period. The share of the maize silage in the DMI and the share of the dry matter ration produced on-farm (self-sufficiency rate) were also computed for each batch. Descriptive statistics of the Italian beef fattening farms and of the main traits of beef batches are given in Table 1, whereas the composition and characteristics of fattening diets are shown in Supplementary Tables 2 and 3, respectively, and the agricultural inputs for on-farm feedstuffs production are given in Supplementary Table 4.

The gross and digestible energy contents of the diets were calculated according to INRA (2007). The nitrogen (N) input-output flow was calculated for each batch according to the guidelines for the calculation of manure N production to be used within the framework of the European Union (EU) Nitrates Directive (Ketelaars and Van der Meer, 1999). The N intake was computed as the average daily DMI x finishing duration x average N content of the diet; the N retention was ((BWF – BWI) x 0.027 kg N/kg BW); and the N excretion was the difference between N intake and N retention. The excretion of P was calculated using the same procedure, with the average P dietary content and a retention factor of 0.0075 kg P/kg BW (Whiters et al., 2001).

Connection of the French beef suckler cow-calf and Italian beef fattening databases

The French data originated from the Charolais Network database of the INRA (Liénard et al., 1998) and concerned 40 suckler cow-calf farms surveyed annually. As stock calves from French beef suckler herds are usually collected by brokers who set up batches to be sold to Italian fatteners, it was impossible to establish a direct connection between a specific French suckler cow-calf herd and a specific Italian fattening batch. With the aim of joining the French and Italian phases, the following procedure was developed. Since the main beef classification criteria for setting up homogeneous batches at the sale to Italy is the BWS, and the farm management in France is strongly linked to the calving period, these variables were used as classification criteria for clustering. The age at sale was also considered to obtain homogenous groups. A cluster analysis (PROC FASTCLUS procedure, SAS, 2012) of the fattening batches based on calving date, BWS and age at the sale to Italy was first performed. This analysis grouped the batches into three clusters differing mainly for calving season, i.e., early (November/December), mid (January/February), and late (March/April) winter. Descriptive statistics for the BWS, age and ADG of the three clusters are given in

Supplementary Table 5. Then, the French farms were classified into 3 classes according to their predominant calving season and were connected to the Italian clusters having the same calving season (e.g., French farms having predominantly early winter calving season were connected with the early winter calving season cluster of batches). Finally, for each suckler cow-calf farm, the beef calves were classified as suitable to be retained in the Italian cluster (IT_CALV) according to the following criteria: i) calving dates included within the interval of the connected calving season; ii) BWS and age at sale included within the average ± 1 standard deviation for BWS and age of the corresponding Italian cluster. The remaining beef calves of each suckler cow-calf farm were classified as sold to other destinations (NOT_IT_CALV). All French farms with less than 50% of IT_CALV were excluded from the analysis. The final French data set included 21 farms (10 early, 7 mid, and 4 late winter calving seasons). The average farm data for each class of calving season were used to create the three suckler cow-calf farm types used to calculate the impact category values for the French suckler cow-calf system.

Suckler cow-calf herd system

The French suckler cow-calf system was modelled using farm observations available from yearly surveys in the INRA Charolais Network (Lienard et al., 1998). For each suckler cow-calf farm type, data about herd management, the use of inputs (concentrates, fertilizers, fuel, plastic, bedding straw), land surface area (extension of grassland, percentage of grassland area destined to hay and grass silage, extension of maize cropland) and outputs were used (Table 2). The herd management was modelled to have a steady-state situation during 1 year and to account for the farm output, represented by the sale of the different animal categories (Figure 1). Suckler cows, (primiparous, secondiparous and multiparous, with a lactating and a not-lactating period), replacement heifers, breeding bulls and birth-to-weaning calves were included in the breeding stock unit (BR). Five animal categories resulted from the BR as outputs: IT_CALV, NOT_IT_CALV, female calves exceeding the replacement needs, cull cows and cull breeding bulls. Female and male calves exited from the BR at weaning, whereas cull cows exited at calf death or at calf weaning, according to the calves' mortality and the replacement rates. A pre-fattening period (from weaning to the sale) was considered for IT_CALV and NOT_IT_CALV to produce calves with BW and an age comparable to those found in the fattening herds of the destination. During finishing, primiparous and multiparous cull cows were assumed to gain 1.20 and 1.30 kg BW/d, respectively (INRA technical staff, personal communication), whereas the duration of the finishing period was set to achieve a mean BW at culling comparable to the values found for this category in each French farm type. The age and average BW at the sale of the post-weaned heifers intended for meat production were determined according to the average proportion of heifers sold at 1, 2 or 3 years of age found in each farm type. Total feed intake for each French farm type (tDMI, kg DM/herd; see Supplementary Table 6a, 6b, 6c) was calculated as follows: using the data from Nguyen et al. (2012) we assumed a feed intake of 5000 kg DM/year for a livestock unit (LU), defined as a suckler cow of 750 kg BW. This value was adjusted to the average BW of suckler cows found in each French farm type, and then multiplied by the number of LU to obtain the tDMI of each farm type. The tDMI was then partitioned into each animal category on the basis of the share of each category to the total LU of each farm type.

The diet composition was split between the summer (pasture, from 1st April to 30th October) and the winter periods (from 1st November to 31st March), according to the most common management practices observed in Central France (Brouard et al., 2014). The summer diet of all the animals, with the exception of the calves, was based only on grass at pasture, and the intake was calculated at the month level as (Feed Intake Capacity / Grass Fill Unit) x 0.9 (INRA, 2007). The values for feed intake capacity were calculated using the equation 0.035 x

$(BWm)^{0.9}$ (Brouard et al., 2014), where BWm was the monthly mean BW, whereas the values for the grass fill unit were obtained from INRA (2007). Winter diets were based on the rations available in Brouard et al. (2014), and the intake of winter DM was computed as the difference between the tDMI and the summer DMI.

Weaning of calves was assumed to occur at 256 d of age, and pre-weaning winter and summer diets were modelled using information from Brouard et al. (2014), considering the growth rate, the sex and the relative use of concentrates observed in each French farm type. The chemical composition of summer and winter diets for all the animal categories was calculated according to INRA (2007), whereas nitrogen and P input/output flows were estimated according to the same procedure used for the Italian phase, deriving the nitrogen content in the BW from Garcia et al. (2010).

Computation of emissions, energy and land occupation

The impacts were assessed taking into account the on- and off-farm activities. The LCA model was applied to the suckler cow-calf and the fattening phases independently, and the impact computed for the French suckler cow phase was added to that calculated for the Italian fattening phase for each batch through the calculation of a BW-based factor (e.g., kg CO_2-eq / kg BW pre-fattened young bull sold to Italian fattening farms) for each impact category and each French farm type. Afterwards, the BW-based factor was multiplied by the batch total BWS according to the cluster in which the batch was inserted.

On-farm impact calculation

Equations for emission calculations related to the French suckler cow-calf and Italian fattening phases are shown in Supplementary Table 7. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) contributed to GWP. Emissions derived from manure management

(CH_4 and N_2O) and agricultural soils (N_2O) were calculated using the International Panel on Climate Change (IPCC, 2006) Tier 2 equations. Computation of the enteric CH_4 production was based on equation 9 proposed by Sauvant et al. (2011), for which the emission was a function of the daily DMI expressed as a percentage of the mean BW, moderated by the percentage of concentrates in the diet. The acidification potential category considered the impacts due to emissions of ammonia (NH_3), nitrogen oxides and sulphur dioxide (SO_2) that occurred at the barn, manure storage and crop fertilization and were computed using equations derived from IPCC (2006). Concerning the suckler cow-calf phase, the winter manure management was based on a deep bedding system (no mixing), whereas during summer, animal manure was deposited directly on the pasture. During the fattening period, the manure management systems were differentiated for each farm as either slurry or solid manure.

The leaching of N and the loss of P at soil level were assessed for determining the EP; the former was calculated as the difference between N input and N output (N harvested and lost into atmosphere) for cropland and using the equation proposed by Vertès et al. (1997) for grassland, while P loss was calculated using the equations derived from Nemecek and Kägi (2007).

The impact factors (IF) for agricultural inputs (fertilizers, pesticides, fuel, seeds) used for producing on-farm feedstuffs were derived from Ecoinvent (Ecoinvent Centre, 2015) and Agri-footprint (Blonk Agri-footprint, 2014) databases. The land surface area for each on-farm feedstuff (at suckler cow-calf and fattening step) was recorded and used for assessing the land use impact. Moreover, fuel used for handling animals was considered an on-farm input and IF values were derived from EEA (2013) and the Ecoinvent database. The conversion of each pollutant compound into the common unit for the impact category, relative to GWP, AP and EP, was based on the factors derived from Myhre et al. (2013) for GWP (common unit kg

CO_2-eq; conversion factor: CO_2: 1, CH_4: 28, N_2O: 265) and Guinée et al. (2002) for AP and EP (SO_2-eq - SO_2: 1, NH_3: 1.88, NO_x: 0.7 and PO_4-eq - NO_x: 0.13, NH_3: 0.35, NO_3: 0.43, P: 3.06, respectively).

Off-farm impact assessment

The off-farm impacts encompassed purchased-feed production, industrial inputs production and use at farm level and transport of the different inputs (including transport of pre-fattened young bulls from central France to northeastern Italy). For the suckler cow-calf phase, France was considered the origin zone for wheat grain; soybean meal used during the suckler cow-calf and fattening periods was assumed to arrive from Brazil via Rotterdam; off-farm maize grain, maize and sugar beet by-products used during the Italian fattening period were assumed to come from the Ukraine (farmers' communication). The impact factors were derived by Ecoinvent and Agri-food print databases (economic allocation), except for the fuel refinement IF (O'Brien et al. 2010) and the electricity IFs, which were derived from Veysset et al. (2011) for the French suckler cow-calf step and from Caputo and Sarti (2015) for the Italian fattening step.

Carbon sequestration in permanent grassland

As permanent grasslands are reported to act as carbon sinks, the offsetting of GHG emissions should be taken into account for grassland-related farm systems (Gac et al., 2010; Soussana et al., 2010). Estimated values for the carbon sequestration capacity in different regions and ecological-climatic conditions have been reported (Schulze et al., 2009; Soussana et al., 2010). In this study, a carbon sequestration value of 570 kg C/ha/year was used, a value proposed as a mean value for the French permanent grasslands systems (Dollé et al., 2013).

Conversely, the net carbon change of cropland soils in northeastern Italy has been assumed to be equal to zero.

Energy and protein feed conversion ratio

The efficiency to convert the gross energy and protein content of feeds into raw boneless beef has been used as food-related indicators for the integrated France-Italy beef production system.

The energy and protein (CP) content of feedstuffs were computed according to INRA (2007). The computation of the human-edible fraction of the beef diets was based on the human-edible factors derived from Wilkinson (2011). The contribution of the French and Italian phase to the overall gross energy and crude protein consumption, as well as to that due to the human-edible fraction, was computed according to the same procedures used in the partition of emissions.

The beef raw boneless yield was computed considering a carcass yield of 0.59 (Valance et al., 2014) and a boneless fraction of the carcass of 0.81 (Wilkinson, 2011). The gross energy and protein content of the raw boneless beef were derived from the National Nutrient database for Standard Reference (USDA, 2013), using an average fat content of 16% (Albertí et al., 2008). The values of 10.67 MJ gross energy/kg of edible beef and 182.7 g crude protein/kg of edible beef were considered.

The gross energy and protein conversion ratios of feedstuffs into raw boneless beef were computed considering both the overall feeds in the beef diets (E_CR and CP_CR, respectively) and the human-edible fraction only (HeE_CR and HeCP_CR, respectively).

Relationships between indicators

Relationships between emissions, energy, land occupation, and energy and protein feed conversion ratio were investigated at batch level using the Pearson's correlation factors (PROC CORR, SAS, 2012).

Results

The results obtained for the different impact categories are reported in Table 3. When compared to the Italian finishing phase, the French suckler cow-calf phase showed similar AP values, 15% and 48% greater EP and GWP values, respectively, but a much lower CED value. The French suckler cow-calf phase also exhibited a nearly 3.5 times greater LO value than the Italian phase. The vast majority of the total LO for the whole beef production cycle was grassland (78%), located in France, whereas the cropland area was mainly located in Italy. When the system was enlarged to consider the carbon storage function of the permanent grassland, the mean GWP for the whole production cycle decreased by nearly 24% (9.9±0.7 kg CO2-eq/kg BW, mass allocation method), with a nearly equal share for the French and Italian phases. The sensitivity analysis applied to the allocation method used to resolve the multi-functionality within the French suckler cow-calf system showed that the use of different allocation methods led to different absolute impact values, with the lowest figures for the impact categories estimated with the mass allocation method compared to the economic and protein methods (from 0% to +6% and from +12% to +17%, respectively).

Taking into account the contribution of the different production steps (Table 4), the impacts related to the on-farm activities largely outweighed those ascribed to off-farm activities for all the impact categories (the on-farm share ranged from 77% to 87% of the total impacts), except for the CED (25%). The large contribution of the on-farm activities to the overall impacts was firstly due to the importance of the French suckler cow-calf phase, which accounted for more than half the total emissions for GWP, AP and EP and for nearly three-quarters of the LO. Conversely, the share of the off-farm impact was dominated by the Italian fattening phase (75 to 90% of total off-farm impacts), which was responsible for more than half of the CED of the whole production cycle. Regarding the different production steps, the first contributor to GWP was the enteric CH_4 emission, obviously confined to the on-farm activities, followed by the feedstuffs production, irrespective of the impact origin (on- or off-farm). The transport, which was multi-connected especially with the off-farm feedstuffs production, had a notable share only for CED, whereas the contribution to the other impact categories was less important. The results for gross energy and protein conversion ratio are reported in Table 5. On average, the dietary feed gross energy requirement to provide one MJ of raw boneless beef was close to 41 MJ, which means that the energy conversion efficiency was close to 2.5%. However, when the gross energy requirement included only the human-edible fraction of the diet, the dietary feed gross energy requirement decreased to nearly 6.4 MJ. To provide 1 kg of CP in raw boneless beef, we found a dietary feed CP requirement of nearly 16.7 kg. Therefore, as expected, the conversion efficiency of dietary CP (close to 6%) was much greater than that of the dietary gross energy. On average, nearly 85% of the gross energy and nearly 80% of the CP required as feed to provide one unit of raw boneless beef derived from feedstuffs not suitable for human consumption.

The French suckler cow-calf phase accounted for nearly 70% of the overall gross energy and protein intake required to provide one unit of raw boneless beef. However, the Italian phase showed a greater consumption of human-edible feedstuffs and contributed to over 60% and 53% of the gross energy and protein intake of such feeds, respectively.

The impact categories (Table 6) were positively correlated (from $r=0.28$ to $r=0.93$, $P<0.01$), with greater values for the impact categories related to pollutant emissions (GWP, AP and EP) than for those related to resource utilization (CED and LO). The conversion ratio indicators showed strong positive correlations with emission-related impact categories (Pearson's r: from 0.50 to 0.82, P<0.001) when computed considering the overall feedstuffs used in the diet. Conversely, when only the human-edible part of the beef diets was considered, the feed conversion ratio was negatively correlated with the emission-related impact categories (-0.32 to -0.48, P < 0.001). The CED did not show a relationship with the feed conversion indicators, whereas LO was positively correlated only with CP food-related indicators.

Discussion

Emission-related impact categories

The emission-related impact categories assess the impact caused by the release of environmentally active compounds into the environmental compartments. Several studies have evaluated these impact categories concerning the beef production system using a cradle-to-farm gate LCA. The results for the GWP found in this study were comparable to those found for the fattened bulls in the French beef sector - 14.2 (Gac et al, 2010), 13.2 (Nguyen et al., 2012), 13.8 (Dollé et al., 2013) and 12.8 kg CO_2-eq/kg BW (Veysset et al., 2014) - and were in the range of values reported by other studies conducted in the European Union (EU) or extra-EU countries (de Vries et al., 2015). Concerning the other impact categories, the mean value found for AP was greater than those reported by Nguyen et al. (2012) and Lupo et al. (2013), probably due to the difference in the volatilization factors used, whereas EP was within the range of variation shown by other studies (Pelletier et al., 2010; Nguyen et al., 2012). Differences in emission values between the French and the Italian phases were evident for the GWP only. However, these differences disappeared when the carbon sequestration of the permanent grassland was included in the computation of the GWP.

Emissions due to on-farm activities largely exceeded those due to off-farm activities. This predominance was particularly evident for the French phase and can be explained considering that the main emission sources (enteric fermentation, manure management and on-farm feed production) are located within the farm. The beef production system typical of the French phase, which largely relies on grasslands with low input rates, tends to exacerbate the on-farm emission level of the suckler cow-calf phase, as the BW sold per LU is low and the roughage-based diets used for the suckler cows allocated to the pre-fattening young bulls increases the enteric fermentation emission (Sauvant et al., 2011; Crosson et al., 2011). Conversely, the more intensive and productive Italian fattening phase, while reducing the impacts per product unit, showed a lower diet self-sufficiency and a greater chemical fertilizer spreading (80 kg N/ha on-farm vs 20-34 kg N/ha for the Italian and French beef farms, respectively), which negatively affected the local nutrient balance.

When the carbon sequestration related to the French permanent grassland was considered, GWP found in this study was greater than that reported by Morel et al. (2016) (9.9 vs and 7.6-8.2 kg CO2-eq/kg BW), probably because the grassland surface area within the system in this study was lower than that found in Morel et al. (2016). The differences found in the carbon sequestration rate and in methods used to take into account the land-use change issue implicate a lack of standardization that has to be considered when including the carbon sequestration as a mitigation factor of GHG emissions due to the beef sector (Flysjö et al., 2011). Applying carbon sequestration values found in literature for the French permanent grasslands other than 570 kg C/ha/year which ranged from 200 kg C/ha/year (Dollé et al., 2009) to 780 kg C/ha/year (mean value derived from Allard et al., 2007), the net GWP found in this study ranged from 12.0 kg CO_2-eq /kg BW to 8.8 kg CO_2-eq /kg BW, respectively.

Resource utilization impact categories

The CED and LO categories are connected with the degree of resource use (ISO, 2006). The mean values for CED found in this study were comparable with values reported by Nguyen et al. (2012) and Pelletier et al. (2010) (35 and 38 MJ/kg BW, respectively), whereas Capper et al. (2012) computed a much lower CED value of 7 MJ/kg BW. The most energy-demanding production steps were related to the off-farm fraction of the production cycle, first of all the production of the off-farm feeds and industrial materials, and the Italian fattening phase greatly outweighed the French suckler cow-calf phase. The predominance of the Italian fattening phase can be explained by the greater use of high energy-demanding concentrates and by the lower self-sufficiency of the diet, particularly for the share of concentrate feeds, which included imports of concentrates from other countries, with the consequent energy consumption during the transport activities.

Conversely, the LO mean result was similar to that found by Nguyen et al. (2012) – 21 m^2/year per 1 kg BW – and lower than the those obtained in LCA studies on beef production systems conducted in the USA and Canada – from 33 (Capper, 2012) to 56 m^2/year per 1 kg BW (Beauchemin et al., 2011). The LO category was much more related to the on-farm than the off-farm production steps, especially due to the French suckler cow-calf phase. The subdivision of the LO category showed how the majority of the land exploited by the integrated France-Italy beef production system was permanent grasslands located in the French Massif Central, an area with a low or no vocation for cultivated crops. When only cropland directly and indirectly used for producing feedstuffs was considered, the LO found in this study (3.6 ± 0.5 m^2/year per 1 kg BW) was similar or less than those found for monogastric (pig and poultry) meat production (Basset-Mens and Van der Werf, 2005; Gonzalez-García et al., 2015; Bava et al., 2015).

Gross energy and protein conversion efficiency

Few studies have assessed the conversion efficiency of dietary gross energy and protein into beef products taking into account also the proportion of human-edible feeds of the beef diets (CAST, 1999; Pelletier et al., 2010; Wilkinson, 2011). A direct comparison for E_CR and HeE_CR is possible only with Pelletier et al. (2010), because Wilkinson (2011) used metabolisable energy and not gross energy. Gross energy is a direct measure that can be obtained through heat combustion, while metabolisable energy needs estimates of digestibility and methane and urinary energy losses. The conversion ratio of gross energy of the whole diet into gross energy of raw boneless beef found in this study was comparable to that reported by Pelletier et al. (2010) for the feedlot-finishing system in the upper mid-western United States, whereas our assessment of HeE_CR was lower than the values of Pelletier et al. (2010), due to the important share of maize silage in the beef diet of the integrated France-Italy beef production system against the high share of grains in the US feedlot system. The conversion ratio of CP of the whole diet into CP of raw boneless beef found in this study was an intermediate between the greater values found in suckler lowland farms by Wilkinson (2011), probably because of the lower level of production intensity of that scenario, and the lower values reported by CAST (1999). Despite the low global conversion efficiency of gross energy and CP into beef products of the French-Italy beef production system, only 15% of the gross energy and 20% of the CP content of feeds were from human-edible ingredients. Moreover, the extensive partner of the beef production system, the French suckler cow-calf farms, accounted for nearly 70% of the total gross energy and CP required to produce a unit of raw boneless beef but nearly 90% of the gross energy and 85% of the CP used by the French farms were from human-inedible ingredients.

Integrated assessment of the environmental impact and conversion efficiencies

The strong and positive correlations between the different impact categories related to the emission of environmentally active compounds found in this study showed that they tend to assess the same dimension of the environmental impact of the integrated France-Italy beef production system. Moreover, the GWP category could be a proxy for the other impact categories, which showed correlations with GWP of 0.53 or more. However, AP and EP showed lower correlations with resource utilization impact categories (CED and LO), indicating that the latter may assess a second dimension of the environmental impact and should be considered when the environmental impact of the beef sector is assessed (Huijbregts et al., 2010; Röös et al., 2013).

Emission-related impact categories were positively correlated with the conversion ratio of gross energy and CP when considering the whole beef diet, but negatively correlated when only the human-edible fraction of the beef diet was taken into account. The increase in the conversion efficiency of the feedstuffs has been correlated to the increase in the use of protein- and energy-concentrated feedstuffs (Steinfeld et al., 2006), most of which are human-edible (e.g., maize grain, soy bean). Improving the conversion efficiency of dietary gross energy and CP may then decrease the emissions of environmentally active compounds but may at the same time lead to greater competition with grain production for human food consumption, giving rise to other environmental and ethical concerns (Garnett, 2011). Therefore, the human-edible share of the beef diets should be considered so that the livestock's contribution to food security can be taken into account (Schader et al., 2015).

Finally, gross energy and protein conversion efficiency parameters were mostly independent from the resource utilization impact categories, even if an intermediate positive relationship has been observed between LO and CP_CR. The results suggest that the adoption of mitigation strategies aimed to decrease the amount of energy and land surface area needed for beef production could be feasible without increasing the share of humane-edible components of the beef diets.

Conclusions

This study aimed to assess the environmental footprint of the integrated France-Italy beef production system by combining environmental impact parameters computed using LCA methodology and food-related indicators based on the conversion ratios of gross energy and CP of feedstuffs into gross energy and CP of raw boneless beef products. This approach allowed for the appreciation of the magnitude of the different indicators of the beef chain considered, and their mutual relationships, highlighting in particular how the share of human-edible feedstuffs into beef diets affects the emission-related environmental impact of beef production systems.

The suckler cow-calf beef production system located in areas of Central France characterized by low vocation for cultivated crops strongly contributes to keep the share of non-human-edible feedstuffs high, but at the same time, the cropland-oriented farms of North-East Italy are characterized by high level of beef productivity and good feed efficiency. For these reasons, the integration of the pasture-based France suckler cow-calf system with the cereal-based Italian fattening farms seems a good strategy in terms of exploitation of resources available.

The controversial relationships found between impact categories, resource utilization categories, and food-related indicators based on the whole beef diet or on the human-edible fraction of the beef diet only suggest that policies and strategies aiming to improve the sustainability of beef production systems should be based on a multi-indicator approach.

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Table 1.

Descriptive statistics (mean ± standard deviation) for the Italian beef fattening farms (N=14) and the beef batches (N=73).

Variable	Unit	Mean	SD
Farm features			
Farm AA[1]	ha	114	74
Herd AA[2]	ha	90	38
Herd size	animals/year	708	281
Chemical fertilizer			
Nitrogen	kg/ha	80	17
P_2O_5	kg/ha	2	6
Concentrates	kg DM/LU[9]	1588	430
Bedding straw	kg/animal/year	56	67
Bedding sawdust	kg/animal/year	5	18
Bedding maize stover	kg/animal/year	18	45
Fuel	L/animal/year	50	40
Electricity	kWh/animal/year	26	10
Batch features			
Batch size	animals, N	66	33
BWS[3]	kg/animal	405	13
BWI[4]	kg/animal	387	13
BWF[5]	kg/animal	731	19
ADG[6]	kg/day	1.52	0.09
Length of fattening	days	226	11
DMI[7]	kg DM/animal/day	10.6	0.5
% maize silage in diet	% DM	28	5
% self-sufficiency rate[8]	% DM	44	11

[1] Farm AA: Farm agricultural area (total agricultural surface destined to herd manure spreading)

[2] Herd AA: Herd agricultural area (total agricultural surface for producing the on-farm feedstuffs)

[3] BWS: body weight of the pre-fattened young bulls at the sale from France to Italian beef fattening farm

[4] BWI: body weight of the pre-fattened young bulls at the arrival to Italian beef fattening farm

[5] BWF: body weight of the young bulls at the end of the fattening period

[6] ADG: average daily gain

[7] DMI: dry matter intake (average composition: 28% maize silage, 13% maize flour, 10% maize grain silage, 10% protein/mineral supplement,8% maize gluten meal, 7% dried sugar beet pulp; for the complete average diet see Supplementary Table 3)

[8] % self-sufficiency rate of diet = total DMI produced on-farm / total DMI

[9] LU: Livestock Unit, defined following the EU livestock schemes (cattle > 2 years = 1 LU, cattle 6 months to 2 years = 0.6 LU)

Table 2.

Descriptive statistics (mean ± standard deviation) for the French suckler cow-calf farms according to the prevalent farm calving season.

Variable	Unit	Calving season		
		November/December	January/February	March/April
Farms	N	10	7	4
Farm AA[1]	ha	171 ± 96	159 ± 55	144 ± 57
Herd AA[2]	ha	112 ± 44	114 ± 31	116 ± 27
Grassland	ha	111 ± 44	114 ± 31	113 ± 22
- Grass silage	ha	10 ± 13	9 ± 10	21 ± 30
- Hay	ha	37 ± 16	38 ± 17	52 ± 17
Maize (silage)	ha	1 ± 3	0	3 ± 6
LU[3]	N	122 ± 45	134 ± 25	147 ± 76
Pregnant suckler cows	N	78 ± 26	87 ± 21	93 ± 73
Calvings	N	82 ± 27	90 ± 20	96 ± 73
Mortality[4]	%	8.2 ± 2.9	8.3 ± 5.1	12.6 ± 5.1
Prolificacy[5]	%	105.3 ± 2.9	103.8 ± 3.6	103.8 ± 3.2
Gestation[6]	%	93.1 ± 3.5	94 ± 5.8	90.7 ± 7.1
Productivity[7]	%	89.4 ± 5.6	88.1 ± 8.6	82.2 ± 7.8
Replacement[8]	%	23.5 ± 6.9	28.6 ± 21.4	22.5 ± 7.7
Animal output	kg BW sold/LU	314 ± 30	310 ± 27	259 ± 48
BW cull cow	kg BW	698 ± 49	710 ± 56	678 ± 39
Chemical fertilizers				
- Nitrogen	Kg/ha	20 ± 22	34 ± 40	31 ± 33
- P_2O_5	Kg/ha	12 ± 10	11 ± 9	43 ± 53
- K_2O	Kg/ha	9 ± 8	9 ± 10	18 ± 15
Concentrates[9]	kg DM/LU	630 ± 173	608 ± 236	541 ± 201
Bedding straw	kg/LU	293 ± 210	152 ± 175	157 ± 104
Fuel	L/LU	76 ± 18	57 ± 10	70 ± 26
Electricity	kWh/LU	106 ± 76	100 ± 60	100 ± 55

[1] Farm AA: Farm Agricultural Area

[2] Herd AA: Herd Agricultural Area (total agricultural surface dedicated to suckler cow-calf herd management)

[3] LU: Livestock Unit, defined following the EU livestock schemes (cattle > 2 years = 1 LU, cattle 6 months to 2 years = 0.6 LU)

[4] Mortality: total pre-weaned calves dead during the year / total calves born in the year

[5] Prolificacy: total calves born in the year / total pregnant suckler cows

[6] Gestation: total pregnant suckler cows in the year / total suckler cows in the year

[7] Productivity: total weaned calves in the year / total suckler cows in the year

[8] Replacement: total cull cows / total pregnant suckler cows

[9] Concentrates: wheat grain 75%, soybean meal 25 %

Table 3.

Values of impact categories per kg body weight sold for the French suckler cow-calf (FRA), the Italian fattening phase (ITA) and the France-Italy integrated beef production system (FRA+ITA), computed using different allocation methods (M: mass, E: economic, P: protein allocation)

Phase	Allocation	GWP[1]	GWPnet[2]	AP[3]	EP[4]	CED[5]	LO[6]			
							total	grassland[7]	cropland[8]	by-products[9]
		kg CO_2-eq		g SO_2-eq	g PO_4-eq	MJ	m^2/year			
FRA	M	14.8±0.5	9.3±0.5	187±10	59±3	18±1	27.1±1.0	26.4±0.9	0.12±0.03	.
	E	15.0±0.6	9.4±0.5	189±11	59±4	19±1	27.4±1.1	27.0±0.9	0.12±0.04	.
	P	16.8±0.5	10.5±0.5	212±10	66±4	21±1	30.8±0.9	30.5±0.6	0.13±0.04	.
ITA		10.0±1.1	10.0±1.1	189±23	51±7	52±12	7.7±1.0	.	5.6±0.9	1.9±0.8
FRA+ ITA	M	13.0±0.7	9.9±0.7	193±13	57±4	36±5	18.7±0.8	14.5±0.8	2.7±0.5	0.9±0.4
	E	13.1±0.8	10.0±0.7	194±13	57±4	37±5	18.9±0.9	14.9±0.8	2.7±0.5	0.9±0.4
	P	14.3±0.8	10.6±0.7	207±13	61±5	39±5	20.8±0.9	16.8±0.8	2.7±0.5	0.9±0.4

[1] GWP: global warming potential

[2] GWPnet: global warming potential adjusted for the carbon sequestration function due to permanent grasslands located in France

[3] AP: acidification potential

[4] EP: eutrophication potential

[5] CED: cumulative energy demand

[6] LO: land occupation

[7] grassland: grassland surface utilized for producing livestock feedstuffs

[8] cropland: cropland surface utilized for producing livestock feedstuffs (economic allocation)

[9] by-products: cropland surface utilized for producing the by-products obtained from other production cycles and included in the beef diet

Table 4.

Contribution (%) to the impact categories of on- and off-farm production steps for the integrated France-Italy beef production system (N=73, only mass allocation method was used in the computations).

	GWP[1]	AP[2]	EP[3]	CED[4]	LO[5]
On-farm	79.5 ± 3.7	86.6 ± 3.1	77.2 ± 4.9	24.7 ± 5.3	83.6 ± 3.7
France	59.1 ± 2.9	51.8 ± 2.8	54.3 ± 3.2	15.6 ± 2.5	78.7 ± 2.8
Enteric fermentation	41.6 ± 2.0				
Manure management	4.3 ± 0.2	13.7 ± 1.3	10.4 ± 0.9		
Fuel for herd/manure management	< 1.0	< 1.0	< 1.0	5.9 ± 1.5	< 1.0
Feed production	12.2 ± 0.9	38.0 ± 2.5	43.8 ± 2.7	9.7 ± 2.5	78.6 ± 2.8
Italy	20.4 ± 2.3	34.8 ± 3.8	22.9 ± 4.2	9.1 ± 4.1	4.9 ± 1.8
Enteric fermentation	13.8 ± 1.2				
Manure management	3.7 ± 1	28.7 ± 2.6	15.2 ± 1.5		
Fuel for herd/manure management	< 1.0	< 1.0	< 1.0	3.7 ± 2.2	< 1.0
Feed production	2.3 ± 0.9	6.1 ± 2.7	7.6 ± 3.6	5.4 ± 2.9	4.8 ± 1.8
Off-farm	20.5 ± 3.7	13.4 ± 2.9	22.8 ± 4.9	75.3 ± 5.5	16.4 ± 3.3
France	4.9 ± 0.8	2.3 ± 1.1	3.6 ± 1.6	17.4 ± 4.1	2.1 ± 0.5
Feed production	3.5 ± 0.4	< 1.0	< 1.0	4.9 ± 1.0	< 1.0
Transport	< 1.0	< 1.0	< 1.0	3.7 ± 0.6	< 1.0
Materials	< 1.0	< 1.0	< 1.0	7.9 ± 2.2	< 1.0
Bedding materials	< 1.0	1.6 ± 1	3.1 ± 1.5	< 1.0	1.8 ± 0.4
Italy	15.6 ± 4	11.1 ± 3	19.3 ± 5.1	57.9 ± 8.1	14.3 ± 3.3
Feed production	10.6 ± 3.1	9.0 ± 2.7	17.0 ± 4.9	35.3 ± 6.2	13.6 ± 3.3
Transport	3.7 ± 0.9	1.3 ± 0.3	1.1 ± 0.3	21.8 ± 3.5	< 1.0
Materials	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Bedding materials	< 1.0	< 1.0	1.1 ± 1.4	< 1.0	< 1.0

[1] GWP: global warming potential

[2] AP: acidification potential

[3] EP: eutrophication potential

[4] CED: cumulative energy demand

[5] LO: land occupation

Table 5.

Gross energy (MJ) and protein (kg) required in the whole beef diet (E_CR and CP_CR, respectively) or in the human-edible part of the beef diet (HeE_CR and HeCP_CR, respectively) to provide a MJ of gross energy or a kg of CP in raw boneless beef for the integrated France-Italy beef production system (N=73).

Item	Overall	French contribution	Italian contribution
E_CR, MJ/MJ	40.70 ± 1.90	29.37 ± 1.71	11.33 ± 0.75
HeE_CR, MJ/MJ	6.36 ± 0.71	2.40 ± 0.25	3.96 ± 0.66
CP_CR, kg/kg	16.70 ± 2.46	11.72 ± 2.42	4.98 ± 0.46
HeCP_CR, kg/kg	3.29 ± 0.42	1.55 ± 0.26	1.74 ± 0.29

Table 6.

Pearson's correlation factors for the impact categories and the food-related indicators calculated for the France-Italy beef production system (N=73; values below diagonal indicate coefficients of correlation, values above diagonal indicate P value).

	GWP	AP	EP	CED	LO	E_CR	HeE_CR	CP_CR	HeCP_CR
GWP[1]		<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.000
AP[2]	0.78		<0.001	0.003	0.017	<0.001	0.006	<0.001	0.001
EP[3]	0.87	0.93		<0.001	0.013	<0.001	0.001	<0.001	<0.001
CED[4]	0.78	0.34	0.56		<0.001	0.063	0.071	0.953	0.076
LO[5]	0.53	0.28	0.29	0.44		0.284	0.157	0.028	0.042
E_CR[6]	0.68	0.82	0.82	0.22	0.13		0.002	<0.001	<0.001
HeE_CR[7]	-0.36	-0.32	-0.37	-0.21	0.17	-0.36		0.055	<0.001
CP_CR[8]	0.50	0.67	0.58	0.01	0.26	0.61	-0.23		<0.001
HeCP_CR[9]	-0.41	-0.40	-0.48	-0.21	0.24	-0.48	0.90	-0.48	

[1] GWP: global warming potential

[2] AP: acidification potential

[3] EP: eutrophication potential

[4] CED: cumulative energy demand

[5] LO: land occupation

[6] E_CR: gross energy conversion ratio (MJ gross energy in the diet/MJ gross energy in in raw boneless beef)

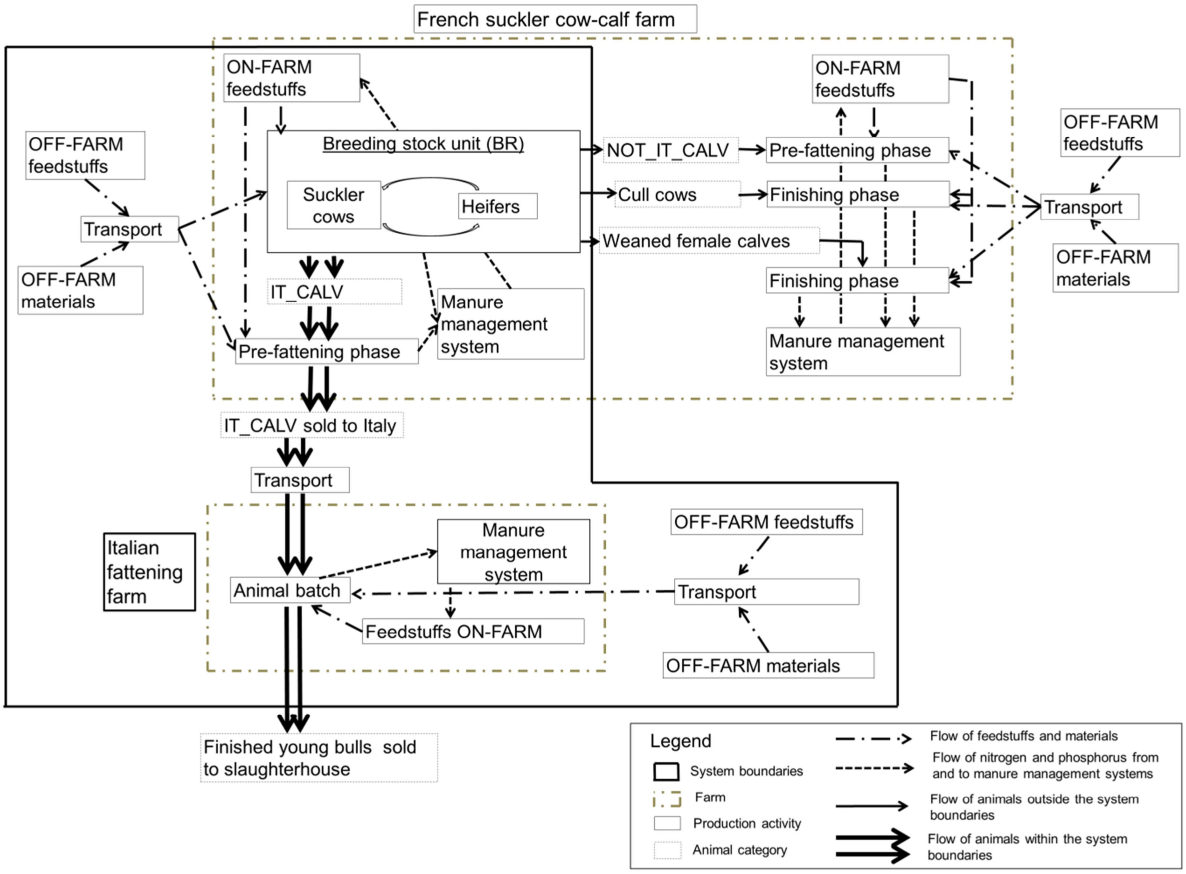
[7] HeE_CR: human-edible gross energy conversion ratio (MJ gross energy in the human-edible fraction of the diet/ MJ gross energy in raw boneless beef)

[8] CP_CR: protein conversion ratio (kg crude protein in the diet/kg protein in raw boneless beef)

[9] HeCP_CR: human-edible protein conversion ratio (kg crude protein in the human-edible fraction of the diet/kg protein in raw boneless beef)

Figure 1

Cradle-to-farm gate system boundaries of the integrated France-Italy beef system



Appendix to Chapter 2

Supplementary Tables to the Chapter 2

Supplementary Table 1.

Economic and protein allocation factors per animal category exiting the breeding stock unit of the French suckler cow-calf system.

Animal category	Economic allocation (€/kg BW at reproduction gate) [1]			Protein allocation (g protein/kg BW)[2]
	Begin Winter	Medium Winter	End Winter	
Weaned males for Italy	2.46	2.39	2.42	220
Weaned males	2.46	2.39	2.42	220
Weaned females	2.50	2.47	2.47	220
Cull cows	2.29	2.32	2.29	156
Breeding bulls	3.00	3.00	3.00	169

[1] Prices derived from France AgriMer (http://www.franceagrimer.fr/filiere-viandes/Viandes-rouges/Informations-economiques/Cotations-des-viandes-rouges/Cotations-viandes-rouges)

[2] Nguyen et al. (2012)

Supplementary Table 2.

Average composition of finishing diets (73 batches reared in 14 north-eastern Italy beef farms, kg DM/head/day).

	Mean	SD	Min	Max
Off-farm				
Maize grain, ground	1.37	1.00	0.00	3.44
Protein supplement	1.08	0.53	0.23	2.28
Maize gluten meal	0.82	0.49	0.00	1.74
Dried sugar beet pulp	0.74	0.61	0.00	2.09
Wheat straw	0.46	0.14	0.00	0.68
Alfalfa hay	0.30	0.32	0.00	0.87
Sugar beet pulp	0.29	0.44	0.00	1.26
Soybean meal	0.25	0.25	0.00	0.83
Maize by-products	0.25	0.50	0.00	1.64
Maize grain	0.22	0.40	0.00	1.55
Barley grain, ground	0.06	0.15	0.00	0.48
Wheat bran	0.04	0.13	0.00	0.47
Fat	0.04	0.05	0.00	0.16
Bread	0.04	0.18	0.00	0.99
On-farm				
Maize silage	2.98	0.55	1.92	4.12
Maize grain silage	1.11	1.29	0.00	4.25
Maize ears silage	0.31	0.63	0.00	2.07
Maize grain	0.09	0.16	0.00	0.52
Barley grain	0.07	0.16	0.00	0.48
Triticale silage	0.03	0.11	0.00	0.72
Wheat straw	0.02	0.11	0.00	0.60
Wheat silage	0.02	0.10	0.00	0.68

Supplementary Table 3.

Descriptive statistics for the chemical composition (g/kg DM) of finishing diets (N=73).

Variable	Mean	SD
Crude protein	135	6
Ether extract	26	3
Crude Fibre	152	14
Ash	56	5
Starch	300	28
NDF[1]	295	20
NSC[2]	488	17
Phosphorus	3.7	0.4

[1] NDF: neutral detergent fibre

[2] NSC: non-structural carbohydrates

Supplementary Table 4.

Agricultural input for on-farm feedstuffs production of the Italian fattening farms (N=14).

Crop	Unit	Wheat	Maize	Barley	Sorghum	Triticale
Farms		2	11	3	2	2
N solid manure	kg/ha	70 ± 36	95 ± 41	41 ± 54	161	73 ± 53
N slurry	kg/ha	43 ± 38	101 ± 91	56 ± 49		73
P_2O_5 solid manure	kg/ha	12 ± 6	15 ± 6	7 ± 9	27	13
P_2O_5 slurry	kg/ha	9 ± 7	18 ± 16	10 ± 9		13 ± 10
N mineral	kg/ha	158 ± 33	157 ± 65	82 ± 26	39 ± 3	195 ± 36
P_2O_5 mineral	kg/ha		1 ± 5	2 ± 3		
K_2O mineral	kg/ha		2 ± 7			
Pesticides	kg/ha	2.3 ± 1.4	6.6 ± 2.5	3.5 ± 0.5		
Herbicides	kg/ha	0.6 ± 0.8	5.3 ± 1.2	1.5 ± 1.3		
Fuel	kg/ha	106	151	121	106	106
Seed	kg/ha	45 ± 25	20 ± 1	23 ± 6	27	27
Yield	t DM/ha	9.3 ± 5.4	19.0 ± 3.0	14.5 ± 5.5	13.1 ± 7.0	16.6 ± 1.8

Supplementary Table 5.

Descriptive statistics of the pre-fattened young bulls (at sale from France to Italy) per each cluster in Italian fattening dataset.

Cluster	N batches	BWS[1] (kg)		ADG[2] (kg/d)		Age (days)		Birth date	
		Mean	SD	Mean	SD	Mean	SD	Min	Max
Early Winter	12	405	9	1.33	0.05	271	10	1-Nov-13	20- Dec-13
Mid Winter	32	406	14	1.18	0.08	306	24	17-Dec-12	25-Feb-13
Late Winter	29	405	13	1.05	0.10	344	29	27-Feb-13	10-Apr-13

[1] BWS: Body weight of pre-fattened young bulls at the sale from France

[2] ADG: Average daily gain

Supplementary Table 6a.

Diet composition and intake (kg DM/year/head) per animal category during the French suckler cow-calf period for Begin Winter cluster.

Animal category	BW$_m$[1] (kg BW)	Period[2] (days)	Diet (kg DM/year/animal)						
			Milk	Hay	Concentrates[3]	Maize silage	Grass silage	Pasture grass	Total
Pre weaning males (destined to Italy)	200	256	209	107	180			571	1067
Pre weaning males (other destination)	200	256	209		152			664	1025
Pre weaning females	171	256	209	45				579	833
Suckler cow	680	365		1058	554	151	227	2670	4660
Suckler cow (2nd parity)	680	365		1032	554	76	227	2592	4481
Primiparous cow	595	365		914	393	76	181	2455	4019
Breeding bull	763	365		2418	91			2271	4780
Heifers (reproduction)	485	365		967	197		151	1729	3043
Cull cow fattened	724	90		444	697				1141
Pre-fattened young bulls (destined to Italy – from weaning to sale)	377	38			120			157	277
Pre-fattened young bulls (other destination – from weaning to sale)	357	53		99	162			80	341
Heifers (for meat)	494	232		809	195		91	1161	2255

[1] BWm: mean body weight in the period

[2] Period: length of the period in which the animal category was in the farm

[3] 75% wheat grains, 25% soybean meal

Supplementary Table 6b.

Diet composition and intake (kg DM/year/head) per animal category during the French suckler cow-calf period for Medium Winter cluster

Animal category	BW_m[1] (kg BW)	Period[2] (days)	Diet (kg DM/year/animal)						
			Milk	Hay	Concentrates[3]	Maize silage	Grass silage	Pasture grass	Total
Pre weaning males (destined to Italy)	194	256	210		150			695	1055
Pre weaning males (other destination)	217	256	210	169	208			610	1189
Pre weaning females	166	256	210					718	928
Suckler cow	647	365		1296	529	0	151	2746	4721
Suckler cow (2nd parity)	622	365		1197	529	0	113	2473	4312
Primiparous cow	577	365		1287	302	0	76	2127	3791
Breeding bull	755	365		2616	91			2297	5004
Heifers (reproduction)	467	365		1307	177		8	1615	3107
Cull cow fattened	683	81		376	624				1000
Pre-fattened young bulls (destined to Italy – from weaning to sale)	368	52		144	140			80	364
Pre-fattened young bulls (other destination – from weaning to sale)	380	58		226	215				441
Heifers (for meat)	406	167		612	117		5	566	1299

[1] BWm: mean body weight in the period

[2] Period: length of the period in which the animal category was in the farm

[3] 75% wheat grains, 25% soybean meal

Supplementary Table 6c.

Diet composition and intake (kg DM/year/head) per animal category during the French suckler cow-calf period for End Winter cluster.

Animal category	BW$_m$[1] (kg BW)	Period[2] (days)	Diet (kg DM/year/animal)						
			Milk	Hay	Concentrates[3]	Maize silage	Grass silage	Pasture grass	Total
Pre weaning males (destined to Italy)	182	257	194	135	80			458	867
Pre weaning males (other destination)	160	257	194	1	40			545	780
Pre weaning females	172	257	194	136				486	816
Suckler cow	644	365		906	529	76	453	2809	4773
Suckler cow (2nd parity)	630	365		846	529	60	378	2870	4683
Primiparous cow	576	365		797	426	60	378	2497	4158
Breeding bull	754	365		2129	121			2526	4776
Heifers (reproduction)	485	365		974	166	30	189	1565	2924
Cull cow fattened	651	60		350	396				746
Pre-fattened young bulls (destined to Italy – from weaning to sale)	365	87		345	174				571
Pre-fattened young bulls (other destination – from weaning to sale)	338	147		711	186			80	945
Heifers (for meat)	419	203		363	93	14	80	894	1443

[1] BWm: mean body weight in the period

[2] Period: length of the period in which the animal category was in the farm

[3] 75% wheat grains, 25% soybean meal.

Supplementary Table 7.

Equations used to calculate the emissions for the integrated France-Italy beef system for methane, reactive nitrogen and phosphorus compounds.

Emission	Equation	Reference
Methane		
From enteric fermentation	CH_4 (g/kg OMD) $=45.42 - 6.66 \times \text{MSI\%PV}^{1} + 0.75 \times (\text{MSI\%PV})^{2} + 19.65 \times \text{PCO}^{2} - 35.0 \times (\text{PCO})^{2} - 2.69 \times \text{MSI\%PV} \times \text{PCO}$	Sauvant et al. (2011)
From manure management (deep bedding)	CH_4 (kg) $= (\text{VS} \times \text{winter cycle (day)}) \times (\text{Bo}_{(T)})^{3} \times 0.67 \times \Sigma\, (\text{MCF}_{(S,k)}{}^{4}/100) \times \text{MS}_{(S,k)}{}^{5})$	IPCC (2006)
From manure management (fattening storage)	CH_4 (kg) $= (\text{VS} \times \text{duration cycle (day)}) \times (\text{Bo}_{(T)}) \times 0.67 \times \sum (\text{MCF}_{(S,k)}/100) \times \text{MS}_{(S,k)})$	IPCC (2006)
	$\text{VS} = (\text{GEI\_DIET}^{6} \times (1 - \text{DE}^{7}\%/100) + (\text{UE}^{8} \times \text{GE\_DIET})) \times ((1 - \text{ASH}^{9})/\text{GE\_DIET})$	
From pasture	CH_4 (kg) = 0.8 g CH_4/Livestock Unit/day	Gac et al., 2010[a]
Nitrous oxide (winter deep bedding)		
Direct, from storage	N_2O (kg) $= \Sigma\, (\text{Head} \times \text{N}_{\text{excreted}} \times \text{MS}_{(S,k)}) \times 0.01$ kg N-N_2O/ kg N excreted $\times 44/28$	IPCC (2006)
NH_3 volatilisation (cow-calf phase)	NH_3 (kg) = N excreted (kg) $\times \text{Frac}_{\text{Gas}} \times 17/14$ $\text{Frac}_{\text{Gas}} = 0.3$ kg N-NH_3/kg N excreted	IPCC (2006)
NH_3 volatilisation (fattening phase)	NH_3 (kg)= (N slurry (kg) $\times \text{Frac}_{\text{GasSLURRY}}{}^{10}$ + N solid manure (kg) $\times \text{Frac}_{\text{GasMANURE}}{}^{11}) \times 17/14$	IPCC (2006)
Indirect, from volatilisation	N_2O (kg) $= NH_3$ (kg) $\times 14/17 \times 0.01$ (kg N-N_2O/(kg N-NH_3volatilized + kg N-NO_x volatilized)) $\times 44/28$	IPCC (2006)
Nitrous oxide (at soil)		
Direct	N_2O (kg) = (mineral N (kg) + manure N (kg) + crop residues N (kg)) $\times$ 0.01 kg N-N_2O/kg N applied + pasture N (kg) $\times$ 0.02 kg N-N_2O/kg N applied $\times 44/28$	IPCC (2006)
NH_3 volatilization	NH_3 (kg) = (mineral N (kg) $\times$ 0.1 kg N volatilized/kg N + (manure N (kg) + pasture N (kg)) $\times$ 0.2 kg N volatilized/kg N manure) $\times 17/14$	IPCC (2006)

Indirect, from volatilisation	N_2O (kg) = NH_3 (kg) x 14/17 × 0.01 kg N-N_2O/(kg N-NH_3 + kg N-NO_x volatilized) x 44/28	IPCC (2006)
NO_3 leaching, (grassland)	NO_3 (kg)= 8.77 x $e^{\text{(grazing days/ha/LU) x 0.003}}$ x 62/14	Vertés et al. (1997)
NO_3 potential leaching (cropland)	NO_3 (kg) = ((mineral N (kg) + manure N (kg)) – N output – N loss (N-N_2O (kg), N-NH_3 (kg))) x 62/14	
Indirect, from leaching	N_2O (kg) =NO_3 potential leaching (kg) x 14/62 x 0.0075 kg N-N_2O/N-NO_3 leach x 44/28	IPCC (2006)
Phosphorus (P) loss		
P leaching ground	P (kg)= ha x P leaching factor (kg/ha per year) x (1+(0.2/80) x P_2O_5 slurry (kg))	
	Cropping P leaching factor = 0.07; Grassland P leaching factor = 0.06	Nemecek and Kägi (2007)
P run off surface	P (kg) = ha x P run-off factor (kg/ha per year) x [1+((0.2/80) x P_2O_5 slurry (kg) +(0.7/80) x P_2O_5 mineral (kg) + (0.4/80) x P_2O_5 manure (kg))]	
	Cropping P run-off factor = 0.175; Grassland P run-off factor = 0.15	

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[1] MSI%PV: dry matter intake per head/day expressed as percentage of mean body weight

[2] PCO: percentage of concentrates into the diet (per animal category)

[3] Bo(T): maximum methane producing capacity for manure produced (m^3CH_4/kg VS)

[4] $MCF_{(S,k)}$: methane conversion factor for manure management system (MCF slurry = 0.14, MCF solid manure = 0.02)

[5] $MS_{(S,k)}$: fraction of animals handled using manure management S

[6] GEI_DIET: Gross Energy Intake (MJ/day per head) calculated with INRA (2007)

[7] DE%: Diet Energy Digestibility (%),calculated with INRA (2007)

[8] UE: urinary energy fraction (IPCC, 2006)

[9] ASH: ash content (kg DM/kg manure) of manure (ASH = 0.08))

[10] $FracGas_{SLURRY}$: fraction of N volatilised from slurry (0.40 kg N-NH_3/kg N excreted).

[11] $FracGas_{MANURE}$: fraction of N volatilised by solid manure (0.45 kg N-NH_3/kg N excreted)

[a] Gac, A., Deltour, L., Cariolle, M., Dollé, J.B., Espagnol, S., Flénet, F., Guingand, N., Lagadec, S., Le Gall, A., Lellahi, A., Malaval, C., Ponchant, P., Tailleur, A., 2010a. GES'TIM, Guide méthodologique pour l'estimation des impacts des activités agricoles sur l'effet de serre. (Projet Gaz à effet de serre et stockage de carbone CASDAR 6147), Version 1.2., Institut de l'Elevage

Chapter 3

Sources of variation of the environmental impact of cereal-based intensive beef finishing herds

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Abstract

The study aimed to investigate the effect of beef category (genetic line x gender) and diet-related factors on the environmental impact of the beef fattening system typical of north-eastern Italy according to a partial Life Cycle Assessment. The reference unit was the batch (group of animals homogeneous for genotype, sex, fattening farm, finishing period). The study involved 245 batches (64±34 heads) herded in 17 fattening farms. The system boundaries were set from the arrival of the animals at the fattening farm to the sale to the slaughterhouse. The functional unit was 1 kg BW gain (BWG). Data on animal performance and farm input were collected for each batch and farm, respectively. Data on feed intake, ingredient formulation and diet sample for the chemical analysis were monthly collected for each batch. Impact categories assessed (mean ± SD per kg BWG into brackets) were: global warming potential (8.8±1.6 kg CO_2-eq), acidification potential (142±22 g SO_2-eq), eutrophication potential (55±8 g PO_4-eq), cumulative energy demand (53±18 MJ), land occupation (7.9±1.2 m2/year). Impact values were tested with a linear mixed model including farm (random effect), beef category, season of arrival and classes of initial BW, feedstuffs self-sufficiency rate (SELF), crude protein (CPI) and phosphorus (PI) daily intake. Impact values have been significantly affected by beef category and SELF, CPI and PI classes. In conclusion this study evidences that beef category and diet-related factors may act as mitigation options for the fattening beef systems and LCA analysis can be an useful tool to support farm management.

Keywords: beef fattening system; environmental impact; Life Cycle Assessment; diet composition and quality.

Introduction

Livestock production is considered responsible for the exploitation of a notable share of natural resources and as a main driver of the emission of various environment-altering pollutants, such as greenhouse gases (GHG), with complex effects on natural ecosystems (Steinfeld et al. 2006; Gerber et al. 2013). In the last decade, Life Cycle Assessment (LCA; ISO 2006) has emerged as one of the most suited methodologies to evaluate the overall environmental impact due to the production of livestock outputs such as meat and milk (de Vries & de Boer 2010). Consequently, a variegate set of mitigation strategies has been proposed in order to develop consistent, economically feasible ways to reduce the impact of the different livestock production sectors. These mitigation strategies can be addressed to the reduction of the environmental footprint of livestock products (farm-level point of view) and/or to the modification of consumer behaviour (consumers-level point of view, Garnett 2013). At the farm level, actions aiming to improve the efficiency of the feedstuffs (Smith et al. 2007) and of the animal production (Gill et al. 2010; de Boer et al. 2011) or to enhance the carbon sequestration capacity of the permanent grassland (Soussana et al. 2010) have been explored. In particular, the mitigating effect of the optimisation of the nutrients (e.g., nitrogen and phosphorus) utilisation has been widely investigated in the literature (Rotz 2004; de Boer et al. 2011), whereas other characteristics of the beef diets, such as the feedstuffs self-sufficiency rate, has been less studied. The implementation of mitigation strategies at the farm level has to be shaped on the specific characteristics of each regional livestock system (Gerber et al. 2015). This is the case of the beef fattening system in the north-eastern Italy, which gives a notable contribution to the European beef supply (European Commission 2011). This system integrates the extensive suckler cow-calf farms of the French Massif Central, which provide stock calves, with the intensive beef herds of northern Italy, where imported stock calves are finished using total mixed rations based on maize silage and concentrates (Cozzi 2007; Gallo et al.2014). Berton et al. (2016), in a previous study aimed to assess the environmental impact of this beef system, found a notable variation of different impact categories among farms. In order to contribute to the understanding of such variability, the aim of this study was to assess the effects of beef category (genetic line x gender) and diet-related factors on the environmental impact of the north-eastern Italy beef fattening system computed according to a partial LCA method.

Materials and Methods

Data collection

Data for this study originated from 245 fattening batches (i.e., a group of animals homogenous for genetic type, sex, origin, fattening farm and finishing period) involving 15614 beef bulls and heifers (64±34 heads per batch on average) reared in 17 fattening farms in north-eastern Italy during 2014. Beef bulls and heifers were of different genetic lines and gender, and were grouped into beef categories (genetic line x gender) as follows (the number of batches is given between brackets): Charolais bulls (137), Limousin bulls (43), Irish crossbred bulls (34), French crossbred bulls (21) and beef heifers (10). For each batch the following information was collected: the number of animals, the arrival and sale dates, the body weight at the arrival (BWI) and at the sale (BWF), the number of animals dead during the fattening cycle, and the average purchase and sale prices per head. The average daily gain (ADG, kg/day) was computed as the difference between BWF and BWI divided by the animal total presence (heads x days), and the length of the fattening cycle was computed as the difference between the sale and the arrival dates. Information concerning the manure management systems, the agricultural input used for on-farm feed production (organic and chemical fertilizers, pesticides, seeds, and fuel for agricultural machines), the bedding and industrial materials (lubricant, plastic, and fuel for animal handling) used in the farm were acquired through monthly visits on the farms performed by the same operator (see Supplementary Table 1). Ingredient composition and feed allowance were collected monthly, together with a sample of each diet fed. Diets samples were used for assessing the content of moisture, crude protein (CP), ether extracts, ash, starch and neutral detergent fibre using the NIRS method. Non-starch carbohydrates content was obtained as difference between the whole dry sample and the sum of crude protein, ether extracts, ash and neutral detergent fibre. The phosphorus (P) content was obtained according to the AOAC procedure (AOAC 999.10, 2000 and ICP-OES), whereas the gross, digestible and metabolisable energy contents of the diets were calculated according to INRA (2007).

Monthly total feed allowance per head was obtained as the mean between two subsequent monthly records multiplied by the period occurred between them, and total feed allowance during the whole fattening cycle as the sum of the monthly feed allowances. The average daily dry matter intake (DMI) was estimated as the total dry matter allowance per head divided by the length of the fattening cycle, and the same procedure was used to compute the daily intakes of CP and P (CPI and PI, respectively).

The self-sufficiency rate of the diet (SELF) was computed as the ratio between the DMI from feeds produced on-farm, computed from the information acquired during the monthly farm visits, and the total DMI. The gain- to-feed ratio (G:F) was calculated as the ratio between the ADG and DMI. The nitrogen (N) input-output flow was calculated for each batch according to the procedure proposed by Ketelaars & Van der Meer (1999) as follows: the N intake was computed as average daily DMI x length of the fattening cycle x average N content of the diet; the N retention as (BWF – BWI) x 0.027 kg N/kg BW; and the N excretion as the difference between N intake and N retention. The excretion of P was calculated following the same procedure, using the average P dietary content of the diets and a retention factor of 0.0075 kg P/kg BW (Whiters et al. 2001).

Income over feed costs (IOFC) per 1 kg BWG was calculated for each batch. The gross margin (€/kg BWG) was computed as the difference between the values at sale and at purchase (€/head), divided by the difference between BWF and BWI (per head). The cost of the diets (€/kg BWG) was computed as the sum of the feedstuffs consumed per head/day multiplied by the relative prices, divided by ADG. The seasonal average prices per feedstuff were derived from the official reports of the commodities trading market of the Mantova province for the second half of 2013, the whole 2014 and the first half of 2015. Finally, IOFC was computed as the difference between the gross margin and the diet cost.

Partial LCA structure and computation of the impacts

The partial LCA model was derived from that used by Berton et al. (2016). The reference unit for computing the environmental impact was the batch and, within each batch, 1 kg BW gained (BWG) was taken as the functional unit. The system boundaries were set from the arrival of the animals in the fattening farm to their sale to the slaughterhouse, which includes the impact due to animal and manure management and on-farm feed production, and that due to the background systems related to the off-farm feed production and the materials used in the farms. The problem of allocating inputs derived from multi-functional processes (e.g., soybean meal as co-product of soy oil extraction) was resolved using an economic allocation method (de Vries & de Boer 2010).

The impact categories assessed were global warming (GWP, kg CO_2-eq), acidification (AP, g SO_2-eq) and eutrophication potentials (EP, g PO_4-eq), cumulative energy demand (CED, MJ), and land occupation (LO, m^2/year). Global warming potential was computed using the equations proposed by the International Panel on Climate Change (IPCC 2006) for methane (CH_4) and nitrous oxide (N_2O) emissions from manure storage and cropland soils. Enteric CH_4 was computed according to the equation proposed by Ellis et al. (2007), where CH_4 emission varied in function of feed intake and chemical composition of the diet. The emissions of ammonia (NH_3), nitrogen oxides (NO_x) and sulphur dioxide (SO_2) due to the manure storage and crop fertilisation were included into the acidification potential category. Acidifying emissions were estimated using the equations from IPCC (2006). Nitrogen volatilisation factors were derived from ISPRA (2011). Eutrophying compounds as leaching nitrate (NO_3) and P lost at soil level were accounted in the eutrophication potential category. Nitrate leaching was obtained as difference between N input and N output (i.e., N harvested and N volatilised). Phosphorus loss was computed using the equation of Nemecek and Kagi (2007).

The impact of agricultural inputs (fertilizers, pesticides, seeds) for the on-farm feed production was computed by applying the impact factors derived from the Ecoinvent (Ecoinvent Centre 2015) and Agri-footprint databases (Blonk Agri-footprint 2014). The impact caused by burning the fuel used for farm activities was derived from the EEA (2013) and Ecoinvent databases. The Ecoinvent and Agri-footprint databases were also used to derive the impact factors for computing the impact due to the off-farm inputs and related background processes. The origin and transport of soybean meal, maize by-products and sugar beet by-products were supposed equal to those described by Berton et al. (2016). All the single pollutant emissions computed for GWP, AP and EP were aggregated into the common unit of each impact category by using the conversion factors derived from Stocker et al. (2013) for GWP and Guinée et al. (2002) for AP and EP.

Data editing and statistical analysis

The impact categories values were processed using the hotspot analysis, which aims to identify the contribution of the different production stages to each impact category (European Commission, 2010).

Prior to statistical analysis, the multicollinearity of the independent variables (BWI, SELF, CPI, PI) was preliminary checked (PROC REG, SAS, 2011), assuming a variance inflation factor lower than 2 as threshold for the absence of multicollinearity. Afterwards, the records were classified as follows:

- season of arrival, according to 4 classes computed grouping the months of arrival into winter (December, January and February), spring (March, April, May), summer (June, July, August) and autumn (September, October, November);

- class of BW at arrival, SELF, CPI, and PI, according to 3 classes computed within beef category as "low" (batches with trait value lower than mean – 0.5 SD), "intermediate" (batches with trait value included between mean – 0.5 SD and mean + 0.5 SD) and "high" (batches with trait value greater than mean + 0.5 SD).

Growth traits, ingredient and chemical composition of the diets, and SELF were analysed with a mixed model (PROC MIXED, SAS 2011) that included the random effect of the farm and the fixed effects of the beef category (Charolais bulls, Limousine bulls, Irish crossbred bulls, French crossbred bulls, beef Heifers) and of the season of arrival. The mixed model used to analyse the impact categories values, in addition to the random effect of the farm and the fixed effects of the beef category and of the season of arrival, included also classes of initial BW, SELF, CPI, and PI. The interactions between these latter effects were included in a preliminary model, but has been removed in the final model as never significant. Differences between least Squares means of beef type, SELF, CPI and PI were contrasted using a Bonferroni correction for multiple testing.

Results

As expected, beef category significantly affected most beef performance traits ($P < 0.01$, Table 1). The BW at the beginning and at the end of the fattening period ranged from 299 to 394 kg and from 521 to 731 kg , respectively, with greater values for Charolais and Irish crossbred bulls, intermediate values for French crossbred bulls and lower values for Limousine bulls and beef heifers. The fattening cycle ranged from 220 to 233 d, with no differences among beef categories. Growth rate ranged from nearly 1 kg/d in heifers to nearly 1.5 kg/d in Charolais and Irish beef bulls, with a trend among beef categories similar to that found for BWF. On average, the DMI of Charolais, Irish crossbred and French crossbred bulls was nearly 1.5 kg/d greater than that of Limousine bulls and beef Heifers ($P < 0.05$). As a result of greater growth rate or lower feed intake, Charolais, Irish beef and Limousine bulls showed better gain to feed ratio, whereas French crossbreds showed intermediate and heifers worst feed efficiency. On average, SELF approached 43%, but it resulted greater for beef heifers than for Limousine bulls, with other genetic types showing intermediate values. The gross margin ranged from

1.71 to 2.24 €/kg BWG. Beef heifers showed greater economic evaluation of the unit of BW gain than the beef bull categories, and Limousine bulls a greater gross margin than the other beef bulls categories. Since the costs of the diet per unit of BW gain were the highest for beef heifers and the lowest for Charolais and Irish crossbred bulls, the trend of IOFC differed from that of gross margin: Limousine, showed the greatest and French crossbreds the worst IOFC per unit of BW gain, whereas Charolais, IRE and heifers were intermediate.

The ingredient and chemical composition of the diets are shown in Table 2. All diets are based on maize silage (from 30% DM for Irish crossbred and Limousine bulls to 41% DM for beef Heifers), with occasional addition of other cereal silages (sorghum, wheat, barley), and included some (8 to 11% DM) fibrous feeds to ensure ruminal activity. Maize grain, as dried whole or ground, but also as grain or ears silage, provides the energy supplementation (from 14% DM in heifers to 28-31% DM in beef bulls). Protein supplementation, originated from protein-mineral, soybean meal and occasionally other sources, ranged between 17 to 20%. Sugar-beet and maize by-products, other cereal grains (e.g., barley grain) and fat supplementation complete the beef diets. In general diets fed to beef bulls were richer in non-structural carbohydrates, in particular starch, and in ether extract content (from +23% to +27% and from +15% to +22%, respectively), and poorer in fibre content (-11%) than those fed to beef Heifers. The CP content (g/kg DM) was the greatest in the diets fed to beef heifers and Limousine bulls and the lowest in the diet fed to Charolais bulls, with Irish and French crossbred bulls showing intermediate values. Diets fed to Limousine bulls were characterized by the greatest P content as well, whereas those fed to Charolais, Irish crossbred and French crossbred bulls by the lowest P content, and diets fed to beef heifers by intermediate values.

The results of the environmental impact categories computed according to LCA methodology and the contribution of each production stage to the impact categories values are reported in Figure 1. Mean GWP was 8.8 kg CO_2/kg BWG and the production of one kg BWG needed 53 MJ of energy and nearly 8 m^2/year of land. The coefficient of variation within impact category was nearly 15-18% for all the impact categories, except in the case of CED (25%). The on-farm production stages outweighed greatly those off-farm for AP, and slightly for GWP and EP. The opposite was observed for CED and LO. The enteric CH_4 emissions and the N volatilisation due to manure management were the main contributor to the on-farm stages for GWP and AP, whereas on-farm feed production was the first on farm contributor for EP and LO. Within the off-farm stages, the feedstuffs production was the first contributor for all impact categories, whereas the transport of the inputs had a notable importance only for CED and GWP.

All effects taken into account significantly affected the impact categories values ($P<0.05$, Table 3). Charolais, Irish crossbred and Limousine bulls showed the lowest values for all the impact categories, French crossbred bulls had intermediate values and beef heifers had the greatest values. If the differences among values within impact category for Charolais, Irish crossbred and Limousine bulls were similar for all the impact categories, French crossbred bulls and beef heifers showed a different pattern. French crossbred bulls showed greater differences for the resource use-related impact categories (CED, LO) than for the emissions-related impact categories (GWP,AP, EP) (from +7 to +9% and from +10% to +15%, respectively), whereas beef heifers had an opposite pattern (from +26 to +36% and from +12% to +25%, respectively).

The increase in SELF resulted in a reduction of all the impact categories, with an average decrease ranging between 5 to 25 % according to the category considered moving from a low to a high rate of SELF. As expected, classes of CPI and PI showed an opposite trend, and moving from high to low CPI or PI led to a 7% to 13% decrease, depending on the impact category.

Discussion

This study aimed to investigate the effect of beef category, level of feed self-sufficiency and protein and phosphorus intakes on the environmental impact of the north-eastern Italy beef fattening system. The results found for GWP and LO were within the range found in the literature dealing with intensive beef fattening production (Pelletier et al. 2010; Nguyen et al. 2012; de Vries et al. 2015). Conversely, the values for AP, EP and CED found in this study were greater than those reported by others (Nguyen et al. 2012; de Vries et al. 2015) because of differences in the emission factors used to compute AP and EP and by the great importance of the transport of the off-farm feedstuffs (CED). Within the north-eastern Italy beef production system, the on-farm production stages outweighed the off-farm stages contribution for GWP, AP and EP, in accordance to the results reported by Beauchemin et al. (2010) and Pelletier et al. (2010). This is due to the fact that the enteric methane (for GWP) and the manure management (for AP and EP) were main drivers of the total emissions. On the opposite, the off-farm stages were more important for CED and LO since feedstuffs production (where the off-farm contribution was predominant) was the stage more related to energy and land use.

Beef category as well as SELF, CPI and PI significantly affected all the impact categories values. Differences in production efficiency may explain differences in impact due to different beef categories. Even if the CO_2-eq emission for the production of one kg of DM was 5 to 23% lower for diets fed to beef heifers than for those of beef bulls, beef bulls evidenced on average 25% greater BWG/kg DM than beef Heifers, which resulted in an average decrease of impact categories ranging from 7 to 33%. The resulting importance of the productive efficiency on the environmental footprint of beef livestock production systems is in agreement with Capper (2011) and Crosson et al (2011) .

The mitigating effect of SELF on the impact categories values was connected to the feedstuffs production stage. Diets containing higher proportions of feedstuffs produced within the farm enabled to reduce the impact due to the feedstuffs production and transports. The mitigating effect of the increase of feedstuffs self-sufficiency rate observed in this study is in agreement with results of Battini et al. (2016). Although that study was focused on dairy farms of the Po Valley, the crop system described was very similar to that considered in our research. The lower values for all the impact categories found for the class “low” than the class “high” of CPI and PI could be related to a more efficient use of CP and P by animals (the ratio between BWG and CPI varied from 1.18 kg BWG/kg CPI for the CPI class “low” to 0.98 kg BWG/kg CPI for the CPI class “high”, and the same trend was observed for classes of PI, data not shown in tables), implying a lower N and P excretion per functional unit and consequently a lower amount of nutrients to be managed in the manure management stage.

Different studies addressed the effects of diet features on the impact of beef fattening bulls. Diet formulation and composition affect enteric CH_4 emission, and differences in some nutrients content, as well as differences in ingredient composition such as maize grain or maize silage, have been related to differences in emission level (Grainger & Beauchemin 2011; Doreau et al. 2011; Nguyen et al. 2012). The results obtained in our study are in agreement with those of Doreau et al. (2011) and Nguyen et al. (2012), who also reported lower enteric CH_4 emission for diets richer in maize-grain-based feeds and poorer in maize silage and fibrous feeds. However, maize silage is a local, abundant and high-yielding feed resource in north-eastern Italy, whereas a notable part of maize grain is imported. Besides, a reduction in maize silage utilisation does not seem advisable in the northern Italy condition, as it would have detrimental effect on SELF level, which evidenced mitigating effects in this study. Moreover, diets fed to heifers, characterized by greater content in silages, evidenced on average 20 % lower CO_2-eq emission/kg DM than those fed to beef bulls, and this was only partially counterbalanced by the 10% greater CH_4 enteric emission estimated for these diets.

Schiavon et al. (2010) found that reducing CP from 145 to 108 g/kg DM did not affect the ADG in Piemontese beef bulls and allowed to strongly reduce the N excretion. Results from our study showed that a reduction of CPI implied not only a decrease in N excretion, since lower CPI values implies lower N intake values, but also a mitigating effect on the overall impact of the beef fattening system. A similar result was obtained regarding the P-related elementary flow. More generally, increasing N and P use efficiency has been suggested as a diet-related mitigation strategy at the farming system level (Steinfeld et al. 2006; de Boer et al. 2011).

However, several constraints have to be taken into account in the evaluation of mitigation strategies (Smith et al. 2007). In the last decade the Italian beef sector is experiencing declining levels of production (-24% in 2005-2015 period) and decreasing self-sufficiency rate (53% of the beef demand observed for 2015 was covered by the national production sector; ISMEA 2015). Any mitigation strategy implying detrimental effects on the production level could have further negative consequences on beef herd economic sustainability and on the national beef supply security. Furthermore, it is recognized that the application of mitigation strategies could result into changes in the economic framework and consumer behaviour that possibly offset the achievable reduction in the impact (IPCC, 2011). Moreover, any possible trade-offs in the GHG emission patterns have to be considered (de Boer et al. 2011). To this purpose, the IOFC can be a better indicator of the farm economic profitability than gross margin, because it takes into account also the cost of the diet, which is the main component of total production costs. In this study IOFC has been expressed per unit of BWG, and its variation could depend both on variation in ADG and in fluctuation of animal prices and feedstuffs costs, which can be of relevance (ISMEA 2015). Data from our study suggest that IOFC was more influenced by the variation in the cost of the diets and in the gross margin than by the variation in ADG. The farmer's choice about the purchase of the feedstuffs is greatly affected by the fluctuation of the prices and costs, and these factors can therefore have a detectable effect on the magnitude of impact categories. As a consequence, an indicator of farm profitability, such as IOFC in this study, should be considered in the implementation of mitigation strategies. Based on the results of the same mixed model used to analyse the impact category values, the increase in feedstuffs self-sufficiency rate, together with the already discussed decrease of the impact categories, led to an increase in IOFC (data not shown in table). Similarly, the reduction in CPI and PI, while decreasing impact categories values, does not affect IOFC. Therefore, the increase in feedstuffs self-sufficiency and the decrease of CPI and PI may be strategies able to provide positive effects on the impact categories values of beef finishing herds, without any detrimental consequences on the farm economic profitability.

Conclusions

The north-eastern Italy beef system has a remarkable role in the area of the study and is integrated with other supply chains, first of all the suckler cow-calf system located in central France (Massif Central). In recent years, the north-eastern Italy beef system has faced different challenges, in particular related to the maintenance of the production level, while enhancing its compliance with the increasing environmental sustainability awareness and the consumers' behaviour changes, that led the sector to a condition of productive and economic vulnerability. The results found in this study showed that the environmental impact of finishing beef herds is affected by beef categories and by several diet-related effects. Namely, mitigation strategies based on enhancing the self-sufficiency rate of the diet and lowering the daily intake of crude protein and phosphorus could significantly mitigate greenhouse gases, acidifying and eutrophying emissions as well as the amount of resources utilized. Moreover, a notable mitigation of the impact could be achieved without affecting the income over feed costs. The consideration of system aspects different from the environmental impact, such as the farm economic profitability, within the assessment of mitigation strategies, allows taking into account the complex framework of interactions that the results of this study evidenced. Further insights on the overall sustainability of the north-eastern Italy beef system, within the wider consideration of the related supply chains, is desirable.

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Table 1.

Least Squares means of beef categories for farm performance traits (N=245 batches).

Variable	Beef Category[1]					SEM
	CH	IRE	FRCR	LIM	HEI	
Batch (N).	137	34	21	43	10	.
Herd (N)	17	8	9	6	3	.
BWI[2]	394 ^{a}	388 ^{ab}	370 ^{b}	299 ^{c}	312 ^{c}	28
BWF[3]	729 ^{a}	731 ^{a}	705 ^{b}	595 ^{c}	521 ^{d}	24
Length of fattening cycle (d)	220	224	233	222	223	20
ADG[4] (kg/day)	1.53 ^{a}	1.54 ^{a}	1.45 ^{b}	1.33 ^{c}	0.96 ^{d}	0.09
DMI[5] (kg/head/day)	10.5 ^{a}	10.4 ^{a}	10.4 ^{a}	8.9 ^{b}	8.7 ^{b}	0.6
G:F[6] (kg BW/kg DM)	0.148 ^{ab}	0.151 ^{ab}	0.142 ^{b}	0.152 ^{a}	0.111 ^{c}	0.01
% self-sufficiency[7]	43.7 ^{ab}	42.5 ^{ab}	42.1 ^{ab}	39.8 ^{b}	48.5 ^{a}	10
Gross margin[8] (€/kg BWG)	1.77 ^{c}	1.76 ^{c}	1.71 ^{c}	1.95 ^{b}	2.24 ^{a}	0.18
Diet cost (€/kg BWG)	1.58 ^{c}	1.58 ^{c}	1.68 ^{b}	1.62 ^{bc}	2.04 ^{a}	0.17
IOFC[9] (€/kg BWG)	0.19 ^{ab}	0.17 ^{ab}	0.03 ^{b}	0.34 ^{a}	0.23 ^{ab}	0.25

1 CH: Charolais bulls; IRE: Irish crossbred bulls; FRCR: French crossbred bulls, LIM: Limousin bulls; HEI: beef Heifers.

2 BWI: body weight at the arrival at the Italian fattening farm, per head.

3 BWF: body weight at the sale to the slaughterhouse, per head.

4 ADG: average daily gain.

5 DMI: dry matter intake.

6 G:F: feed-to-gain ratio.

7 Self-sufficiency rate: percentage of dry matter intake produced on-farm.

8 Gross margin: difference between sale and purchase values (€/head) divided by the difference between BWF and BWI (BWG).

9 IOFC: income over feed costs, as gross margin – cost of the diet.

a,b,c: LS Means with different superscripts within row differ significantly ($P<0.05$).

Table 2.

Least Squares means of beef category for the average ingredient and chemical composition of diets (% of dry matter allowance) and diet-related greenhouse gases emission (N=245 batches).

Variables	Unit	Beef category[1]					SEM
		CH	IRE	FRCR	LIM	HEI	
Ingredient composition							
Maize silage	%	30 ^{b}	29 ^{bc}	27 ^{c}	30 ^{b}	40 ^{a}	6
Maize grain-based feeds[2]	%	29 ^{a}	29 ^{a}	31 ^{a}	28 ^{b}	14 ^{c}	5
Protein by-products and supplements[3]	%	18 ^{b}	19 ^{ab}	20 ^{a}	20 ^{a}	17 ^{b}	6
Fibrous feeds[4]	%	8 ^{bc}	8 ^{bc}	7 ^{c}	9 ^{b}	11 ^{a}	3
Sugar beet by-products	%	8	9	8	7	7	5
Maize by-products	%	4	3	4	3	5	5
Other cereal silages[5]	%	1.0 ^{b}	0.5 ^{b}	0.3 ^{b}	1.1 ^{b}	5.4 ^{a}	2.2
Other cereal grains[6]	%	1.7 ^{a}	1.9 ^{a}	1.8 ^{a}	0.4 ^{b}	0.5 ^{b}	3.7
Fat	%	0.4	0.4	0.5	0.6	0.4	0.5
Chemical composition of diet							
CP[7]	g/kg DM	136 ^{b}	137 ^{ab}	138 ^{ab}	139 ^{a}	140 ^{a}	3
P[8]	g/kg DM	3.7 ^{b}	3.7 ^{b}	3.8 ^{b}	4.0 ^{a}	3.9 ^{ab}	0.1
EE[9]	g/kg DM	27 ^{a}	26 ^{a}	28 ^{a}	28 ^{a}	23 ^{b}	2
Starch	g/kg DM	301 ^{a}	299 ^{ab}	300 ^{ab}	292 ^{b}	237 ^{c}	14
NDF[10]	g/kg DM	293 ^{b}	293 ^{b}	291 ^{b}	290 ^{b}	328 ^{a}	9
Greenhouse gases emissions							
CH_4 enteric[11]	g/kg DM	13.2 ^{c}	13.1 ^{c}	13.0 ^{c}	13.6 ^{b}	14.6 ^{a}	14.9
CO_2-eq diet[12]	g/kg DM	668 ^{b}	689 ^{b}	740 ^{a}	676 ^{b}	560 ^{c}	143

1 CH: Charolais bulls; IRE: Irish crossbred bulls; FRCR: French crossbred bulls, LIM: Limousin bulls; HEI: beef heifers.

2 Maize grain-based feeds: maize grain (whole and ground), maize grain and maize ears silages.

3 Protein by-products and supplements: soybean meal, cotton seeds, protein and mineral supplements.

4 Fibrous feeds: straw ad hay.

5 Other cereal silages: sorghum, barley and wheat silages.

6 Other cereal grains: barley grain (whole and ground).

7 CP: crude protein content.

8 P: phosphorus content.

9 EE: ether extracts content.

10 NDF: neutral detergent fibre content.

11 CH_4 enteric: emissions due to enteric fermentation.

12 CO_2-eq diet: emissions due to the production of the feedstuffs composing the diets.

a,b,c: LS Means with different superscripts within row differ significantly ($P<0.05$).

Table 3.

Least Squares means of beef category, class of diet self-sufficiency rate (SELF, %), crude protein (CPI, kg DM/head/day) and phosphorus daily intake (PI, kg DM /head/day) for the different impact categories (N=245 batches).

Effect	GWP[1]	AP[2]	EP[3]	CED[4]	LO[5]
Beef category[6]:					
P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
CH	8.7 ^{a}	138 ^{a}	54 ^{a}	52 ^{a}	7.7 ^{a}
IRE	8.7 ^{a}	135 ^{a}	53 ^{a}	53 ^{a}	7.6 ^{a}
FRCR	9.5 ^{b}	150 ^{b}	58 ^{b}	60 ^{b}	8.5 ^{b}
LIM	8.9 ^{a}	140 ^{a}	54 ^{a}	52 ^{a}	7.7 ^{a}
HEI	11.1 ^{c}	187 ^{c}	68 ^{c}	58 ^{c}	9.6 ^{c}
SEM	1.4	19	7	11	1.1
SELF (%)[7]:					
P value	< 0.001	< 0.001	0.021	< 0.001	< 0.001
Low (34 ± 7)	9.9 ^{b}	155 ^{b}	59 ^{b}	61 ^{b}	8.8 ^{c}
Intermediate (44 ± 6)	9.5 ^{b}	152 ^{b}	58 ^{b}	57 ^{b}	8.4 ^{b}
High (60 ± 7)	8.7 ^{a}	143 ^{a}	56 ^{a}	46 ^{a}	7.4 ^{a}
SEM	1.7	22	8	9	1.1
CPI (kg/head/day)[8]:					
P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Low (1.27 ± 0.06)	8.9 ^{a}	144 ^{a}	55 ^{a}	52 ^{a}	7.9 ^{a}
Intermediate (1.38 ± 0.07)	9.4 ^{b}	152 ^{b}	58 ^{b}	55 ^{b}	8.3 ^{b}
High (1.53 ± 0.07)	9.8 ^{c}	154 ^{c}	60 ^{c}	57 ^{b}	8.5 ^{c}
SEM	1.5	19	8	12	1.2
PI (g/head/day) [9]:					
P value	0.001	0.002	< 0.001	0.026	0.002
Low (34 ± 2)	9.0 ^{a}	141 ^{a}	55 ^{a}	52 ^{a}	7.8 ^{a}
Intermediate (39 ± 2)	9.5 ^{b}	150 ^{b}	58 ^{b}	55 ^{ab}	8.2 ^{b}
High (43 ± 2)	9.6 ^{b}	160 ^{b}	60 ^{b}	57 ^{b}	8.6 ^{b}
SEM	1.5	20	7	12	1.2

1 GWP: global warming potential.

2 AP: acidification potential.

3 EP: eutrophication potential.

4 CED: cumulative energy demand.

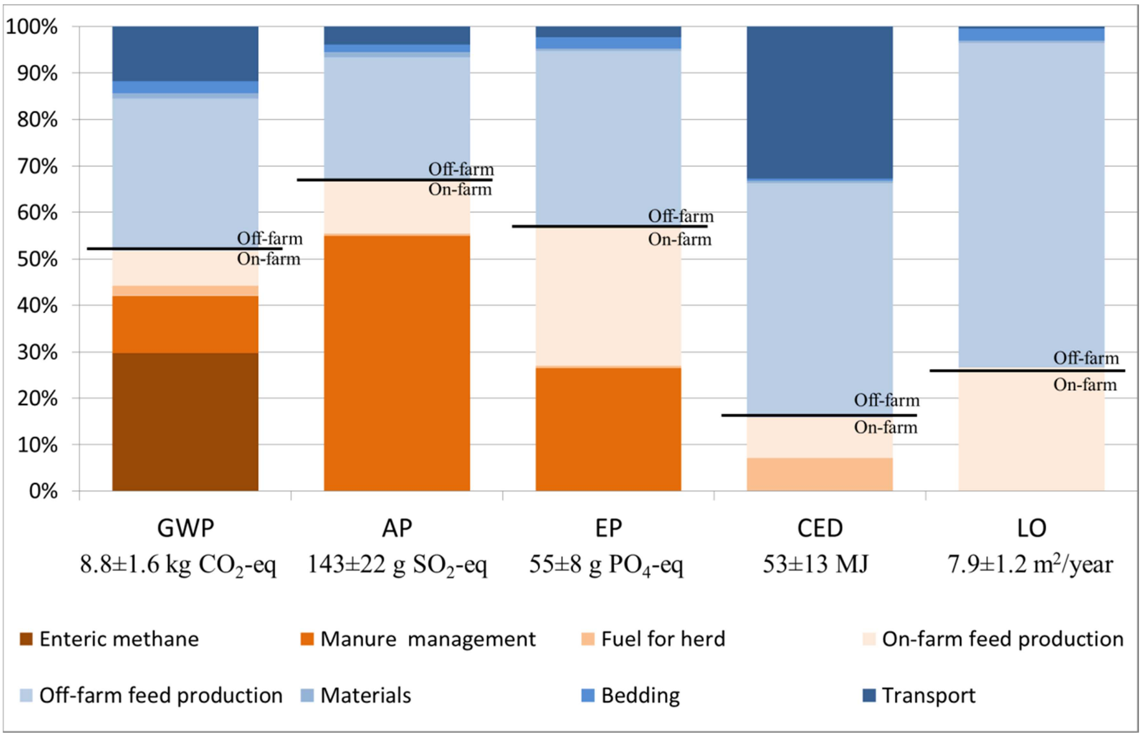
5 LO: land occupation.

6 CH: Charolais bulls; IRE: Irish crossbred bulls; FRCR: French crossbred bulls, LIM: Limousin bulls; HEI: beef heifers.

7 SELF: self-sufficiency rate class (percentage of dry matter intake produced on farm). Mean ± standard deviation for each class is reported into brackets.
8 CPI: daily crude protein intake. Mean ± standard deviation for each class is reported into brackets.
9 PI: daily phosphorus intake. Mean ± standard deviation for each class is reported into brackets.
a,b,c: LS Means with different superscripts within column differ significantly ($P<0.01$).

Figure 1.

Descriptive statistics (mean ± SD) for the impact categories values (expressed per 1 kg BWG) and contribution (%) of each production stages (on-farm stages coloured in orange and off-farm stages coloured in blue) to each impact category (N=245 batches).



Appendix to Chapter 3

Supplementary Tables to the Chapter 3

Supplementary Table 1.

Description of size (ha), number of animals composing the mean herd (animals/day) and amount of materials (per animal/year) for the Italian beef fattening farms (N=17).

Farm	Farm AA[1]	Herd AA[2]	Herd	Plastic (kg)	Fuel (kg)	Bedding materials (kg)	Electricity (kWh)	Lubricant (g)
1	56	46	310	15.3	33.4	88	38.3	116
2	134	124	872	1.2	21.8	14	18.1	123
3	95	91	798	0.6	21.7	116	41.6	0
4	91	76	860	1.0	38.0	242	27.0	316
5	194	97	404	1.4	52.2	186	4.3	803
6	266	170	672	0.3	78.1	359	16.4	1671
7	218	145	1035	0.8	21.7	0	13.7	0
8	38	37	274	2.9	43.7	310	28.1	438
9	37	19	273	4.0	30.7	264	40.6	659
10	87	53	543	0.4	48.8	425	26.4	369
11	189	90	748	2.4	13.9	157	25.0	241
12	173	84	491	1.6	15.6	298	41.8	183
13	337	180	924	0.9	43.5	62	16.0	351
14	187	72	1010	0.5	48.5	820	17.0	149
15	95	83	522	0.6	21.7	0	16.9	361
16	90	82	267	3.8	76.9	384	25.6	1189
17	229	150	1035	0.9	26.3	0	42.8	292

[1] Farm AA: Farm agricultural area (total agricultural surface destined to herd manure spreading, in hectare)

[2] Herd AA: Herd agricultural area (total agricultural surface for producing the on-farm feedstuffs, in hectare)

General discussion and conclusions

Life Cycle Assessment has emerged as one of the most suitable methodologies to assess the environmental footprint of the livestock production systems, being capable to take into account the peculiarities of a regional system such as the integrated France-Italy beef production system. The results of this PhD thesis show that the environmental footprint of the integrated France-Italy beef production system was similar to that found for other European and extra-Europe beef systems (De Vries et al., 2015). In particular, the mean GWP value found in this PhD thesis was within the range found for alternative beef production systems totally located in France, whose GWP values ranged from 12.8 to 14.5 kg CO_2-eq/kg BW (Gac et al, 2010; Nguyen et al., 2012; Dollé et al., 2013; Veysset et al., 2014; Morel et al., 2016). The differences reported by de Vries et al. (2015) about the methodologies applied for the computation of the emissions could invalidate a direct comparison the absolute impact categories values, as different methods can be based on different assumptions or focus on different parameters to estimate the same variable. For this reason, the consideration of a range of values found in other studies considering the same type of beef production system could be more effective. Although the diversity of methodologies has to be taken into account when reporting the LCA-based results of the environmental footprint of a production system, the rank of GWP and AP values found for the different beef categories reared in the north-eastern Italy beef fattening system was not altered by considering three different methods to compute enteric CH_4 production and the acidification emissions from barns and manure management systems, respectively, as reported in the first contribution of this PhD thesis. Nevertheless, the variability of the absolute values found for the three different methods confirmed that an improvement of the standardization of the LCA model and emission computation methodology is necessary in perspective.

The attributional LCA methodology allows to give a photograph of specific environmental relations of the integrated France-Italy production system (Finnveden et al., 2009), and the consideration of indicators related to other livestock issues such as the food security and the competition with a direct human use of the human-edible feedstuffs could improve the insights on the production system-environment relationships. The integration of the pasture-based France suckler cow-calf system with the cereal-based Italian fattening farms seems a good strategy in terms of exploitation of resources available, as it keeps the share of non-human-edible feedstuffs high, mainly thanks to the suckler cow-calf beef system located in the low cropland-suited territories of Central France, but at the same time, it takes advantage of the beef productivity and the good feed efficiency of the cropland-suited farms of north-eastern Italy. Furthermore, the trade-off between emission-related impact categories and human-edible feed conversion ratios highlighted that different types of indicators should be considered in order to obtain a more accurate assessment of beef livestock systems.

Moreover, the photograph of the environmental footprint obtainable with the LCA methodology could show where the impact hot-spots are and could suggest where is possible to act to mitigate the environmental impact generated by the production system. As reported in the second contribution of this PhD thesis, the GWP, AP, EP and LO were more related to the on-farm production stages, due to the share on the on-farm impact of the French suckler cow-calf phase, whereas the CED was more related to the off-farm stages due to the great use of off-farm feedstuffs and related transport in the Italian fattening phase. The consideration of the different location and agro-ecological types of the land surface area implied into the integrated France-Italy beef production system is important when different production stages such the feedstuffs production are connected with the natural biogeochemical cycles

(Soussana et al., 2010). As the majority of the LO mean value found in this PhD thesis was permanent grasslands located in Central France area with low or no vocation for crop production, the carbon sequestration capacity of permanent grasslands has to be considered: the mean value of GWP found for the integrated France-Italy beef production system decreased of 24% when enlarging the system boundaries in order to take into account the carbon sequestration function. The uncertainty regarding the value of carbon sequestration rate may lead to overrate or underrate the GHG offset due to permanent grasslands (Flysjo et al., 2011): using a range of carbon sequestration rates found in literature for the French permanent grasslands (Dollé et al., 2009; Allard et al., 2007), the GHG offset ranged from 7.7% to 32% of the GWP mean value. To have a global perspective on GWP, further research are needed to evaluate the effect of temporal variation of the carbon sequestration rate as well as to take into account the uncertainty related to the carbon loss due to the land-use change (e.g., deforestation).

Focusing into the Italian beef fattening system, the variability shown among farms and the great importance of the on-farm production stages in the environmental footprint values implied the possibility to implement mitigation actions in order to reduce its environmental footprint. The approach based on the batch introduced in the first chapter of this PhD thesis allowed to analyse the effects of specific management actions within the same farm and among farms and was tested in the third contribution for studying the mitigation effect of some diet-related factors and of the beef category on the impact categories (GWP, AP, EP, CED and LO) values. It highlighted that more efficient beef categories, enhanced self-sufficiency rates of the beef diets and lower crude protein and phosphorus daily intakes had a significant mitigation effect on the impact categories values. Moreover, these effects did not seem to affect the productive performances as well as the farm economic profitability, suggesting that the environmental mitigation of the north-eastern Italy beef fattening system is feasible with the production and economic concerns. Nevertheless, further investigations precisely aiming to evaluate the relationships between mitigation actions and farm productivity and profitability are needed.

In conclusion, while the consumers awareness about livestock systems environmental footprint is increasing and the livestock systems faced complex and different challenges at environmental level, as well as at social and economic ones, the multi-indicators LCA methodology could give an important contribution to address the environmental challenge, because it allows the emerging of the impact hot-spots and possible trade-offs between different livestock-related environmental issues. The information acquired might direct the strategies aimed to reduce the environmental footprint without negatively affecting other important issues such as the food security, the food vs feed competitive destination of the human-edible feedstuffs and the farm economic profitability.

In perspective, the multi-indicators LCA-based methodology developed in this PhD thesis could be applied to other livestock production systems such as the Italian dairy production system and to suggest further improvements to Italian beef fatteners considering the supply chain in an integrated point of view.

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Appendix IV

This paper was presented at 22nd Animal Science Days meeting in Kaposvar (HU) in 2014. At the congress, I presented some preliminary results of my PhD project. This contribution is attached to the PhD thesis as supplementary material.

Sustainability of intensive beef production system in North-East Italy: relationships between phosphorus supply and productive performance

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Abstract

The beef sector of the Veneto Region is based on young bulls imported mainly from France and reared intensively using total mixed rations based on maize silage and concentrates. While nitrogen excretion of the sector is regulated by Nitrate Directive, the excretion of phosphorus (P) is less studied, despite of its potentially great impact on environment. This study aims at analysing the relationships between productive and economic performances and P content of the diet in 14 farms of the region. For a whole productive year feed consumption, ingredients and chemical composition of diets were monthly collected. Average Daily Gain (ADG), Feed conversion ratio (FCR), daily gross profit (DGP), and P balance were calculated. ADG, FCR, and DGP were analysed with a mixed model using arrival season, arrival weight, class of dietary content of P, protein and starch as fixed effects and farm as random effect. Average daily gain was 1.39±0.08 kg/d, FCR was 0.14±0.01 kg/kg, and DGP 2.5±0.40 €/d. The P dietary content was on average high (0.38±0.04, % DM), which resulted in P intakes and excretions of 13.49±1.94 and 9.85±1.92 kg/head/place, respectively. None of the productive and economic traits was affected by phosphorus content of the diet. As a consequence, the phosphorus supplementation can be reduced without the risk of weakening productive and economic performances.

Keywords: Beef cattle, intensive farms, environment, Charolais breed, P excretion.

Introduction

Livestock production has complex interactions with the natural environment, especially for nitrogen (N) and phosphorus (P) excreted by animals (*Gerber et al.,* 2013). In the recent years, the research has mainly focused on human-related nitrogen impacts on environment, whereas phosphorus impacts have been less studied (*Schipanski and Bennett,* 2012).

The beef sector of the Veneto Region (North-East Italy) represents an important contributor to the national beef production. It is based on young bulls imported mainly from France (especially Charolais breed), and intensively reared for 7-8 months using total mixed rations (TMR). The most important feeds used are maize silage and concentrates (*Xiccato et al.,* 2005).

In the last years, the sector has met the European Union's thresholds about nitrogen application on agricultural fields imposed by the Nitrate Directive (n.676/92). However, although manure application is carried out to meet crops N requirements, and also to respect the EU nitrogen thresholds, P surpluses in soils are observed, since the N/P ratio required by plants is higher than that in manure (*Kissinger et al.,* 2005).

Due to the affinity of phosphorus compounds with soil's elements (*James et al.,* 1996), and the practice to concentrate the application of manure nearby their production sites in intensive farming systems (*Defra,* 2004), these surpluses have led to soil P accumulation in various areas of Europe (*Hooda et al.,* 2001*; Ott and Rechberger,* 2012). The resulting reduction of soil capacity to adsorb phosphorus could cause an increase of leaching rates to groundwater bodies (*Pautler and Sims,* 2000), and also of phosphorus loss with runoff events, carrying to a greater eutrophication risk of surface water resources (*James et al.,* 1996).

Overfeeding of beef cattle with P is common in the practice, partly because is frequent the inclusion in the diet of feeds naturally high in P, partly because additional P supplementation may occur irrespective of the actual P content of the diets (*Vasconcelos et al.,* 2007). This study aimed to analyse the effects of phosphorus supply on animal productive performances in the North-East Italy intensive beef sector, in order to evaluate whether P excretion could be reduced without consequences on productive and economic performances.

Material And Methods

Data for this study originated from 14 specialized fattening herds located in the Veneto region and associated to AZoVe (Associazione Zootecnica Veneta, Ospedaletto Euganeo, Italy), a large cooperative of beef producers. The reference unit for data collection was the batch, defined as a group of stock calves homogeneous for genetic type, origin, finishing herd and fattening period. For each batch the following data were acquired: average BW at arrival and at sale (kg); fattening length (d); purchase and sell price per head (€/head). These data were used to compute the following traits: average daily gain (ADG, kg/d), calculated as (live weight at sale – live weight at arrival)/fattening length; feed conversion ratio (FRC, kg/kg), calculated as (live weight at sale – live weight at arrival)/total feed DM intake in fattening period; daily gross profit (DGP), calculated as value at sale - value at purchase, and expressed per day of fattening (€/d). Herds were visited monthly during the whole year, diet formulations and a sample for TMR were collected for each batch, and the weight of total mixed ration (TMR) uploaded into the manger for each batch was recorderd. Two subsequent intake observations were averaged to obtain the mean daily dry matter intake (DMI). Diets were chemically analysed for determination of dry matter (*AOAC method 934.01*, 2003), crude protein (*Kjeldahl, AOAC method 976.05*, 2003), ash (*AOAC method 942.05*, 2003), Neutral Detergent Fiber according to *Van Soest* (1991), starch (HPLC method; *Bouchard et al.*, 1988) and phosphorus content (*AOAC 999.10*, 2000 and ICP-OES).

Only batches with Charolais breed and more than four month samples were considered in the study. The final data set included 126 batches, 8545 animals and 105 diets.

Phosphorus balance

Phosphorus balance was calculated following the ERM method (2001). The model estimates P excreted as P intake – P retention. Each element refers to 1 head/batch/year. The single elements are obtained as follows:

P intake = Intake* (P diet/100) (kg), where Intake is the total feed intake for head/batch/year

P retention = (LWf – LWi) * K_P (kg), where LWf and LWi are final and initial live weight respectively, and K_P is phosphorus retention per life weight unit coefficient, corresponding to 0.0075 kg/kg (*Whiters et al.,* 2001).

Statistical analysis

For statistical analysis, the database was edited as follows: the P content (% DM) of the diet was grouped in three classes (ClP) on the basis of 25th and 75th quartile; the same procedure was used for protein (ClPr) and starch (ClS) content. Season of arrival was classified as winter, spring, summer, autumn on the basis of arrival month of the batch; arrival weight was divided into three classes based on the mean±1SD. A preliminary analysis (GLM) showed a large variability among farms in P dietary content (Figure 1). The P content was correlated ($r=0.41$, $P<0.001$) with the proportion of feeds used to increase N dietary content (mix of oilseed by-products, corn distiller and maize gluten feed, and a commercial mineral-protein supplement), and the variability among farms can be explained with different feeding strategies and management practices. For this reason, we decided to use the farm as random effect in the final statistical model.

Average daily gain (ADG), feed conversion ratio (FCR), and daily gross profit (DGP) were analysed with mixed linear models (SAS, 1991), with arrival season, arrival weight class, protein class (ClPr), starch class (ClS), and P class (ClP) as fixed effect and farm as random effect.

Results And Discussion

Mean initial and final body weight were 390 and 714 kg, respectively (*Table* 1), and the fattening period averaged 233 d. In this period, the mean daily DMI resulted of 10.2 kg/d, ADG was 1.39 kg/d, and FCR was 0.14 kg/kg, with a range of variation among batches wider for ADG than for FCR.

The ADG found was similar to those obtained for Charolais breed reared in Veneto Region (*Sturaro et al.*, 2005). Moreover, ADG and FCR mean values were similar to those obtained in performance experiments using maize-based diets (*Mandell et al.*, 1997; *Arthur et al.*, 2001). About economic result, DGP was 2.50 €/d on average. A relevant variation among batches was recorded, with the maximum value being almost double than the minimum. A positive correlation existed between ADG and DGP (n=123, r=0.56, P<0.001).

The TMRs of all the batches contained maize silage and soybean meal, and almost all contained also maize flour (89% of TMRs) and sugar-beet pulp (83% of TMRs); corn distiller, maize gluten feed, alfalfa hay, wheat straw, hydrogenated fat and mineral-protein supplement completed the mean diet; other ingredients were less important (data not shown).

The mean chemical composition of diets is shown in *Table 2*. Mean phosphorus level resulted 0.38% DM, with a relevant variability since the highest TMR content was 1.7 times the lowest one. The range of P dietary contents observed is higher, even in the lowest values, than the reference P requirements for beef NRC (2000), 27.6-52.7 g P/d observed vs 21-22 g P/d recommended, probably because of the practice of including P supplementation in the protein supplement without accounting for the basal diet content. Protein levels were on average 1.42 kg/d, higher than the NRC (2000) recommendations of 1.07 kg/d CP, although also in this case there was a remarkable variability (range: 11.5-15.5% DM). Finally, contents of starch, which is an important source of energy for fattening young bulls varied from 27 to 43%.

The results of P balance are given in *Table* 3. The intake, depending on the combination of varying DM intakes and P (%DM) contents, varied more than the retention, which depended on a moderately variable growth rate. The resulting P excretion was close to 10 kg/head/d, with a wide variability; the same value, expressed as kg/day/1000 heads, was higher than that found for US intensive beef production (28.1 vs 23.1 kg) (*Cole and Todd*, 2009). Phosphorus efficiency was in the lowest values of the ranges reported in literature, and highly variable.

The results of statistical analysis of ADG, FCR, and DGP are given in *Table 4*. The effect of arrival season was statistically significant for all variables, as expected from what usually observed in the practice of this fattening system: ADG, FCR and DGP were higher for batches arrived in summer than in winter (ADG: 1.41 and 1.36 kg/d; FCR: 0.14 and 0.13 kg/kg; DGP: 2.72 *vs* 2.2-2.1 €/d). Effects of arrival weight were less marked, and significant only for ADG, which decreased with increasing weight class (1.42 to 1.36kg/d, respectively for the light and heavy classes) and FCR, which observed the same trend with increasing weight class (0.14 to 0.13 kg/kg, respectively for the light and heavy classes). This was also expected since young bulls lower at arrival tend to grow faster (*Chambaz et al.*, 2001). The levels of P had no effect on ADG, FCR, and DGP. This is not surprising since P intakes were in general higher than requirements (see *Table 2*). Similarly, the class of dietary protein had no significant effects on productive and economic parameters. Class of starch influenced ADG, with better values for the high as respect to the low class (1.41 kg/d vs 1.35 kg/d), and

DGP, with better values for intermediate class (2.55 €/d) and high class (2.50 €/d) as respect to low class (2.33 €/d).

Conclusions

The productive performances of intensive North-East Italy beef sector were not influenced by phosphorus content of diet. As a consequence, P content of most diets appeared in excess, and it could be reduced without impairing growth performances In relation with P environmental fate, and its impact on promoting eutrophication of surface waterbodies, this reduction can be an important tool to improve the relation between the local beef sector and the local environment.

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Table 1.

Descriptive statistics for productive performances

Item	Unit	Mean	SD	Min	Max
Initial live weight	Kg	390	28	322	458
Final live weight	Kg	714	20	670	772
Duration	D	233	18	190	324
DMI	kg/head/d	10.22	0.79	8.27	11.73
ADG	kg/d	1.39	0.08	1.19	1.60
FCR	kg/kg	0.14	0.01	0.11	0.17
Daily gross profit	€/d	2.50	0.40	1.66	3.39

DMI: dry matter intake; ADG: average daily gain; FCR: feed conversion ratio

Table 2.

Descriptive statistics for chemical composition of diet (% DM)

Item	Mean	SD	Min	Max
P	0.38	0.04	0.27	0.45
CP	13.86	0.74	11.48	15.55
Ash	5.93	0.37	5.06	6.62
Starch	33.89	3.90	27.06	42.74
NDF	32.03	2.98	24.31	38.23
NSC	44.75	3.20	38.54	53.05

CP: crude protein; NDF: neutral detergent fibre; NSC: not structural

Table 3.

Descriptive statistics for phosphorus balance

Variables	Unit	Mean	SD	Min	Max
P intake	kg/head/y	13.49	1.94	9.65	18.45
P retention	kg/head/y	3.64	0.21	3.12	4.20
P excretion	kg/head/y	9.85	1.92	6.05	15.11
P efficiency	%	27.55	4.20	18.09	37.31

Table 4.

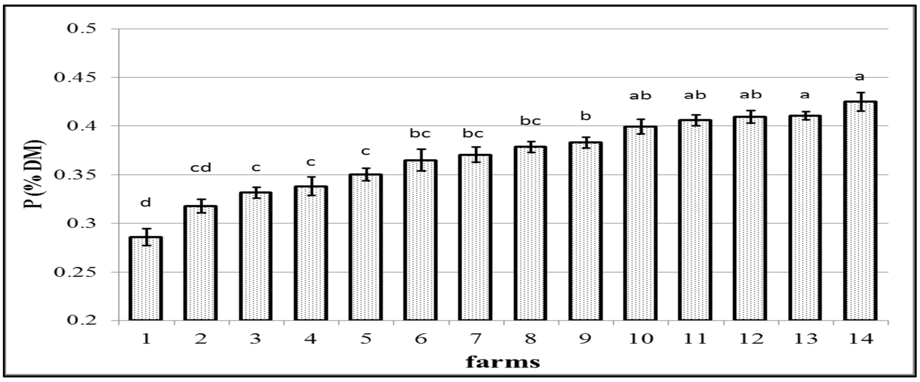
Mixed model analysis for productive performances

Effect	ADG (kg/d)		FCR (kg/kg)		DGP (€/d)	
	F	P-value	F	P-value	F	P-value
Arrival Season	4.51	0.01	12.76	< 0.01	34.84	< 0.01
Arrival weight	3.41	0.04	4.23	0.02	1.75	0.18
ClP	0.43	0.65	1.20	0.31	0.90	0.41
ClS	3.18	0.05	2.26	0.11	3.90	0.02
ClPr	0.43	0.65	2.84	0.06	2.73	0.07
RMSE	0.05		0.01		0.25	

ClP: classes of P (%DM), ClS: classes of starch(%DM), ClPr: classes of protein (%DM)

Figure 1.

LSmeans for P content of diet (% DM) per farm



Appendix V

Curriculum Vitæ

Personal Information

Surname	BERTON
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Education

Date	13/09/2013
Title	Master degree
Final mark	110/110 cum laude
Title of the thesis	Intensive beef fattening sector of north-eastern Italy: productive performance and environmental sustainability
Degree course	LM-75, Science and Technology for the Environment and Territory
University	University of PADOVA - Via 8 Febbraio, 2 – PADOVA (Italy)

Date	30/09/2011
Title	Bachelor degree
Final mark	110/110 cum laude
Title of the thesis	Prevention of the damages caused by deer (Cervus elaphus L.) in mountainous farms
Degree course	L-32 Science and Technology for the Environment
University	University of PADOVA - Via 8 Febbraio, 2 –

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Experiences

Period	01/01/2014 - today
Position	PhD candidate
University	University of PADOVA - Via 8 Febbraio, 2 – PADOVA (Italy)
Department	Department of Agronomy, Food, Natural resources, Animals and Environment
PhD course	ANIMAL AND FOOD SCIENCE

List of publications

Publications in ISI journals

BERTON M., Agabriel J, Gallo L, Lherm M, Ramanzin M, Sturaro E. Sustainability of the integrated France-Italy beef production system assessed through a multi-indicator approach. (submitted to Agricultural Systems).

BERTON M., Cesaro G, Gallo L, Pirlo G, Ramanzin M, Tagliapietra F, Sturaro E (2016). Environmental impact of a cereal-based intensive beef fattening system according to a partial Life Cycle Assessment approach. LIVESTOCK SCIENCE; p. 81-88, ISSN: 1871-1413, doi:http://dx.doi.org/10.1016/j.livsci.2016.06.007.

Other publications

BERTON M., Sturaro E, Ramanzin M, Bittante G (2016). Multi-indicators approach for the evaluation of efficiency of mountain dairy farms. In: Book of Abstracts of the 67th Annual Meeting of the European Association for Animal Production. Belfast, 29/08/2016-02/09/2016, Wageningen: EAAP scientific committee, ISBN/ISSN: 978-90-8686-284-9, doi: http://dx.doi.org/10.3920/978-90-8686-830-8.

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