Modeling Greenhouse Gas Emissions from Spanish Dairy and Beef farms: Mitigation Strategies

by

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List of Abbreviations

ADF	Acid Detergent Fiber
BW	Body Weight
C	Carbon
CF	Carbon Footprint
CH4	Methane
CHO	Carbohydrate
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalents
CNCPS	Cornell Net Carbohydrate and Protein System model
CP	Crude protein
CT	Condensed tannins
DCD	Dicyandiamide
DM	Dry Matter
ECM	Energy Corrected Milk
EMO	Environmental movements
EU	European Union
FA	Fatty acid
GEI	Gross Energy Intake
GWP	Global-warming potential
GHG	Greenhouse Gases
Ha	Hectare
IFCN	International Farm Comparison Network
IFSM	Integrated Farm System Model
IPCC	Intergovernmental Panel on Climate Change
IVDMD	In vitro dry matter digestibility

Kg	Kilogram
L	Liter
LCA	Life Cycle Assessment
Mcal	Megacalorie
ME	Metabolisable Energy
MJ	Mega joule
MNE	Milk N Efficiency
N	Nitrogen
N_2	Non reactive nitrogen
N, E	Nord, Est
NEL	Net Energy Lactation
NFE	Net Feed Efficiency
NH3	Ammonia
NH_4^+	Ammonium
P	Phosphorus
N_2O	Nitrous Oxide
RDP	Rumen Degradable Protein
T	Tonne
Total VFA	Total Volatile Fatty Acids
UNFCCC	United Nations Framework Convention on Climate Change
Ym	Emission factor

RESUMEN

Las emisiones de gases de efecto invernadero (GEI) y sus posibles efectos sobre el medio ambiente se ha convertido en un problema nacional e internacional importante. La producción bovino de leche y de carne, junto con todos los demás tipos de producción animal, se reconocen las fuentes de emisiones de gases de efecto invernadero, pero existe poca información sobre las emisiones netas de las granjas lecheras y de carne. Componente de modelos para predecir todas las fuentes importantes de CH_4, N_2O y CO_2 a partir de fuentes primarias y secundarias en la producción de leche se han integrado en una herramienta de software se llama Integrate Farm System Model (IFSM). Esta herramienta calcula la huella de carbono de la producción de leche y carne como el intercambio neto de todos los gases de efecto invernadero en equivalentes de CO_2 por unidad de energía de leche corregida (ELC) producida o kg de peso corporal (PC). IFSM y Cornell Net Carbohydrate and Protein System (CNCPS) se utilizaron en este estudio para evaluar las granjas lecheras típicas españolas para el cálculo de las emisiones de GEI y la evaluación de dieta y su contribución en la producción de metano, respectivamente. Las tres regiones más importantes de producción de vacuno lechero en España fueron seleccionados Mediterráneo área (Cataluña, Valencia y Murcia), Zona Cantábrica (Galicia, Asturias y Cornisa Cantábrica) y la zona Centro (Castilla-La Mancha, Castilla y León, Madrid y Aragón), en además dos otros granjas se han seleccionados (una ecológica y otra de la isla de Baleares).

El promedio de la huella de carbono de todas las granjas evaluadas fue de 0,83 kg de unidades de CO_2 equivalente / kg de ECM. Las granjas de zona mediterráneas tienen la más alta huella de carbono (promedio 0,98 kg CO_2e/kg de ECM), mientras que la Zona Central fue de 0,84 y el más bajo fue en las granjas del área Cantábrica (0.67). Dos extremos granjas se seleccionaron la primera tenía la huella de carbono el más alta y el metano no entérico (granja 197MA), mientras que la segunda tenía la huella de carbono más baja y el metano entérico el más alto (64CA), el primera fue simulada por el modelo IFSM utilizando diferentes escenarios de cambio de gestión, mientras que el segunda se simula con el modelo CNCPS utilizando diferentes estrategias de cambio en la dieta. Hemos encontrado que el cambio de gestión reduce las emisiones de metano hasta en un 30%, mientras que el cambio de dieta redujo hasta un 5%.

Tres granjas españolas representativas de terneros de cebo (dos granjas sin ensilaje de maíz, una con la raza Holstein y otra mixta, y la tercera con ensilado de maíz) se utilizaron para simular las emisiones de gases de efecto invernadero los mismos modelos. Los valores de la huella de carbono oscilaron desde 6,38 hasta 7,03 kg con un valor medio de 6,86 CO2e por kg de peso corporal. La granja de engorde con ensilaje de maíz tuvo un valor promedio de la huella de carbono de 6,98 Kg CO2 eq / kg de peso corporal, mientras que sin el ensilaje de maíz fue 6,90 Kg CO2 eq / kg de peso corporal.

Se concluyó que tanto la industria láctea española y sector de la carne tiene una menor huella de carbono y las estrategias de gestión proporcionan un mayor potencial para reducir las emisiones de metano en comparación con los cambios de escenarios dietéticos.

Palabras clave: gas de efecto invernadero, huella de carbono, la granja, el metano, IFSM, CNCPS, metano.

ABSTRACT

Greenhouse gas (GHG) emissions and their potential effect on the environment has become an important national and international issue. Dairy and beef production, along with all other types of animal agriculture, are recognized sources of GHG emissions, but little information exists on the net emissions from dairy and beef farms. Component models for predicting all important sources of CH_4, N_2O, and CO_2 from primary and secondary sources in dairy production were integrated in a software tool called the Integrate Farm System Model (IFSM). This tool calculates the carbon footprint of dairy and beef production as the net exchange of all GHG in CO_2 equivalent units per unit of energy-corrected milk (ECM) produced or kg body weight (BW). The IFSM and Cornell Net Carbohydrate and Protein System (CNCPS) were used during this study to evaluate typical Spanish dairy farms for GHG emissions calculation and diet evaluation for methane production, respectively. The Three most important regions of dairy cattle production in Spain were selected Mediterranean (Catalonia, Valencia and Murcia), Cantabric Area (Galicia, Asturias and Cantabria) and Central zone (Castilla-La Mancha, Castilla-Leon, Madrid and Aragon), in addition to two other farms (one organic and one from Baleares Island).

The average carbon footprint of all evaluated farms was 0.83 kg of CO_2 equivalent units/ kg of ECM. Mediterranean farms have the highest Carbon footprint (average 0.98 kg CO_2e/kg of ECM), while Cental Zone was 0.84 and the lowest was in Cantabric farms which (0.67). Two extreme farms were selected the first one had the highest carbon footprint and non-enteric methane (197MA), while the second had the lowest carbon footprint and the highest enteric methane (64CA), the first one was simulated by the IFSM model using different management change scenarios, while the second was simulated with CNCPS model using different dietary change strategies. We found that the management change reduced methane emission up to 30% while dietary change reduced it up to 5%.

Three representative feedlot beef Spanish farms (two farms without corn silage; one Holstein and another mixed breed, and the third with corn silage) were used to simulate GHG emissions using the same models. The carbon footprint values ranged from 6.38 to 7.03 kg with an average value of 6.86 CO_2e per kg BW. The feedlot farm with corn silage had an average carbon footprint value of 6.98 Kg CO_2e/ Kg BW while without corn silage was 6.90 Kg CO_2e/ Kg BW.

It was concluded that both the Spanish dairy and beef sector has a lower carbon footprint and the management strategies provide a greater potential to reduce methane emissions as compared with dietary scenarios changes.

Key words: greenhouse gas, carbon footprint, farm, methane, IFSM, CNCPS.

Introduction

Global demand for food is expected to increase 70% by 2050 as a result of population growth, predicted to peak at 9.2 billion by 2075 (FAO, 2010). To meet this demand, the worldwide production of meat and milk should be more than doubled. This strong growth in meat and dairy production will be driven not only by increasing population numbers but also by rising demand for animal products as more sectors of the population become increasingly affluent. Unfortunately, animal production and, in particular, ruminant production carries a significant environmental cost.

The environmental impact is mainly represented by the global warming phenomenon, as it is evident from recent observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising sea levels (Intergovernmental Panel on Climate Change, IPCC, 2007. Most of the observed increase in global temperatures is likely due to the observed increase in anthropogenic greenhouse gas (GHG) emissions (IPCC, 2007). It has been estimated that global GHG emissions in 2005 totalled 41,950 million tonnes of CO_2 equivalents (t CO2e), with Spain responsible for 356 thousand tonnes CO_2eq, ~1% of world emissions (Climate Analysis Indicators Tool, 2009). Agriculture is responsible for 10–13.5% (FAO, 2010) of GHG emissions, and ruminants are the most important livestock producers of these emissions, due to their larger mass and rumen fermentation (USDA, 2004). The main GHG from ruminant production are Methane (CH_4), Nitrous oxide (N_2O) and Carbon dioxide (CO_2). Methane is mainly produced by anaerobic bacteria decomposition of organic compounds in feed which is emitted as a product of enteric fermentation, and from decomposition of manure under anaerobic conditions (Moss et al., 2000). Nitrous oxide is emitted from manure and mineral fertilization as an intermediate product of nitrification/denitrification under conditions of low oxygen availability and degradation of organic matter (Fabbri et al., 2007), and CO_2 is produced mainly from fossil fuel and energy usage. In Spain, livestock contributes over 35% of total CH_4 emissions, of which 60% are from cattle (UNFCCC, 2013).

On the other hand, social pressure has generated a negative perception of conventional animal production as it is detrimental to animal welfare, and there is an increasing amount of evidence to support the notion that consumers are concerned about animal welfare (Capper and Hayes, 2012; Calsamiglia, 2008). Such evidence includes increasing demand for food products which are perceived by consumers to be more “animal friendly”, the growth in the number of vegetarians and calls for tougher regulation of welfare in animal production (Croney et al, 2012; RD 348/2000).

Furthermore, global warming, the emergence of highly contaminated geographical foci and the accumulation of GHG have created an urgent alarm and mobilized politicians and scientists for the study and implementation of control measures. The views are very different, their calculations are complex and the possibility of making mistakes (intentional or not) to interpret these results is likely. Therefore, today it is not easy to get a clear idea of the situation of agriculture in this context: the overall contribution, the most effective strategies for mitigation and the impact of their implementation to resolve the problem.

Spain is committed to the United Nations Framework Convention on Climate Change (UNFCCC) and annually reports its national emission inventory following guidelines promoted by IPCC (2006) to limit or reduce GHG from different sectors through national measures.

I. The Environmental Issue

1. The Global Environmental Problem

The environment has been an issue of growing concern over recent years all over the world, especially in the European Union. The environmental problem has aroused the attention of politicians, industry and consumers from different countries. It is no longer confined to local situations; it is now a global as well as a local problem.

The contemporary rise of environmental movements (EMO) started in the '60s in the US and Western Europe in connection with the development of the atomic energy, the chemical revolution in agriculture, the proliferation of synthetic materials, and the increased power generation and resource extraction technologies (Rome, 2003). The number of organizations involved in EMO grew from several hundreds to over three thousands by the '70s in the US, and the number of citizens joining EMO organizations increased significantly (Coglianese, 2001). In Europe, the peak of environmental organization activities and protests took place in the '80s (Rootes, 2003). Presently, social movements seem to be "a permanent component of western democracies" (Della Porta and Diani, 2006). Regional, national and supranational governments decisions concerning such crucial issues as, inter alia, environment, are carefully followed by social movements participants ready for prompt reaction.

The environmental problem is multi-factorial, including overpopulation, food production and distribution, depletion of energy resources, extinction of species, and environmental pollution. Each of them represent long term threats to the ecological balance of the planet, threatening the sustainability of the development of human beings as a whole (FAO, 2010).

The consciousness of the population towards environmental issues has been triggered by the observed damage to Earth: the depletion of the ozone layer, various kinds of pollution, acid rain, deforestation, climate change, global warming, and extinction of wild life. Pollution is in the center of environmental problems and the GHG greatly contribute to many environmental problems including climate change and global warming (IPCC, 2007a). This popular interest, in turns, has been translated into a multitude of state and supra-state legislative efforts to clean up, protect, and conserve the environment and its resources. State agencies implement most of these laws and regulations through rules based on scientific advances and technologies.

2. Climate Change and The Carbon Footprint

The climate change problem is currently one of the most crucial and pressing environmental matters in the international arena. It is a worldwide issue that affects both developed and developing countries alike. Therefore, it is important to combat the problem at the international level. The European Union claims to be the world leader in environmental protection, international negotiations and the development of a legal framework in climate and global warming (Kulessa, 2007).

The scientific research (Steinfeld et al., 2006; IPCC, 2007) proves that the climate change is occurring and can lead to serious economic and social problems. According to IPCC (2007), noticeable changes in the climate system are unequivocal and largely attributed to human activities (Kulessa, 2007). The major cause of the climate change is the increasing level of GHG in the atmosphere. As a result, the surface of the Earth is warmed by the atmosphere letting through shortwave solar radiation while increasing the absorption of longer infrared radiation coming back to the Earth (Grubb et al., 1998). The overall consequence is a rise in global temperatures (Figure 1).

During the past 100 years the average temperature of the Earth's surface has increased by 0.74 °C (EPA, 2007). If the level of anthropogenic GHG emissions continues to increase, it is possible that global warming by another 1-6°C may occur by the end of the century. The implications of a significant rise in global temperature would mostly include glacial melt, rising sea levels (Figure 3 and 4), changing weather conditions, flash flooding, hurricanes, droughts and the devastation of many fragile ecosystems (IPCC, 2007).

Among GHG, the carbon dioxide (CO_2) is the major culprit. Increasing CO_2 levels account for over 60% of the enhanced greenhouse effect (Figure 2). Internationally concerted action is necessary to stabilize the GHG concentration in the atmosphere and avoid dangerous anthropogenic interference with the climate system. The fact that some environmental damage can be irreversible requires an urgent action.

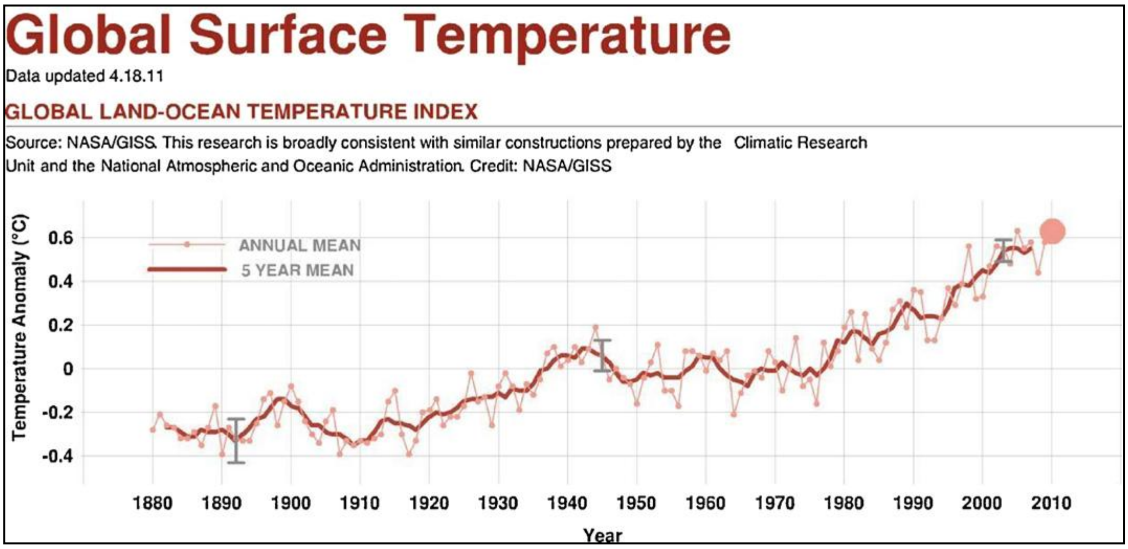

Figure 1. Global temperature variation (NASA satellite observations).

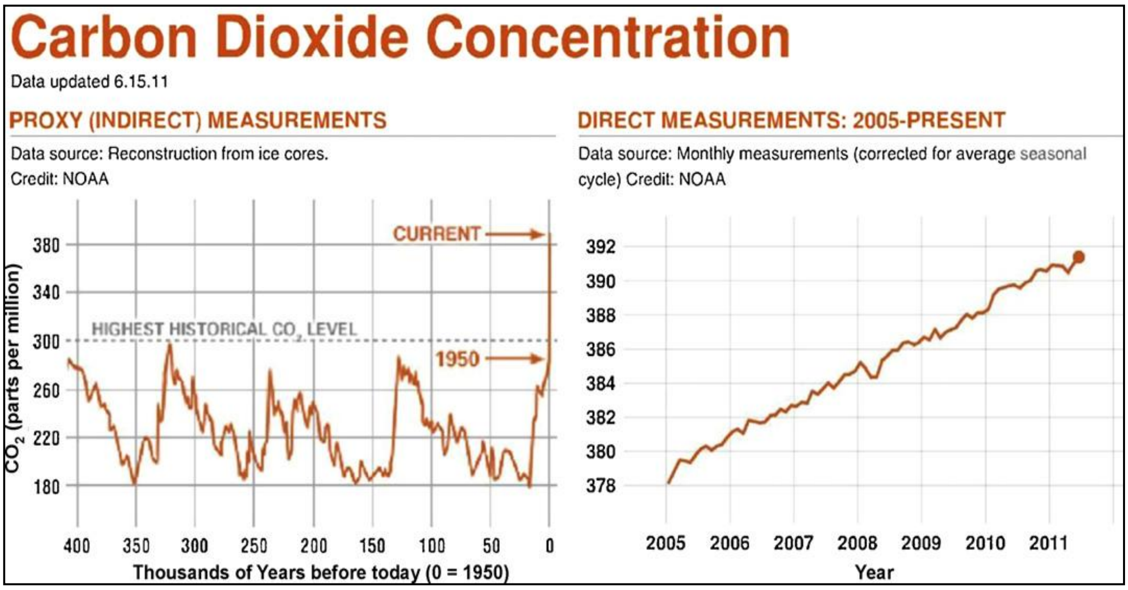

Figure 2. Carbon dioxide concentration level (NASA satellite observations).

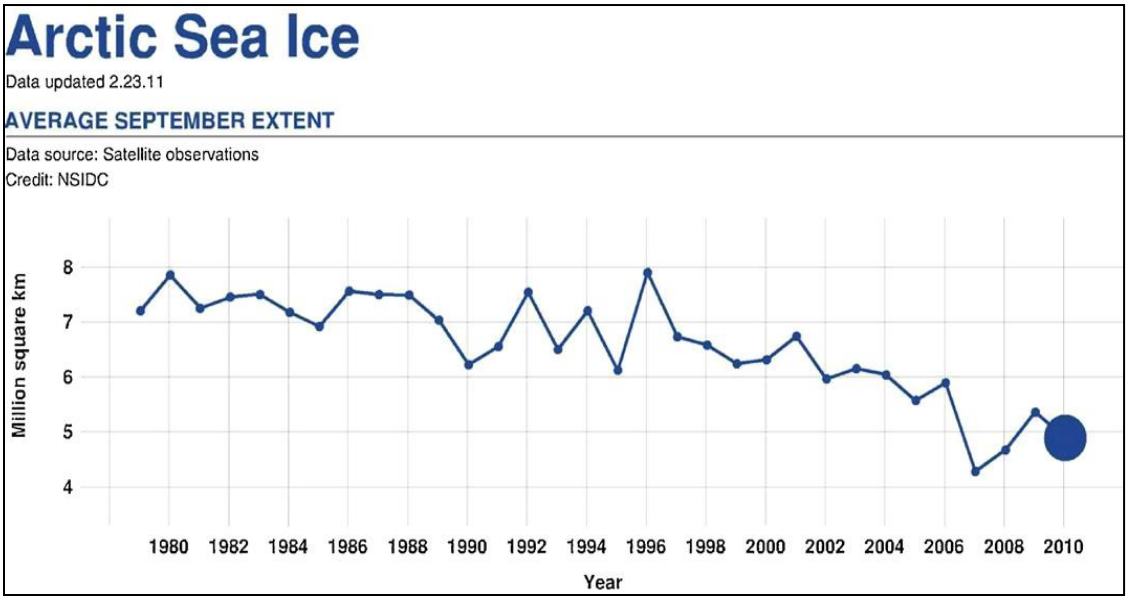

Figure 3. Arctic sea-ice level (NASA satellite observations).

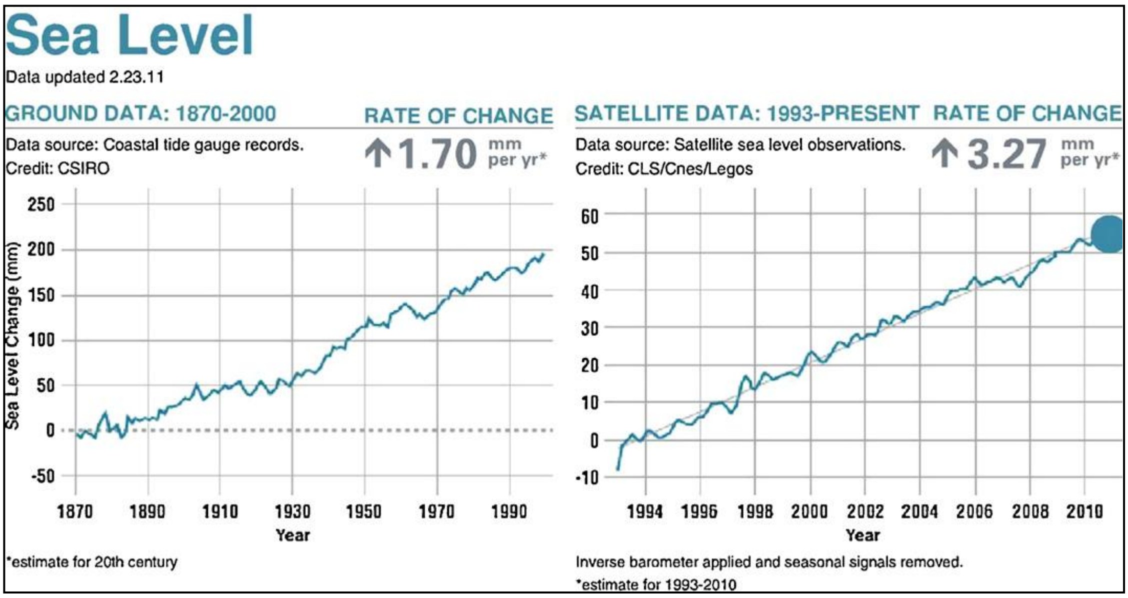

Figure 4. Sea leve (NASA satellite observations).

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its parties by setting internationally binding emission reduction targets. Recognizing that developed countries are the main contributor for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on developed nations under the principle of common but differentiated responsibilities.

The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005. The detailed rules for the implementation of the Protocol were adopted at COP 7 in Marrakesh, Morocco, in 2001, and are referred to as the "Marrakesh Accords". Its first commitment period started in 2008 and ended in 2012.

Recently, the "Doha Amendment to the Kyoto Protocol" (Doha, Qatar, on 8 December 2012) was adopted. Eventually, differentiated target plans were fixed, with each country establishing its own feasible aim. The European Union took the most ambitious of the targets, agreeing to a reduction of eight per cent of the six greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) below 1990 levels.

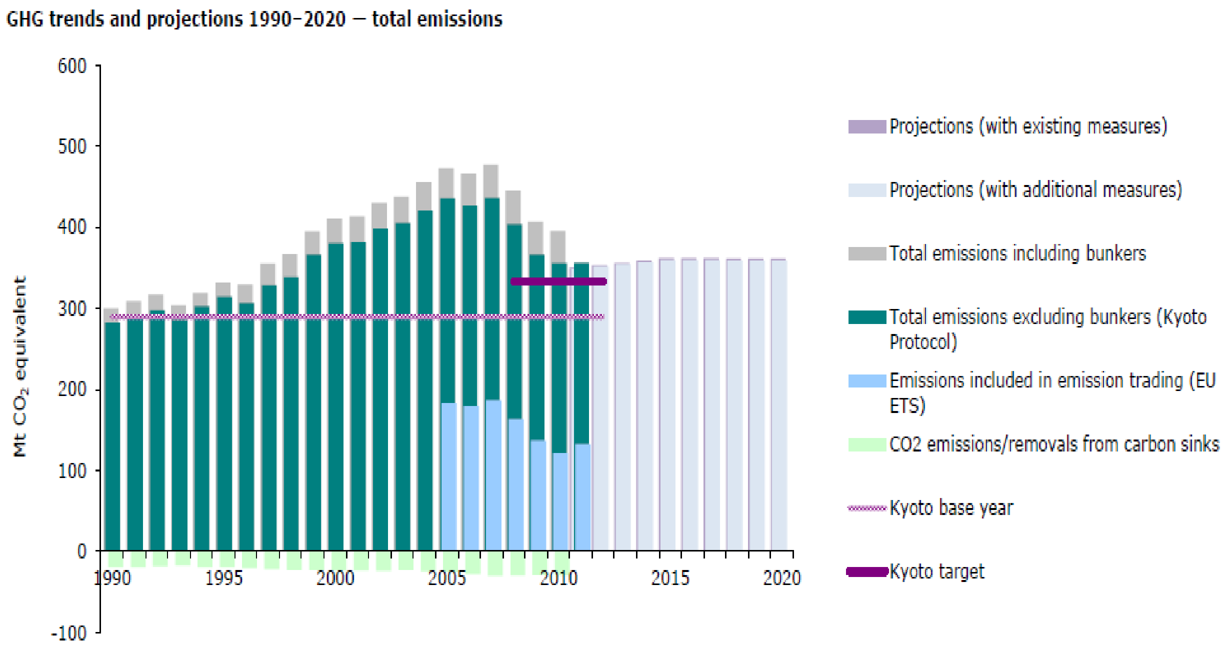

Figure 5. GHG trends and projections in Spain and his position from the Kyoto protocol (Source: Eurostat, 2010).

With the growing concern over global climate change and the potential impact of GHG emissions on the environment, there is a need to express the total emission of GHG associated with a product, process, or service in common units. A term that has come to represent this quantification is the carbon footprint. A carbon footprint is defined in many ways depending upon the product, process or service represented. In general, though, the carbon footprint is the total GHG emission, expressed in CO_2 equivalent units (CO_2e), associated with a product, process or service. The conversion of GHG to CO_2e is done using the Global-warming potential (GWP) of each gas where GWP values used for CH_4 and N_2O are 25 and 298, respectively (IPCC, 2001; EPA, 2007).

The carbon footprint of milk or beef production is the net of all greenhouse gases assimilated and emitted in the production system expressed as CO_2e divided by the total energy corrected milk or by kg of carcass produced. All emission sources of the three gases are summed and the net CO_2 assimilated in the feed production process is subtracted to give the net emission of the production system (Carbon Trust, 2010).

3. The Contribution of Agriculture and Animal Production to the Greenhouse Effect

Climate change is one of the greatest concerns facing our society (Steffen et al., 2007). During recent years, the livestock sector has been revealed as one of the main contributors to climate change, representing 18% of the GHG emissions (Steinfeld et al., 2006). This number has further been disaggregated, showing that the dairy sector (including meat by-products) is responsible for 4.0% of global emissions (Gerber et al., 2010a). If emissions are divided between dairy products and by-products (i.e. beef), dairy products represent 2.7% of global GHG emissions (Gerber et al., 2010a). GHG emissions associated with agricultural products, especially animal products, differ from those of other sectors (e.g. transport or energy). For most sectors, fossil carbon dioxide (CO_2) dominates GHG emissions, while in agriculture methane (CH_4) and nitrous oxide (N_2O) are the most important contributors. In addition, biogenic CO_2 from land use change contributes significantly in agriculture.

Figure 6 shows GHG emissions for different sectors. In this schematic representation, the agricultural contribution is only 13.5%, but this is because diesel consumption by tractors (reported under energy supply), transportation of feed (reported under transport) and production of fertilizers (reported under industry) are not included in agricultural emissions. Moreover, emissions from land use change are reported under forestry. If all these contributions were included, the agricultural sector would actually be accountable for about one third of global anthropogenic GHG emissions. Hence, agriculture is likely responsible for 30-35% of the global GHG emissions (Foley et al., 2011).

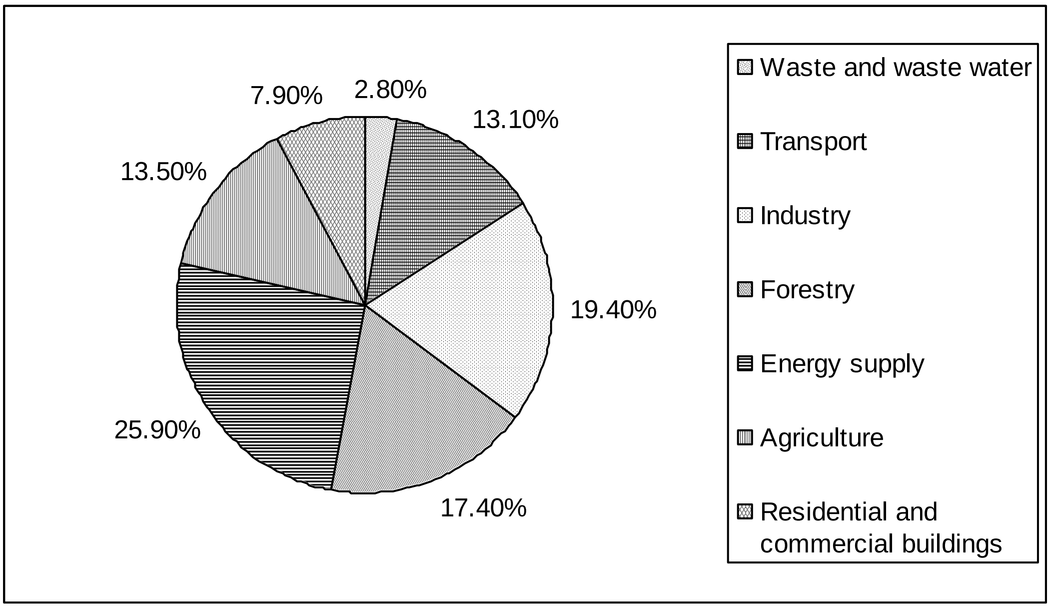

Figure 6. Greenhouse gas emissions per sector (FAO, 2010).

Methane is the highest contributor to GHG produced by ruminants. The amount of this gas emitted by ruminants depends essentially on the make-up of their digestive system and diet. Ruminant species have higher emission rates due to the type of fermentation that generates methane in the rumen as part of their digestion process. In Spain, the main species of ruminants include cattle, sheep and goats. Among the pseudo-ruminants (horses, mules, asses) and the monogastric species (swine), methane emission rates are far lower.

Figure 7 shows the contribution, relative to emissions, of each of the activities of animal production. In 2011, the main source of CH_4 in this activity were non-dairy cattle (beef, dry cattle and replacement heifers) with 43% of emissions, followed by sheep with 30% and dairy cattle with 17% of total emissions activity. Taken together, the rest of animals represent almost 10 % of the emissions produced.

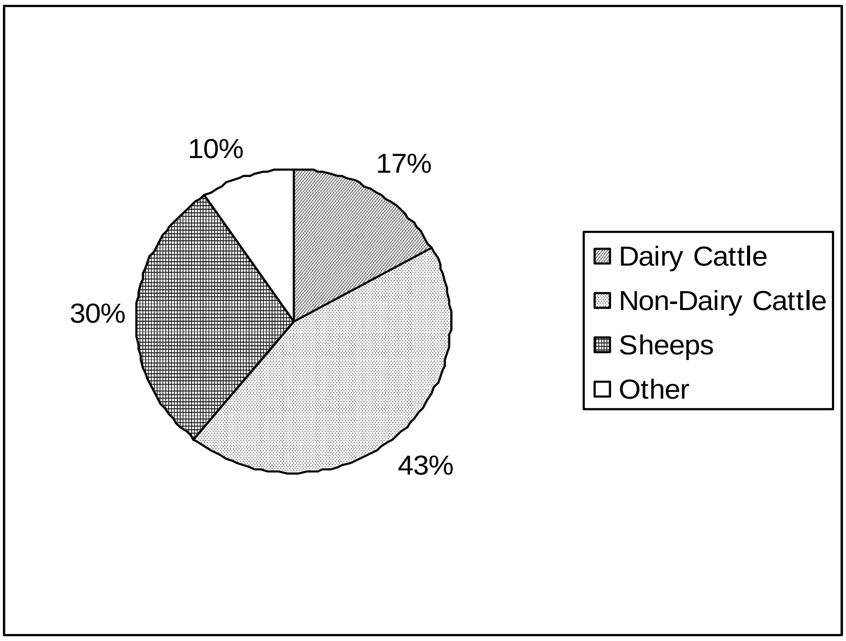

Figure 7. Distribution of emissions according to livestock activity in Spain (UNFCCC, 2013).

II. Sources of Greenhouse Gas Emissions from Dairy and Beef Farm

In all dairy and beef production systems, the most important sources of GHG including carbon dioxide (CO_2) , methane (CH_4) , nitrous oxide (N_2O) and indirect greenhouse gases/pollutants (NH_3) are the animal themselves, animal housing, storage and treatment areas for manure, and spreading of manure and chemical fertilizers (Steinfeld et al., 2006).

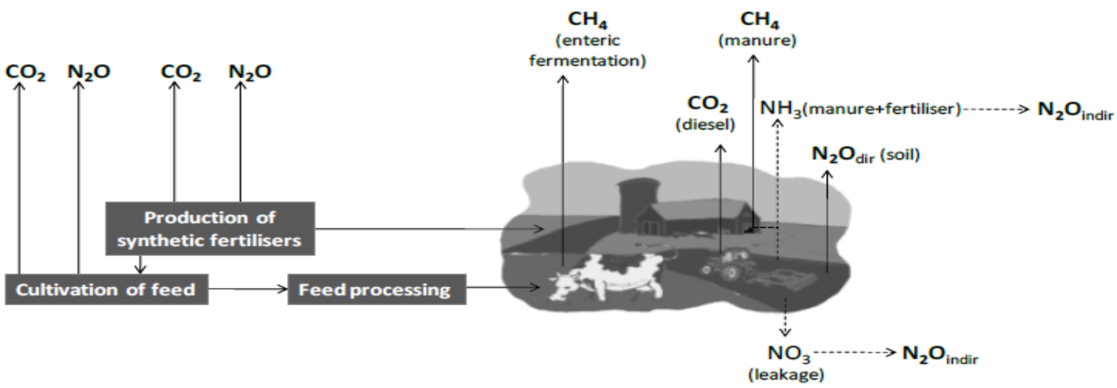

Figure 8. Overview of the main greenhouse gas emissions at farm level (Berglund et al.2009).

1. Methane Emission (CH_4)

1.1. Enteric Emission: Enteric Fermentation

Enteric fermentation in ruminants is the largest source of CH_4 emission from dairy farms (Chianese et al., 2008a). In the rumen, CH_4 is formed from hydrogen and CO_2 due to archaea methanogens. Hydrogen originates from the fermentation of carbohydrates by bacteria and protozoa, and the amount depends on the ratio of different volatile fatty acids: The pathway for the synthesis of acetate and butyrate produces H and the pathway for the synthesis of propionate consumes H. The processes are detailed in Morgavi et al. (2010a).

The CH_4 produced is released to the atmosphere by belching. The amount of CH_4 produced from enteric fermentation depends on various factors including animal type and size, digestibility of the feed, and the intake of dry matter, total carbohydrates, and digestible carbohydrates (Chianese et al., 2008a).

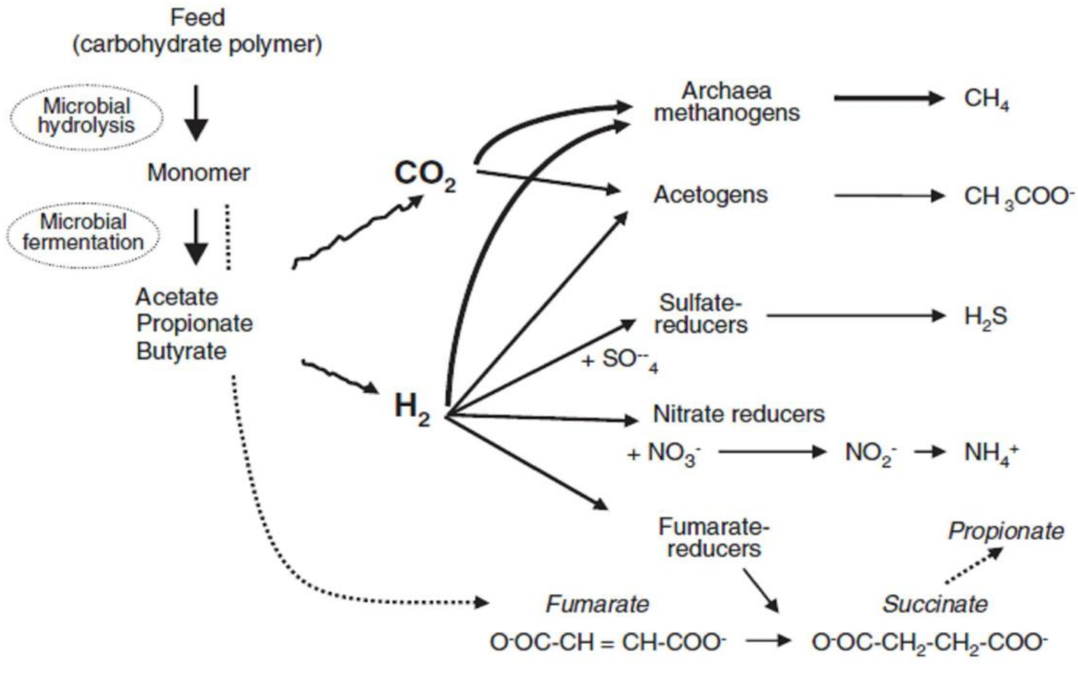

Figure 9. Schematic microbial fermentation of feed polysaccharides and H_2 reduction pathways in the rumen (Morgavi et al., 2010a).

1.2. Non-Enteric Emission: Manure Storage

During manure storage, CH_4 is also generated through a reaction similar to that described for enteric fermentation. The cellulose in the manure is degraded by microbes, and the products of this process serve as substrates for methanogenesis (Kreuzer and Hinderichsen 2006). Temperature and storage time are the most important factors influencing CH_4 emissions from stored manure because substrate and microbial growth are generally not limited (Boadi et al., 2004). Although the processes are similar, there are important differences between the two. The temperature in the storage varies, in contrast to the relatively constant temperature in the rumen, and the manure in storage is more heterogeneous (e.g., the substrate is less well mixed and some carbohydrates are already partially decomposed compared with the consistency of the rumen) (Lassey 2007; Saggar et al. 2004a).

2. Nitrous Oxide Emission (N_2O)

These emissions result from nitrogen turnover in agricultural soil from the use of synthetic fertilizers and manure, crop residues left after harvesting and excreta deposited during grazing. N_2O is produced naturally in soils through nitrification and denitrification processes (Figure 10). Several factors influence the production of N_2O, such as soil type, drainage, degree of soil compaction and climate (Henriksson et al., 2011; Bouwman and Boumans, 2002). A high precipitation, freeze and thaw periods, clay and organic soils, high pH, application of nitrogen, soil compaction and tillage lead to increased N_2O emissions, while draughts and drainage leads to reduced N_2O emissions (Berglund et al., 2009; Bouwman and Boumans, 2002). None of these aspects are generally considered when estimating N_2O in carbone footprint (CF) studies.

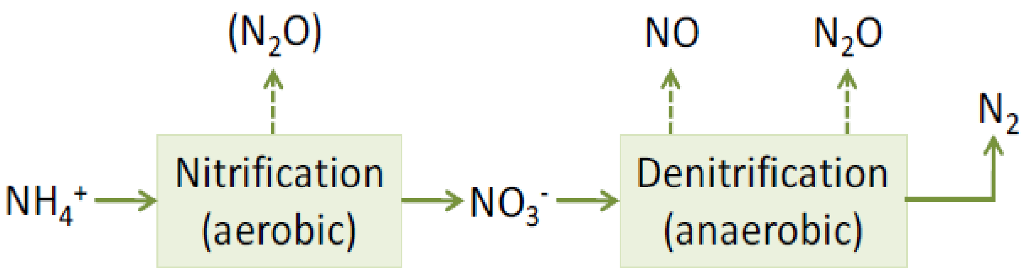

Figure 10. Schematic overview of nitrification and denitrification processes (Berglund et al., 2009).

3. Carbon Dioxide (CO_2)

Multiple processes emit CO_2 from dairy and beef farms. Carbon dioxide emissions are primarily due to the manufacturing and operation of farm machinery and vehicles, the manufacturing of fertilizers and agrochemicals, and the manufacturing of farm buildings and electrical power generation. Additional emissions are associated with a change in land management practices, which can influence carbon stored in the soil, resulting in either CO_2 emissions or CO_2 sequestration, as soil organic carbon. Land use change can also be a significant source of CO_2 as a result of the loss of soil carbon, as well as above-ground biomass associated with land degradation and/or deforestation (Chianese et al., 2009a).

4. Ammonia (NH_3)

This gas is not considered as a direct GHG, however, it is a precursor to N_2O (direct active GHG) and NO (Clemens et al., 2001). An important part (65%) of all NH_3 emissions from terrestrial systems come from animal farming systems (National Research Council, 2002) from the anaerobic digestion of food proteins. In cow's rumen, microbes use NH_3 to produce proteins. But often, NH_3 is in excess in the rumen goes into the blood and it is excreted in urine in form of urea. Once excreted, urea is degraded releasing NH_4 to the atmosphere. When NH_3 is in the atmosphere, a part of this gas comes back to the ground, which can cause environmental problems such as soil acidification or changes in the soil structure, and the other part remains in the atmosphere and reacts with some atmospheric acids to produce aerosols, which can be a problem for air quality and for animals and human health (McGinn et al., 2007).

III. Methodology for Quantification of Greenhouse Gas Emissions from the Livestock Sector and Modeling Emissions

Over the last 100 years several different methods have been developed with the purpose of measuring and estimating methane emissions from ruminants. These methods, such as respiration chambers, SF_6 tracer technique, in vitro gas production technique, CO_2 technique and N_2O technique, have various scopes for application, advantages and disadvantages, but none of them is perfect. Some direct, experimental methods are expensive and others are of limited capacity of testing large number of animals. The description and critical evaluation of such methods have been described by Ida et al. (2012).

Direct measurement of greenhouse gas emissions can be expensive and complicated (Ellis et al. 2007). However, prediction equations and models can be used to estimate emissions of enteric CH_4 and CH_4, NH_3 and N_2O from manure, without undertaking costly experiments for each estimation.

1. Intergovernmental Panel on Climate Change Reporting Protocols

The IPCC published guidelines for calculating national GHG inventories (IPCC, 1997a). These were subsequently updated in 2000, 2003 and 2006 and allowed for quantification of national emissions based on readily available activity data, such as power usage, fossil fuel consumption, fertilizer sales, animal numbers and land use change, as well as associated emission factors for each activity.

In terms of agriculture, the simplified approach of the IPCC protocols was applied with large variations in different agricultural practices within and among countries, which made direct national scale measurements of farm emissions impossible. IPCC guidelines provide the best widely applicable defaults for compiling national GHG inventories and, as such, are the main methodologies by which sectorial emissions can be compared among countries. However, the robustness of these inventories is dependent on country specific emission factors and verification of emissions inventories via modeling and/or direct measurement (IPCC, 1997b).

Consequently, the IPCC operates with three different levels to estimate GHG. These three levels depend on the quality of the database established in the country in question, and are known as Tiers 1, 2 and 3, where Tier 1 is the simplest calculation method and Tier 3 the most complex and data-dependent method. For example, in case of methane, the three methods are based on the proportion of the cow's gross energy intake (GE) excreted. Thus Tier 1 utilizes an emission factor (Ym) of 6.5% and an assumed GE, which results in an estimated methane production of 109 kg/cow/year in Western Europe. When using Tier 2, and especially Tier 3, more information is required to determine Ym, e.g., in relation to the digestibility and nutrient content of the feed.

However, the structure of the IPCC reporting protocols are not conducive to integrated systems analysis as a result of the sector based approach. Specifically, emissions that arise in agricultural systems are reported in three sectors for IPCC purposes according to the 1996 guidelines (IPCC, 1997a); agriculture, land use change and forestry, and energy. Further, indirect emissions related to agricultural production may also arise in the industrial processes and waste categories. In addition, if data from these three sectors are combined to generate a whole farm balance, any emissions generated outside the national boundaries are not included. Because of the limitations of IPCC methodology for modeling farm level emissions, whole farm modeling is widely used. Whole farm GHG emissions models may be categorized as systems analysis models or life cycle assessment models (reviewed by Crossona et al., 2011).

1.1. Life Cycle Assessment Methodology

Life cycle assessment (LCA) is a method used to compile and assess total environmental impacts and emissions from the entire life cycle of a product or service. The life cycle of a product includes acquisition of raw materials, processing, use, and final disposal (ISO 14040, 2006). LCA methodology has gained wide acceptance, and although many assumptions are made in its execution, modern assessments are at least minimally comparable if they follow the pattern laid out by the International Organization for Standardization (ISO 14040, 2006). An ISO 14040 compliant LCA consists of 4 parts: goal and scope definition, life cycle inventory, impact assessment, and interpretation. Best practices for important assumptions that must be made in LCA analysis are also included in the ISO standards, such as methods to allocate environmental impacts between products resulting from the same production system.

LCA methodology is well-adapted to evaluate agricultural systems because it provides an objective method of defining the production system and quantifies the impact in terms of the outputs of a production system (Casey and Holden 2006; Thomassen et al., 2008a). Availability of a farm-produced commodity to be consumed by humans or to enter another production process is generally the scope of modeling in agricultural LCA. This means use and end-of-life scenarios are not considered for agricultural production systems. Typical LCA of manufactured product is termed a “cradle to grave” analysis because all impacts on the environment from the life of that product have been included. Without use phase or end-of-life scenario, agricultural LCA is generally termed a "cradle to gate" analysis. This name denotes an analysis that quantifies all environmental impacts of raw materials and processing to deliver the farm product to the farm gate, where another entity is assumed to pick up the commodity (Kim and Dale, 2005; ISO 14040, 2006; Saunders and Barber, 2007).

The different phases of LCA are shown in Figure 11. In the first phase, goal, scope and the purpose of the study is described, as well as the functional unit, system boundaries, method for product handling, and data and data quality requirements. Product handling is typically performed using either system expansion or allocation. System expansion is a method for avoiding allocation by expanding the system boundaries to include the additional functions related to the products. Allocation means splitting the environmental burden between products based on, for instance, their economic value. In the second phase, inventory analysis, data is collected and calculations take place, i.e. emissions are quantified per functional unit. In the third phase, impact assessment, emissions are classified (all emissions contributing to e.g. global warming are defined) and multiplied by their characterization factor.

The final phase, interpretation, is an iterative process that should take place during the whole assessment. Aspects that should be included in this phase are identification of significant issues based on results, evaluation of completness, sensitivity check, limitations, conclusions and recommendations.

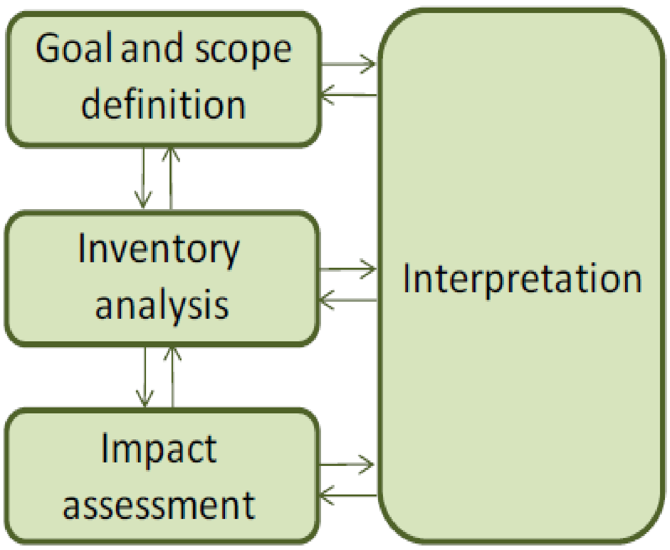

Figure 11. Framework for life cycle assessment illustrating the different phases defined in ISO 14040 (ISO, 2006).

The study of the LCA is a widely accepted analysis to assess the impact of a production system (diary or beef cattle) on the carbon balance. Recently published studies of GHG emissions based on the LCA from beef and dairy production were conducted by Williams et al., (2006); Peters et al. (2010); Beauchemain et al. (2010); Basset-Mens et al. (2009b); Gerber et al., (2010); Casey and Holden., (2006).

2. Whole-Farm Modelling

The development of whole-farm approaches for the mitigation of GHG emissions has been taken up recently by several research groups in Canada, USA and Australia. A feature of all this models is the ability to calculate CH_4 and N_2O emissions from dairy or beef farms. However, the calculation procedures for the GHG emissions are not always the same. Furthermore, the models vary considerably on many other aspects. In this section, a short description of the available models in general, and more specific of GHG simulation procedures, is provided.

2.1. HOLOS

Holos is a whole-farm model developed by Agriculture and Agri-Food Canada (Little et al., 2008) that estimates GHG emissions from dairy and beef farms. Holos is an empirical model, with a yearly time-step, based primarily on IPCC (2006) methodology, modified for Canadian conditions and farm scale. The model considers all significant emissions and removals on the farm, and emissions from manufacture of inputs (fertilizer, herbicides) and non-agricultural emissions of N_2O derived from N applied on the farm. Holos estimates a whole-farm GHG emission, calculating emissions for soil-derived N_2O, enteric CH_4, manure-derived CH_4 and N_2O, CO_2 from on-farm energy use and the manufacturing of fertilizer and herbicide, and CO_2 emission/removal from management-induced changes in soil carbon stocks. This approach allows net whole-farm emissions to be calculated from management changes on any part of the farm.

2.2.DairyWise

DairyWise is an existing empirical model integrating all major subsystems of a dairy farm into one whole-farm model (Schils et al., 2007). The model is used extensively in research, consultancy and teaching for technical, environmental and financial simulations of dairy farms. To operate DairyWise, the required input data are classified into several categories such as general farm management, soil characteristics, herd type and feeding management, cropping plan, grass and forage management, buildings, and machinery.

The key submodels of DairyWise are the GrassGrowth model, DairyHerd model, FeedSupply model, submodel Nutrient cycling and GHG model. The GrassGrowth model predicts the daily growth and quality of grass as a function of soil type, N application and previous management. The DairyHerd model predicts daily feed intake and milk production of a complete dairy herd, including young stock. The FeedSupply model combines the herd requirements in terms of energy and protein with the supply of home-grown grass and other forage crops and imported compound feeds. The submodel of Nutrient cycling simulates all internal and external flows of nitrogen, potassium, and phosphorus (P). The nitrogen farm gate surplus is partitioned among ammonia, nitrate and nitrous oxide losses. Recently, a GHG module has been added in which CH_4, N_2O and CO_2 emissions are calculated with refined emission factors (Schils et al., 2006b).

2.3. FarmGHG

FarmGHG is a model of carbon (C) and N flows in dairy farms. The model is designed to allow quantification of direct and indirect gaseous emissions of CH_4 and N_2O from dairy farms, so that the model can be used for the assessment of mitigation measures and strategies. The pre-chain emissions included in the model comprise the use of energy, fertilizers, pesticides and feedstuffs. However, energy costs associated with farm buildings and machinery are not included. The imports, exports and flows of all products through the internal chains on the farm are modeled. Thus the model allows assessments of emissions from the production unit and all pre-chains. The model includes N balance, and allows calculation of environmental effect balances for greenhouse gas emissions (CO_2, CH_4 and N_2O) and eutrophication (nitrate and NH3) (Olesen et al., 2006).

2.4. $SIMS_{DAIRY}$

Sustainable and Integrated Management Systems for Dairy Production (SIMSDAIRY) is a deterministic modeling framework which simulates at the farm level the effect of the interactions between farm management, site conditions and plant/animal theoretical genetic traits on: N cycling, N and P losses, CH_4 losses, farm economics and sustainability attributes of biodiversity, landscape, product quality, soil quality and animal welfare . The model is very sensitive not only to management but also to climate, topography and soil characteristics. The effect of management practices on N, P and CH_4 losses are predicted for an average climatic year within different components and through different processes in the soil–plant–animal system using a monthly time step and applying the principle of mass conservation. These practices can be defined in terms of management, for example, manure, mineral fertilizer, herd size and composition and forage area. SIMSDAIRY optimization routine allows the user to find optimal solutions at the farm level for management factors (including genetic improvement) according to a criterion of minimizing GHG emissions per unit of product (e.g. milk). SIMSDAIRY can also optimize mineral fertilizer N use (rate and timing) for each land area using a criterion of maximizing N use efficiency (Del Prado et al., 2006).

2.5. FarmSim

FarmSim (for FARM SIMulation) is a model of greenhouse gas emissions at the livestock farm scale, structured into 9 interacting modules. FarmSim includes imports, exports and internal flows of products between the different components of the farm system. FarmSim includes the PASIM model for the greenhouse gases exchanged over the different grassland types on the farm and integrates the IPCC methodology Tier 1 and Tier 2 (IPCC, 1997a) for the CH_4 and N_2O emissions coming from croplands and cattle housing. FarmSim uses detailed data inputs concerning the farm structure (area and type of crops and of grasslands, herd types), the herd (number of animals per type each fortnight), the grasslands (grazing and cutting dates, stocking rates, organic and inorganic fertilizer applications), the crops and the feeding and waste management systems. From these data, FarmSim calculates inputs needed to run the pasture simulation model (PASIM) for each of the grassland plot in the farm. The PASIM model allows to simulate the average net annual balance of greenhouse gases (CO_2, N_2O, CH_4) exchanged by the managed grassland plots (reported by Schils et al., 2007).

2.6.DairyGHG

The Dairy Greenhouse Gas Model (DairyGHG) is a software tool for estimating the greenhouse gas emissions and carbon footprint of dairy production systems (USDA-ARS, 2011b). A dairy production system generally represents the processes used on a given farm, but the full system extends beyond the farm boundaries. A production system is defined to include emissions during the production of all feeds whether produced on the given farm or elsewhere. It also includes emissions that occur during the production of resources used on the farm such as machinery, fuel, electricity, and fertilizer. Manure is assumed to be applied to cropland producing feed, but any portion of the manure produced can be exported to other uses external to the system. DairyGHG uses process-based relationships and emission factors to predict the primary GHG emissions from the production system. Primary sources include the net emission of carbon dioxide plus all emissions of methane and nitrous oxide occurring from the production system. Emissions are predicted through a daily simulation of feed use and manure handling. Daily emission values of each gas are summed to obtain annual values. Total greenhouse gas emission is determined as the sum of the net emissions of all three gases where methane and nitrous oxide are converted to carbon dioxide equivalent units (CO_2e).

2.7.IFSM

The integrated farm system model (IFSM) version 3.6 developed and validated by Rotz et al. (2012) is used to predict the GHG emission from the dairy, beef and crop farm in the US. The model includes input data such as detailed information about herd, crop and pasture production, crop harvest, feed storage, grazing, feeding, and manure handling. In addition, the model takes into account the prevailing local weather conditions and farm management practices. The input information is used in the model to determine the GHG emissions. The IFSM model predicts carbon (C) and N flows in farms.

The model is designed to measure direct (Animal, Manure and feed production) and indirect (Fuel combustion, pesticides, fertilizers, feedstuffs and purchased feed and animals) CH_4, N_2O and CO_2 emissions from dairy, beef and crop farms and to assess the mitigation strategies. The imports, exports and flows of all products through the internal chains in the farm are modelled. The model thus allows assessments of emissions from the production unit and all pre-chains.

3. Analytical Comparison of the Existing Models

Different types of models can be used to quantify GHG. Each type of models has its pros and cross. One should thus be careful when choosing a model for a specific condition. For instance, if accumulated data are sufficient and cover a wide range of the possible model variables, an empirical model with simple input variables would be suitable. However, if insufficient data are available and more accurate estimation is needed, a mechanistic model would be preferred. Although there are several published models that can be used to predict GHG emissions by dairy and beef cattle, they are not readily applicable to situation other than the models were originally built from.

Moreover, the overall predictability of current models is still low and needs to be improve with further research. More accurate predictions of GHG emission by dairy and beef cattle require the development of a more mechanistic models that accounts for more of the biologically important variables that affects all GHG and this model should be able to integrate all of the farm-specific components. It can be concluded from the Table 1 that IFSM is very useful to predict GHG emission by dairy and beef cattle and helpful to find most appropriate mitigation strategies.

The IFSM model can simulate whole farm emissions of CH_4, NO_2 and CO_2 and evaluate the overall impact of management strategies used to reduce GHG emission. the IFSM was further refined into a process-based whole farm simulation including major components for soil process, crop growth, tillage, planting, the harvest operation, feed storage, feeding, herd production, manure storage and economic both in dairy and beef farms (Rotz et al, 2009).

In addition, most existing models work with a top down method which demands small amounts of information, but the margin of error will be greater in the output. The IFSM model uses a bottom up method with a large amount of specific and detailed information and integrating all the processes that affect the GHG emissions at farm and animal level. Moreover, this model takes account at the same time estimation of the carbon footprint at dairy and beef farms (Belflower et al., 2012; Rotz et al., 2010; Rotz et al 2011). Furthermore, this model is more comprehensive, convenient and can be selected to be used during the simulation of dairy and beef farms.

Table 1. General characteristics of whole-farm GHG models.

	DairyWise	FarmGHG	$SIMS_{DAIRY}$	FarmSim	Holos	DairyGHG	IFSM
Model type	Empirical	Empirical	Semi-mechanistic	Semi-mechanistic	Empirical	Empirical and mechanistic	Empirical and mechanistic
CH_4 and N_2O emissions	x	x	x	x	x	x	x
CO_2 emissions	x	x		x	x	x	x
C sequestration				x		x	x
NH_3 emissions	x	x	x	x		x	x
Pre-chain emissions	x	x	x	x		x	x
Economics	x		x			x	x
Carbone Footprint (Kg CO_2 e/ Kg of product)					x	x	x
Target animals	Dairy farms	Dairy farms	Dairy farms	All type	All type	Dairy farms	Dairy and beef farms

IV. Mitigation Measures for the carbon Footprint of Dairy and Beef Cattle

There are several strategies that may be employed in the beef and dairy cattle industry to reduce GHG. These strategies may be categorized into dietary and management strategies. Each one will be discussed in the following section.

1. Dietary Strategies

1.1. Strategies to Reduce Enteric Methane from Cattle

1.1.1. Concentrate (Proportion, Nature)

It is well established that increasing the level of concentrate in the diet leads to a reduction in CH_4 emissions (g/kg DM intake) compared with feeding forage based diets. Starch fermentation promotes propionate production in the rumen creating an alternative hydrogen sink to methanogenesis, lowers ruminal pH, inhibits growth of rumen methanogens, and decreases rumen protozoal numbers limiting the transfer of hydrogen from protozoa to methanogens (Grainger and Beauchemin, 2011). Sauvant and Giger-Reverdin (2007) conducted a meta-analysis of literature data and showed that the relationship between concentrate proportion in the diet and CH_4 production is curvilinear (Figure 12). It is clear from this figure that an increase in proportion of concentrate in the diet decreases CH_4 emission.

The use of cereal forages that contain high quantities of starch has been proposed as a means to increase the starch content of the diet and lower CH_4 emissions (Beauchemin et al., 2008). Feeding forages high in starch favours the production of propionate over acetate, which should reduce enteric CH_4 emissions. Furthermore, intake of whole crop silages is often higher than that of grass forages, and thus shorter residence times in the rumen could reduce CH_4/kg of feed intake.

In a study with growing beef cattle, Mc Geough et al. (2010a) compared diets (i.e., 240 g concentrate and 760 g silage/kg DM) containing one of four maize silages to a high concentrate diet (i.e., up to 834 g concentrate and 166 g grass silage/kg DM). Maize silages were harvested at increasing stages of maturity such that starch content increased from 315 to 386 g/kg DM and neutral detergent fiber content decreased from 485 to 434 g/kg DM. Cattle fed the high concentrate diet (i.e., starch content of 369 g/kg DM) produced 19% less CH_4 (g CH_4/kg DM intake) than cattle fed the maize silage diets. For maize silages, CH_4 output relative to DM intake tended to linearly decline to a 10.9% reduction in response to increasing the starch to neutral detergent fiber ratio. Thus, increasing the starch content of forages can help decrease CH_4 emissions, but CH_4 emissions of forage fed cattle is still considerably higher than concentrate fed cattle.

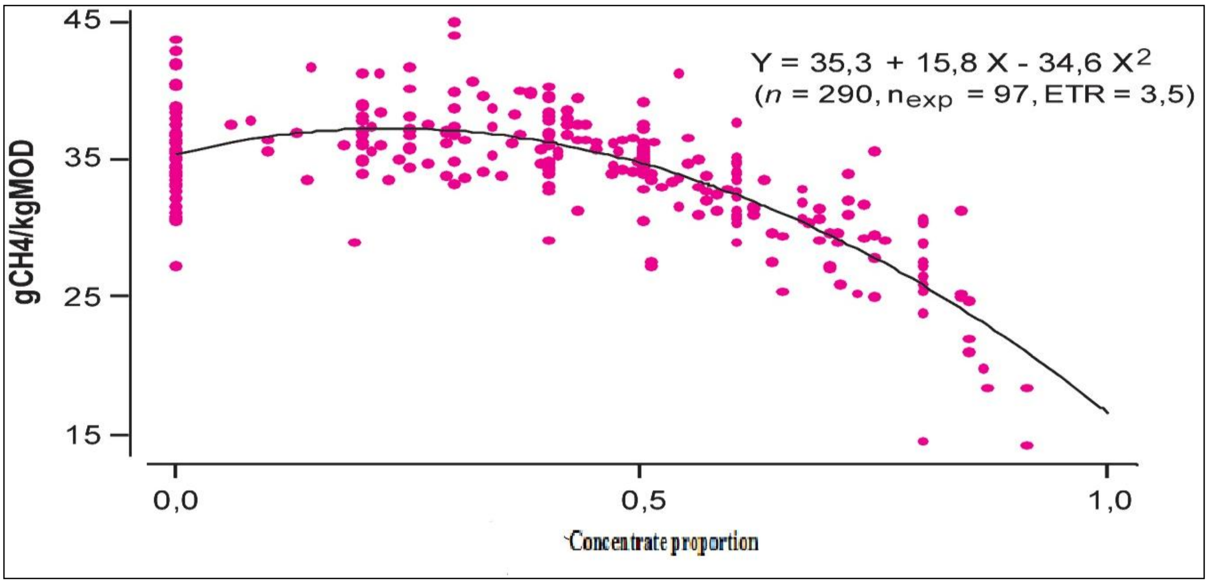

Figure 12. Effect of the concentrate proportion on the CH_4/kg production Sauvant and Giger-Reverdin., (2007).

1.1.2. Level of Intake

An increase in feeding level induces lower CH_4 losses as percent of GEI. Johnson and Johnson (1995) noted that CH_4 losses as percentage of GEI declined by 1.6 percentage units for each multiple increase of intake. This is caused mainly by the rapid passage of feed out of the rumen. As a result of the increased passage rate, the extent of microbial access to organic matter is decreased, which in turn reduces the extent and rate of ruminal dietary fermentation. Boadi et al. (2004) reported a 29% decrease in CH_4 production of cattle when the fractional passage rate of particulate matter was increased by 63%. According to Giger-Reverdin et al (2003) and Sauvant and Giger-Reverdin (2007), the acceleration of passage rate observed in the rumen with high levels of ingestion favors propionate production, which is a competitive pathway for the use of hydrogen. However, the extent to which intake levels affect passage rate of roughages is proportionally less than with concentrate or mixed diets.

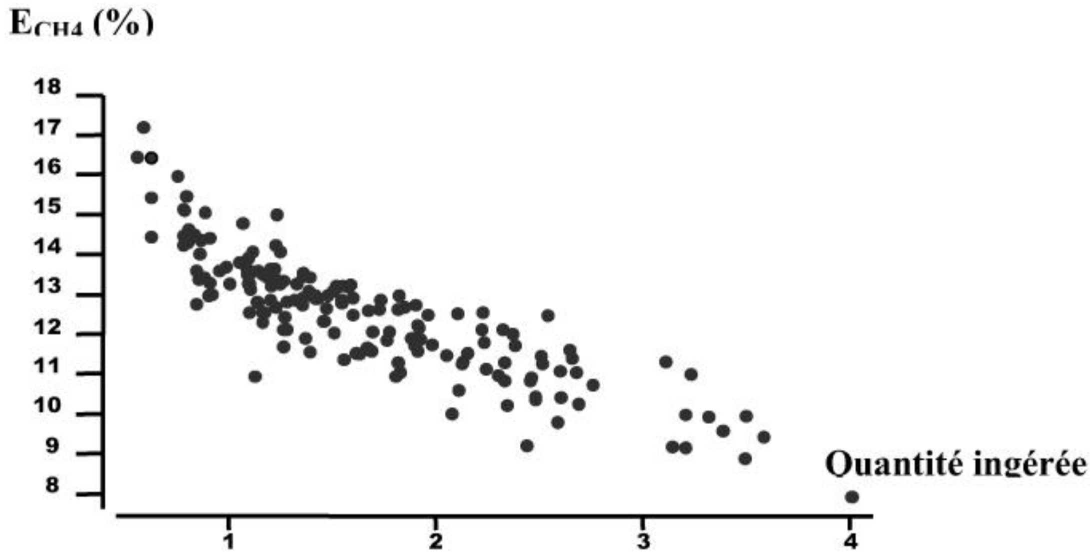

Figure 13. Influence of feeding level on the metabolizable energy share lost as methane (Giger-Reverdin et al 2003; Sauvant and Giger-Reverdin 2007).

1.1.3. Forage (Type and Quality)

Improving forage type reduces enteric CH_4 emissions in ruminants. According to the prediction model of Benchaar et al. (2001), the substitution of timothy hay by lucerne decreases CH_4 emissions by 21% (expressed as % of digestible energy). Moreover, the lower CH_4 loss observed with legumes compared with grasses can be attributed to the lower proportion of structural carbohydrates in legumes and faster rate of passage, which shift the fermentation pattern towards higher propionate production.

Boadi and Wittenberg (2002) also demonstrated that forage quality has a significant impact on enteric methane emissions. Cattle given hay of high (61.5 % IVOMD), medium (50.7% IVOMD) and low (38.5% IVOMD) quality differed ($P < 0.01$) in dry matter intake, as animals consumed 9.7, 8.9 and 6.3 kg/d, respectively. Moreover, differences existed in enteric methane emissions ($P < 0.01$), as 47.8, 63.7 and 83.2 CH_4 L/ kg digestible organic matter intake was produced from cattle consuming the high, medium and low quality forages, respectively. The same authors subsequently demonstrated this same effect on pasture (Boadi et al., 2002). Steers grazing during the early period of the grazing season had 44% and 29%

less energy lost as methane ($P < 0.01$) than steers grazing during the mid and late grazing periods, respectively.

The impact of pasture forage quality and availability on enteric methane emissions from cattle in grass-based production systems has been studied by Ominski et al. (2004). Enteric methane emissions measured early and late in the grazing season were influenced by pasture type and season of grazing. Further, it appeared that emissions were influenced by pasture dry matter availability and quality, in that emissions were highest (11% of GEI) when pasture quality and availability were low. Emissions were lower when pasture quality was high and availability was low (6.9% of GEI) or when quality was low and availability was high (7.1-9.4% of GEI).Unfortunately, neither pasture ever attained a status of high forage quality and high pasture availability. It can be concluded that enteric emissions are highest when the animal is presented with poor quality forage and has limited opportunity to select higher quality forage as a consequence of reduced dry matter availability.

1.1.4. Addition of Lipids

Dietary fat shows a promising nutritional alternative to depress ruminal methanogenesis without decreasing ruminal pH as opposed to concentrates (Sejian et al., 2011b). Their effect has been summarised by equations provided by Giger-Reverdin et al. (2003) and by Eugene et al., (2008) who reported a mean decrease in CH_4 of 2.2% per percentage unit of lipid added in the diet of dairy cows, independently of the nature of fatty acid (FA) supply. Lipids cause the depressive effect on CH_4 emission by toxicity to methanogens, reduction of protozoa numbers and therefore protozoa associated methanogens, and a reduction in fibre digestion. Beauchemin et al. (2008) recently assessed the effect of level of dietary lipid on CH_4 emissions over 17 studies and reported that with beef cattle, dairy cows and lambs, for every 1% (DMI basis) increase in fat in the diet, CH_4 (g/kg DMI) was reduced by 5.6 %. Martin et al., (2009) also confirmed that the effect of lipids on methanogenesis is proportional to their level of supply.

The effect of FA is also dependent on their nature. Medium-chain FA, mainly provided by coconut oil, are more depressive (7.3% decrease per percentage unit of added lipids). According to Soliva et al., (2004) oils containing lauric Acid (C12:0) and myrstic acid (C16:0) are particulary toxic to methanogens. When taken alone they have similar effects, but a combination of these two acids has a synergistic effect leading to a sharp decrease in CH_4

(60%) *in vitro*. In another study of fat effects on enteric CH_4, the supplements rich in polyunsaturated FA such as linoleic acid (C18:2 from soybean and sunflower) and linolenic acid (C18:3 from linseed) also have a negative effect on CH_4 production (4.1% and 4.8% decrease per percentage unit of added lipids) (reported by Martin et al., 2010).

1.1.5. Additives

1.1.5.1. Ionophores

Ionophores are highly lipophilic substances able to delocalize the charge of ions and facilitate their movement across membranes (Boadi et al. 2004). Monensin is the most commonly used and studied ionophore, with others such as lasalocid, tetronasin, lysocellin, narasin, salinomycin and laidomycin also being used commercially.

The ionophore monensin has been used as a feed additive in cattle production to improve feed conversion efficiency and N metabolism, and for the prevention of bloat and post-calving ketosis. Monensin can be delivered as a premix added to the diet, as a slow release capsule inserted into the rumen or, increasingly in pasture-based systems, in the water supply in paddocks using a form of monensin designed for in line water dispenser systems. Duffield et al. (2008) offered the most thorough analysis of monensin effects on milk production and DM intake, and concluded that monensin decreased DM intake by 0.3 kg/d, increased milk yield by 0.7 kg/d, and improved milk production efficiency by 2.5%.

Appuhamy et al. (2013) conducted a meta-analysis of literature data and showed that 32 mg/kg DM of monensin reduced CH_4 emissions and CH_4 conversion rate (Ym) in beef steers fed total mixed rations by 19 g/animal per d ($P < 0.001$) and 0.33 ($P = 0.047$), respectively. In dairy cows the reductions were 6 ± 3 g/animal per day ($P = 0.065$) and 0.23 ± 14% ($P = 0.095$) for monensin given at a dose of 21 mg/kg DM. Moreover, Beauchemin et al. (2008) studied the effects of monensin on CH4 emissions and found evidence of a dose response with monensin at <19 mg/kg DM intake not reducing CH_4 emissions, but at 24–35 mg/kg DM intake, it reduced CH_4 (as g/kg DM intake) by 3–8%.

1.1.5.2. Plant Extracts

This category includes a variety of plant secondary compounds, specifically essential oils, tannins and saponins. The term plant secondary compound is used to describe a group of chemical compounds found in plants that are not involved in the primary biochemical processes of plant growth and reproduction (Agrawal and Kamra, 2010). Many of these compounds function as defense a mechanism which ensures survival of their structure and reproductive elements protecting against insect or pathogen predation or by restricting grazing herbivores. Several thousands of plant secondary compounds have been reported in various plants and many of them have found their use in traditional Indian and Chinese medicine (Kumar et al., 2007). Furthermore there is a growing interest in the use of plant secondary compounds as a CH_4 mitigation strategy (Jouany and Morgavi, 2007). Preparations from plants are seen as a natural alternative to chemical additives that have been banned in the EU or may be negatively perceived by consumers.

Essential oils have antimicrobial properties that are capable of affecting rumen fermentations. A number of studies have recently evaluated the ability of essential oils to reduce enteric CH_4 production (Table 2). Evans and Martin (2000) examined effects of increasing concentrations of thymol (50, 100, 200, and 400 mg/L of culture fluid) on in vitro 24 h batch culture fermentation of D-glucose by mixed rumen bacteria (Table 2). Methane concentration was not affected when thymol was supplied at 50, 100, and 200 mg/L of culture fluid. However, at 400 mg/L, thymol increased the pH of the medium and decreased CH_4 (−94%) acetate (−44%) and propionate (−78%) concentrations. A higher pH and a reduction in VFA concentrations are an indication of an overall inhibition of rumen microbial fermentation, and these changes would not be nutritionally beneficial to the host animal if the same effects were expressed in vivo. Macheboeuf et al. (2008) evaluated in batch cultures (16 h incubation) the effects of thyme (T. vulgaris; 470 g/kg thymol, 200 g/kg terpinene and 200 g/kg p-cymene) on rumen fermentation. A minimum of 300 mg/L of thymol provided as is, or via thyme oil, was required to inhibit CH_4 production with a concomitant decrease in total VFA production, acetate and propionate production (Table 2). Busquet et al. (2005b) were the first to report effects of garlic essential oil and two of its compounds (i.e., diallyl disulphide and allyl mercaptan) on CH_4 production (Table 2). When added at 300 mg/L in 17 h in vitro batch culture fermentations, allyl mercaptan decreased CH_4 production by 19.5% without altering digestibility. At the same concentration, garlic and diallyl disulphide reduced CH_4

production by −74 and −69%, respectively, but DM digestibility and VFA concentration were also depressed.

Condensed tannins (CT) have been shown to reduce CH_4 production by 13%–16% (DMI basis) (Woodward et al., 2004; Grainger et al., 2009), mainly through a direct toxic effect on methanogens. However, high CT concentrations (> 55 CT/kg DM) can reduce the voluntary feed intake and digestibility (Beauchemin et al., 2008; Grainger et al., 2009). Plant saponins may also potentially reduce CH_4, and some saponin sources are clearly more effective than others (Beauchemin et al., 2008). Similar reduction in methane production by saponins were reported in vitro (Lila et al., 2003; Hu et al., 2005) and in vivo (Santoso et al., 2004a). In addition, many authors reported that the effect of tannins/saponins on methanogenesis dependent on the dose and the source of tannins /saponins (Table 3).

Table 2. Effects of essentials oils and extracts of plants on methane production.

Essential oil/ extract of plant	Dose	Test	Methane reduction	Total VFA∗	Reference
Garlic oil	300mg/L	*In vitro*	74%	–	Busquet et al. (2005b)
Thymus vulgaris	0.5 mM	*In vitro*	12%	=	Macheboeuf et al. (2008)
Thymol oil	400mg/L	*In vivo* (cattle)	94%	–	Evans an Martin (2000)
α-Cyclodextrin–horseradish oil complex	80 g/d	*In vivo* (steers)	90%	+	Mohammed et al.(2004)
Peppermint (*Mentha piperita*)	0.33 mg/L	*In vitro*	19.9%	=	Agarwal et al. (2009)
Garlic oil (diallyl disulfide)	2 g/ kg (DM)	*In vivo* (sheep)	No effect	=	Klevenhusen et al. (2011)
Cashew nut shell liquid (CNSL)	4 g/100 kg BW	*In vivo* (cattle)	20%	NR	Shinkai et al. (2010)
Origanum vulgare L. *leaves*	500 g/d	*In vivo* (Dairy cattle)	35%	=	Tekippe et al. (2011)
Extract of oregano	250 mg/d	*In vivo* (sheep)	9.8%	+	Wang et al. (2009)
Crina Ruminants (thymol, eugenol, vanillin limonene)	1000 mg/d	*In vivo* (beef cattle)	No effect	=	Beauchemin andMcGinn.(2006)

∗ Total VFA: Total Volatile Fatty Acids; NR, not reported; +, increase; −, decrease; =, no change

Table 3. Effect of tannins and saponins source on the emission of methane.

Source of Tannin/ Saponin	Animal	Result	References
Tannin			
Castanea sativa wood extract	Lambs	No effect	Sliwinski et al (2002)
Acacia. Mearnsii	Lambs	Reduction	Carulla et al (2005)
Quebracho	Cattle	No effect	Beauchemin et al (2007)
Acacia. Mearnsii	Dairy cattle	Reduction	Grainger et al (2009)
Acacia. Mearnsii	Bulls	Reduction	Staerfl et al (2012)
Saponin			
Yucca	*In vitro*	Reduction	Pen et al. (2006)
Sapindus saponaria	*In vitro*	No effect	Hess et al. (2003)
saponins of tea	*In vitro*	Reduction	Hu et al. (2005)

1.1.5.3. Probiotics

Probiotics are defined as microorganisms which, when administrated to animals, may provide beneficial effects to the host by improving the environment of the indigenous micro flora. The use of probiotics for the modification of rumen microbial populations to decrease CH_4 emissions remains a potentially interesting approach. Active dry yeast and yeast cultures based on Saccharomyces cerevisiae are widely used on commercial dairy farms in North America and Europe to improve milk yield and production efficiency (Desnoyers et al., 2009; Robinson and Erasmus, 2009), but these yeast products have not been evaluated for their effects on CH_4 production. Newbold and Rode (2006) suggested that it might be possible to select yeast strains that, when added to cattle diets, result in reduced CH_4 emissions while promoting rumen fermentation and fiber digestion. They proposed that because some strains of yeast increase rumen bacterial growth (Chaucheyras-Durand et al., 2008), less CH_4 may be produced due to a shift in partitioning of hydrogen between microbial cells and fermentation products (Newbold and Rode, 2006). However, McGinn et al. (2004) evaluated effects of two commercially available strains of yeast on CH_4 emissions in beef cattle and reported no effects. Although microbial preparations are commercially available as rumiant feed additives, there is a need for more research to establish the potential of probiotics for reducing CH_4 production.

1.1.5.4. Other Additives

Organic acids are minor constituents of some plants and can be used to reduce methanogenesis when added to the diet of ruminants. Three organic acids have been studied, malate, fumarate and acrylate, which are precursors of propionate production in the rumen and can act as an alternative H_2 sink, restricting methanogenesis. Fumarate and acrylate have been shown to be the most effective in vitro (Martin et al., 2010). In contrast to the well-documented CH_4 production response to organic acids in vitro, responses to dietary supplementation in vivo remains inconclusive and highly variable. An exceptional decrease in CH_4 production up to ~75% has been shown with 10% encapsulated fumarate in the diet of lambs without negative effect on animal growth (Wallace et al., 2006). In contrast, encapsulated fumarate had no significant effect in another trial in dairy cows (Martin et al., 2010).

Another approach proposed by scientists is the use of enzymes, Beauchemin et al. (2008) proposed that it might be possible to develop enzyme feed additives that reduce CH4 emissions. Adding enzymes to ruminant diets has the potential to improve fiber digestion, thereby enhancing feed utilization and animal performance, although responses are highly variable depending on the enzymes used and conditions of the experiment (Beauchemin et al., 2008). While the possibility of using feed enzymes to reduce CH_4 production/kg feed intake exists, little research has been published to substantiate this hypothesis.

1.2. Strategies to Reduce N Excretion from Cattle (NH_3)

Tamminga (1992) calculated that 75-85% of the ingested N is excreted in faeces and urine, and identified the most important pathways for losses; (i) urinary excretion of urea synthesized from ammonia lost in the rumen, (ii) fecal and urinary excretion resulting from indigestible or endogenous excretion, and (iii), urinary excretion because of an inefficient utilization of absorbed protein for maintenance and for the synthesis of milk and body protein. Because of the larger losses and easier intervention, the rumen, and particularly the N losses in the form of NH_3, was proposed to be the most appropriate step for intervention (Tamminga, 1992, 1996).

1.2.1. Improving Efficiency of N Utilization in the Rumen

Efficiency of N utilization is defined as the amount of N retained in animal products per amount of N offered. For example, in dairy cows the N efficiency is calculated as milk N efficiency (MNE) and it is defined as the amount of N produced in milk per amount of N intake (Huhtanen and Hristov,2009). The efficiency of N utilization in ruminants is typically low (around 25%) and highly variable (10% to 40%) compared with the higher efficiency of other production animals. The low efficiency has implications for the production performance and the environment (Calsamiglia et al., 2010).

In the rumen, NH3 is produced via desamination of amino acids or non protein nitrogen compounds, like urea and amides, which are converted to ammonia in the rumen (Van Soest, 1994; Bach et al., 2005). Ammonia then may be used for microbial growth if energy is available, escape at the lower gastrointestinal tract, or be absorbed through the rumen wall and transferred to the blood and liver. In the liver, ammonia is transformed to urea and excreted in the urine (Van Soest, 1994; Dijkstra et., al 1996). An important factor in this process is the availability of energy in the rumen. When energy is available in the rumen, amino acids and ammonia are used for microbial synthesis, but if energy is limiting, amino acids will be desaminated and may absorbed and excreted as urea.

The concept of ruminal synchrony proposed by Johnson (1976) establishes that ruminal NH3 utilization and microbial protein synthesis would be maximized if there is a synchrony between the availability of energy and N in the rumen (balanced amounts at the same time). This could be achieved by changing the carbohidratos or N sources, o changing the feeding patterns (time of supplementation in grazing) or the feeding frequency (Cabrita et al., 2006). A better ruminal synchrony could be achieved under grazing systems when the CHO sources have a degradation rate of 13 to 14% h^{-1}, because this is similar to the RDP degradation rate of pasture (Van Vuuren et al., 1990), although degradation rate of pasture will vary with different circumstances (Aufrere et al., 2003).

1.2.2. Feeding Low CP Diets

Several studies suggested that lower levels of CP than requirements could be fed maintaining the same milk yield, reducing N excretion and improving MNE (Colmenero and Broderick, 2006; Agle et al., 2010; Lee et al., 2012). Lee et al. (2012) demonstrated that reducing CP level from 16.7 to 14.8% of DM reduced NH3 emissions from fresh dairy cow manure incubated in a controlled environment and from manure-amended soil. In addition, Colmenero and Broderick (2006) utilizing a wide range of CP (13.5, 15.0, 16.5 and 17.9% of DM) reported that MNE and fecal N excretion (% of N intake) decreased linearly and urinary N excretion (% of N intake) increased linearly by increasing dietary CP concentration. Moreover, MNE for the low CP diet (13.5% of DM) was improved by 18.5% compared with feeding CP according to requirement (16.5% CP), and 43.7% compared with overfeeding CP diet (17.9% of CP). However, other studies reported a reduced milk yield and DMI when CP concentration was reduced below requirements (Alstrup and Weisberg, 2012; Weisberg et al, 2012). However, in general CP is usually overfed in dairy and beef herds in excess of NRC recommendations all over the world, while underfeeding CP reduces milk production.

1.2.3. Strategies that Target Ruminal Protein Degradation

The N cycle in a dairy farm closes with the volatilization of NH3 in manure. But the starting point is the degradation of protein in the rumen. Many strategies to reduce ruminal protein degradation have been tested and can be categorized in tow groups: those that affect feed protein and those that target rumen microbes. The first include methods that intend to change ruminal availability of CP by decreasing RDP and increasing RUP content of feeds. Those that target rumen microbes include different feed additives that act as modulators of ruminal microbial population.

1.2.3.1. Feedstuff Processing and Manipulation

Heat processing is the most common method used to decrease RDP by denaturation of proteins and the formation of protein-carbohydrate (Maillard reactions) and protein-protein cross links. Different processing technologies have been developed, such as heating, roasting, flaking, extruding and expanding. The effectiveness of these techniques depends on the processed feed and processing conditions (Foskolos, 2012). However, heat treatment may also reduce the digestibility of RUP. Stern et al. (2006) reported the variability of RUP and intestinal digestibility of heat processed feedstuffs, including animal by products. Intestinal protein digestion of soybean meal treated with various techniques ranged from 57.7% to 83.8%, suggesting a considerable variation caused by processing.

Chemical treatment of feed proteins includes three categories: chemicals that induce cross links with proteins, chemicals that alter protein structure by denaturation, and chemicals that bind proteins but with little or no interaction with the protein structure. Protein feedstuffs, and especially soybean meal, have been treated with sodium hydroxide, but the most common chemical treatment is formaldehyde. Formaldehyde forms reversible cross linkages with amino acids and amide groups which reduce protein degradability in the rumen (Foskolos, 2012), but their use is not allowed in the EU.

1.2.4. Targeting Microbial Populations in the Rumen

Ionophores have successfully reduced N losses and improved animal performance. The addition of monensin in continuous culture affected ruminal fermentation reducing the acetate to propionate ratio, without affecting total VFA production, and reduced NH_3 concentration (Busquet et al., 2005a; Castillejos et al., 2006). Tedeschi et al., (2003) show that the use of monensin reduced N excretion from ruminants. Moreover, several in vitro studies suggested that essential oils compounds may alter protein metabolism mainly through the inhibition of peptidolysis or desamination (Table 4), reducing the NH_3 concentration in rumen fluid (Foskolos, 2012).

Table 4. The effects of some essential oils compounds on nitrogen metabolism in the rumen as indicated by in vitro studies (Foskolos, 2012).

Essential oil	N-metabolism	References
Thymol	Desamination ↓	Brochers, 1965; Cardozo et al., 2005; Castillejos.,2006
Eugenol	Peptidolysis ↓	Busquet et al., 2005c
	Desamination ↓	Busquet et al., 2006 ; Castillejos.,2006
Cinnamldehyde	Peptidolysis ↓	Cardozo et al., 2004 ;Ferme et al.,2004
	Desamination ↓	Busquet et al., 2005a ; Ferme et al.,2004
Anethol	Peptidolysis ↓	Cardozo et al., 2004
	Desamination ↓	Cardozo et al., 2005
Garlic oil	Desamination ↓	Cardozo et al., 2004,2005 ;Ferme et al.,2004
Capsaicin	Desamination ↓	Cardozo et al., 2005
Carvacol	Peptidolysis ↓	Busquet et al., 2005c

In addition, tannins are used to reduce N excretion; Condensed tannins (CT) form complexes with proteins in the rumen, protecting them from microbial digestion, resulting in either more efficient digestion or the tannin protein complex being excreted in feces (De Klein and Eckard, 2008). Carula et al. (2005) mentioned that sheep fed a CT extract had an increased partitioning of nitrogen from urine to feces, where urine nitrogen decreased by 9.3 % as a proportion of total nitrogen excreted. Similarly, Misselbrook et al. (2005) found that dairy cows fed on 3.5 % CT diet excreted 25 % less urine, 60 % more dung, and 8 % more nitrogen overall compared with cow on 1 % CT diet. The inclusion of CT appears to reduce nitrogen excretion in urine, increase nitrogen excretion in faeces and improve the nitrogen retention in the animal. This approach reduces the concentration of nitrogen in urine leading to a reduction in emissions.

VI. Management Strategies

1. Improvement of Genetic Merit of Cows

Genetic improvement is a relatively cost-effective mechanism by which to achieve reductions in greenhouses emissions. The larger North American Holstein genotype has been found to produce between 8 to 11% less methane as a percentage of GE intake, on both a total mixed ration and pasture-based diet, than a small New Zealand Holstein (Robertson et al., 2002), presumably due to differences in level of feed intake. However, larger cows have greater maintenance requirements. For the same level of production, a smaller cow is obviously a more efficient converter of feed into milk. This is why selection programmes in both New Zealand and Australia, in particular have focused on increasing the rate of genetic gain in traits that contribute to profitability per unit of feed eaten (Pryce et al.,2007).

Moreover, cows which were ~88% North American Holstein selected on increased milk fat and protein production (Select line cows) were found to grow faster and had increased kg milk per kg dry matter intake during their productive life when on a high energy dense diet, compared with cows selected to represent the UK average for milk fat and protein production on the same diet (Bell et al., 2010). Select genetic line animals have a high genetic potential for mobilizing body energy reserves for production, which has been found to have deleterious effects on health and fertility (Dillon et al 2006), particularly later in life (Wall et al.,2010). However, it was found that Select line cows responded to a diet containing a low proportion of forage, rather than a high forage diet, by having a significantly shorter calving interval (Bell et al., 2010). Select line animals on a low forage diet also produced lower CO_2-eq. emissions per energy corrected milk compared with non-select and cows on a high forage diet over their lifetime. In addition, Okine et al. (2002) calculated annual CH_4 emissions from Canadian high Net Feed Efficiency (NFE) steers to be 21% lower than that for low NFE steers. Selection for high NFE in beef cattle also decreased manure N, P, K output due to a reduction in daily feed intake and more efficient use of feed, without any compromise in growth performance (Okine et al. 2002).

2. Increased Animal Productivity

Increasing productivity, such as growth rate, annual milk or meat production, fertility and efficiency of feed conversion, by breeding or precision management, will reduce net

GHG emissions, because fewer animals, and hence less feed, land, water, fossil fuels, and fertilizers, are needed to produce the same amount of product.

Furthermore, the daily nutrient requirement of all animals within the dairy herd comprises a specific quantity needed to maintain the animals' vital functions (the maintenance requirements) plus extra nutrients to support the cost of growth, reproduction or lactation. As shown in figure 14 (Capper et al., 2009b), the maintenance energy requirement of a 650 kg lactating cow does not change as a function of production but remains constant at 10.3 Mcal/d (NEL). A high-producing dairy cow requires more nutrients per day than a low-producing dairy cow, but all nutrients within the extra feed consumed are used for milk production. The total energy requirement per kg of milk produced is therefore reduced: a cow producing 7 kg/d requires 2.2 Mcal/kg milk, whereas a cow yielding 29 kg/d needs only 1.1 Mcal/kg milk.

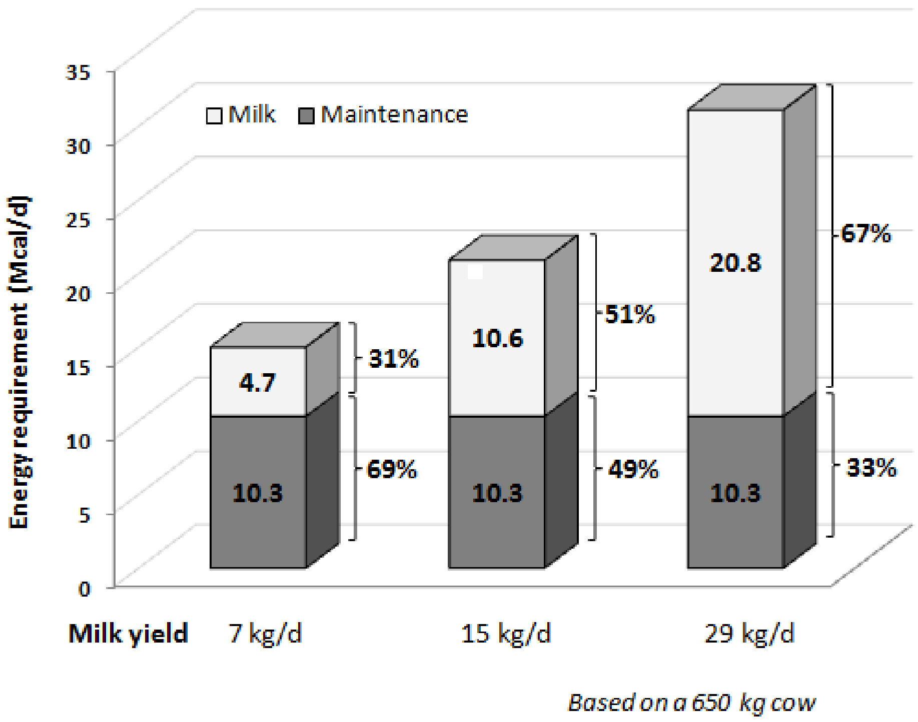

Figure 14. The dilution of maintenance effect conferred by increasing milk production in a lactating dairy cow (Capper et al. 2009b).

Capper et al. (2009b) reported that the improved dairy productivity between 1944 and 2007 resulted in a 79% decrease in total animals (lactating and dry cows, heifers, mature and young bulls) required producing a set quantity of milk. Feed and water use were reduced by 77% and 65%, respectively, while cropland required for milk production in 2007 was reduced by 90% compared with 1944 .

In contrast, Zehetmeier et al., (2011) found that increasing the milk yield from 6000 to 8000 kg/cow per year, the GHG emissions remained approximately constant. Whereas further increases in milk yield (10000 kg milk/cow per year) resulted in slightly higher (8%) total GHG emissions.

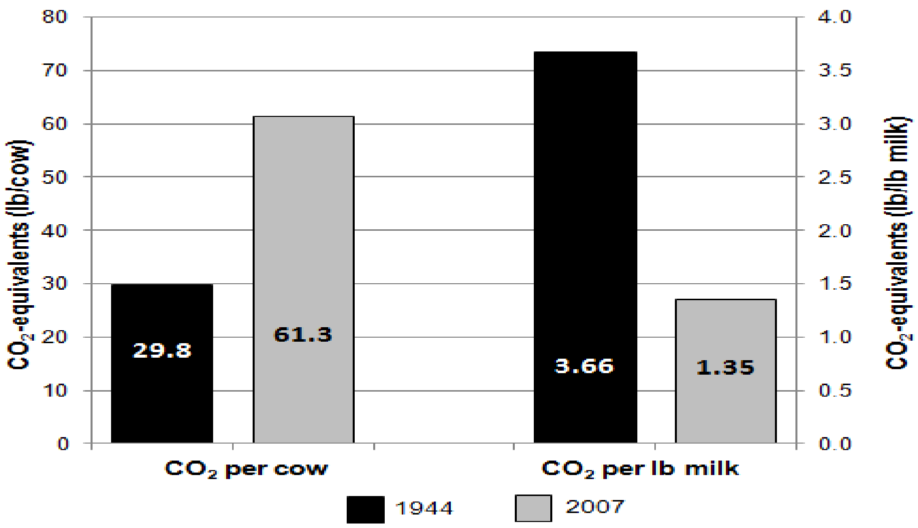

Figure 15. Carbon footprint per cow and per Ib of milk for 1944 and 2007 US .dairy production systems (adapter from capper et al., 2009b).

Similar results in beef production were reported by Capper (2010a) where the improvement in productivity allowed reducing the use of resources and the emission of greenhouse gases. In this regard, beef carcass yield per animal in USA increased over the past 30 yr from 274 kg in 1977 to 351 kg in 2007, which in combination with reduced time to slaughter over the same time period (606 d vs. 482 d), reduces resource use per unit of meat.

In addition, Crosson et al (2010) found that the improvement in animal performance (live weight gain; g/d) from 855 to 1047 (g/d) reduced by 50 % CO_2e/kg beef carcass (figure 16).

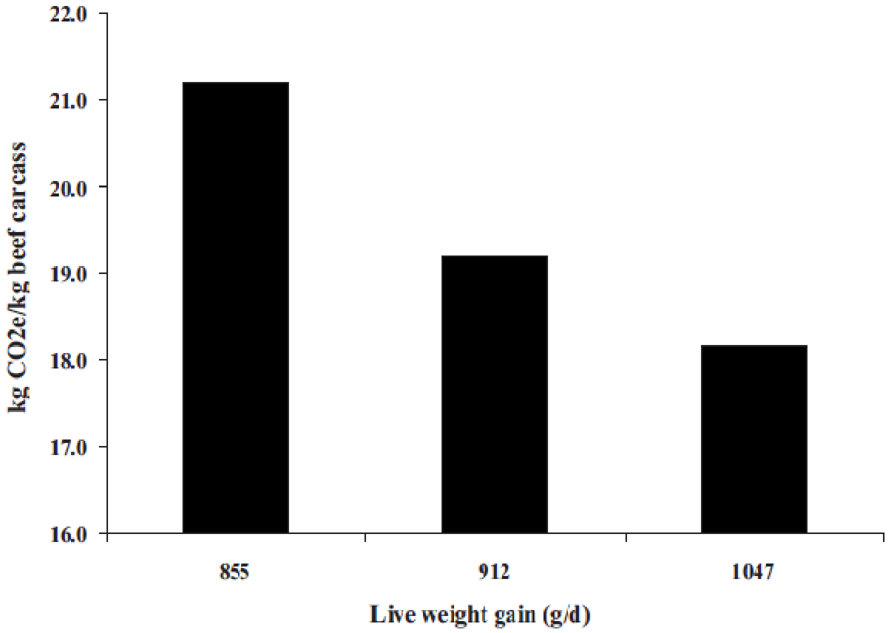

Figure 16. Implications of level of animal performance (live weight gain; g/d) on GHG emissions for Irish suckler beef production systems (from Crosson et al., 2010).

3. Intensification of Production

The intensification of production is an additional strategy to maintain a balance between production and the environmental impacts. The FAO (2006) concluded that it is essential to continue with the process of intensification of animal production in order to provide food and reduce the environmental impacts of livestock production. These observations contrast with the growing public view that assumes extensive pasture- based systems are more appropriate in terms of their contribution to the production of greenhouse gas emissions.

Impacts of intensification of dairy and beef production systems were also investigated by a number of authors, in many cases through comparison of organic and conventional production regimes. For example, in modelling Dutch dairy systems, Thomassen et al. (2008) found that conventional production systems had lower emissions/kg milk than organic production systems. Capper (2010b) showed that emissions are higher in traditional systems of meat production in the finishing phase on pasture (grazing system), intermediate in the beef production of feedlot systems without the use of new technologies (natural or ecological systems), and lower in the feedlot systems using the technology available today (conventional systems) (Figure 17).

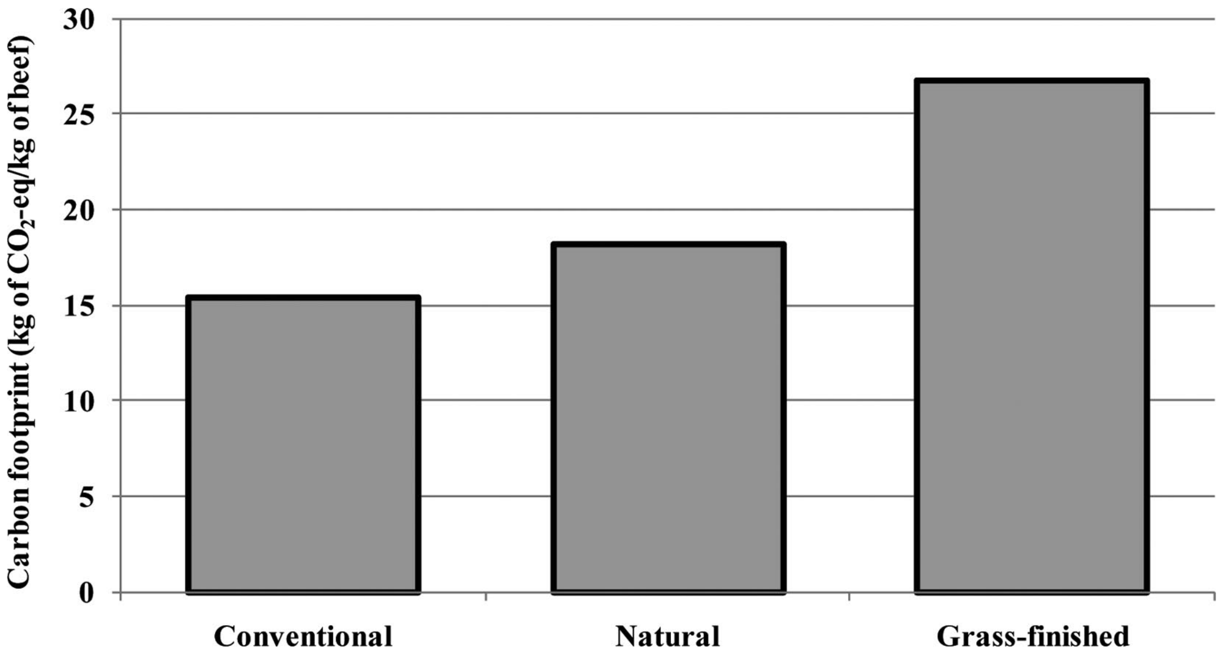

Figure 17. The comparative carbon footprint of conventional, natural, and grass-fed beef (Capper, 2010b).

In contrast, Haas et al. (2001) found no difference between organic and conventional intensive production systems. However, this latter study also found that conventional extensive production systems had lower emissions/kg milk than conventional intensive or organic production systems. This is supported by Basset-Mens et al. (2009b), who reported that increased production intensity in New Zealand production systems, in terms of output/ha, increased emissions/kg product.

4. Manure Management and Treatment

Manure management options focus mainly on reduction of N_2O and CH_4 emissions by anaerobic digestion and manure treatment.

4.1. Manure Storage and Separation

Greenhouse gas emissions from stored manure are primarily in the form of CH_4 (due to anaerobic conditions). Volatilization losses of NH_3 are large and N_2O emissions could also occur. One simple way to avoid cumulative GHG emissions is to reduce the time manure is stored (Philippe et al., 2007; Costa et al., 2012). Increasing the time of manure storage increases the period during which CH_4 (and potentially N_2O) is emitted, as well as the emission rate, creating a compound effect (Philippe et al., 2007). Storage treatments that provide aeration such as mechanical aeration or intermittent aeration have been shown to reduce CH_4 emissions. Temperature is a critical factor regulating processes leading to NH_3 and CH_4 emissions from stored manure (Sommer et al., 2006). Decreasing manure temperature to < 10 °C, by removing the manure from the building and storing it outside in cold climates, can mitigate CH_4 emissions (Monteny et al., 2006).

4.2. Anaerobic Digestion

Anaerobic digestion is the process of degradation of organic materials by Archaea in the absence of oxygen, producing CH_4, CO_2, and other gases as by-products, and it is a promising practice for mitigating GHG emissions from collected manure. In addition, when correctly operated, anaerobic digesters are a source of renewable energy in the form of biogas, which is 60 to 80 percent CH_4, depending on the substrate and operation conditions (Roos et al., 2004). Moreover, Dhingra et al. (2011) showed that anaerobic digesters reduce GHG emissions between 23 percent and 53 percent.

Moreover, the digested manure (digestate) has a number of unique characteristics including a higher pH which could promote NH_3 losses but it has little effect on the total nitrogen content of manure. A negligible amount of N may be emitted as NH_3, lower DM content and viscosity which could reduce NH_3 losses by infiltrating more rapidly into soil. Further, the digestate may contain relatively more NH_4-N and less organic C resulting in a lower C: N ratio, all of which are properties that tend to increase the ratio of N_2O:N_2 produced by denitrification. Further the leakage of Nitrous oxide cannot be avoided which increases the contamination of ground water by nitrite.

Digestate also contains less metabolizable organic C, which limits available C for soil microorganisms and decreases N_2O emissions (VanderZaag et al, 2011). In addition the digestate (treated manure) has a higher fertilizer value (more inorganic N) than untreated manure and thus less N fertilizer is needed, which reduces N_2O emissions. However, the organic N in manure has residual effects after the year of application, which also needs to be accounted for (reported by Flysjö et al, 2011b).

4.3. Acidification

Acidification is a means of mitigating NH_3 losses because NH_3 volatilization is pH dependent and decreases with acidity. The efficacy of this strategy has been documented for decades. For example, Stevens et al. (1992) found that acidifying cattle slurry with nitric acid to a pH of 6.5 decreased NH_3 volatilization by 75% after surface application to a cut sward. Stevens et al. (1992) also reported synergistic effects by combining acidification with dilution and separation. Despite these positive results, farm adoption of acidification had been minimal for practical reasons (e.g., on farm handling of strong acids, manure foaming). Recently, Kai et al. (2008) reported a new acidification technology that makes this strategy feasible, and it has been approved as a 'Best Available Technology' in Denmark, as their results show that acidifying cattle slurry in the barn from pH 7.5 to 6.3 decreased NH_3 loss by 67% when manure was band spread on winter wheat. In spite of these promising results, there has been no published research on effects of applying acidified manure on direct N_2O emissions. Because acidification preserves more N in the manure and N_2O production is favored at a low pH, acidification could cause an increase in direct N_2O emissions. However, if the preserved manure N was used to reduce synthetic N use, and emissions associated with synthesizing N, then there could be a reduction in N_2O emissions. However, much uncertainty remains about the effects of acidification on N_2O emissions.

5. Use of Nitrification Inhibitors

Several amendment options show potential to decrease N_2O emissions from soil, such as nitrification inhibitors. Nitrification inhibitors are chemical compounds that retard the formation of nitrate (NO_3^-) from ammonium (NH_4^+) based fertilizers in soils, or from urine, thereby reducing the amount of nitrous oxide emissions (Di and Cameron, 2002). There are two main commercially available nitrification inhibitors to use at the farm level; nitrapyrin and dicyandiamide (DCD). These coating substances have been shown to be effective in reducing N_2O emissions by approximately 80 % (de Klein et al., 2001). Nitrification inhibitors can also effectively reduce N_2O emissions from animal urine by 61% – 91%, with pasture yield increases of 0% – 36% (Di et al., 2007; Kelly et al., 2008; Smith et al., 2008). In this respect, VanderZaag et al., (2011) found that nitrapyrin decreased total denitrification losses by >50% from cattle slurry injected into grassland in winter, and DCD (dicyandiamide) reduced the denitrification rate in grassland receiving cattle slurry. Reduced denitrification probably decreased N_2O flux, although N_2O flux was not measured in that study. In another study where N_2O flux was measured, DCD reduced N_2O loss by 60% from surface applied cattle slurry on a poorly drained grassland in Spain (Merino et al., 2002).

6. Grazing Management

Recent research has shown that restrictive grazing practices can reduce direct and indirect emissions of NO_2 by up to 10 % (de Klein et al., 2006; Luo et al., 2008; Schils et al., 2006). In the referenced studies, animals were allowed to graze for 3-15h per day, and were kept off pasture either indoors or on a feed pad for the remaining of the day. Schils et al. (2006) reported that a combination of the reduced grazing time and fertilizer use in Netherland study farms reduced emissions by around 50 % when reported per unit of output scale, and around 10 % on a whole farm basis. The improved nitrogen utilization increased farm efficiency while reducing nitrogen losses and production was held constant.

Luo et al. (2008) and de Klein et al. (2006) reported whole farm reductions in the level of emissions of 7-11 % for restricted grazing regimes, following subsequent land application of effluent collected when animals were kept on feed or stand-of pads compared with conventional grazing.

Conclusion

Assessing the carbon footprint (CF) of agricultural products has gained a lot of attention in recent years. Conducting a CF assessment involves a number of methodological choices which have a significant impact on the final result. In some cases, it could be difficult to determine whether a difference in the CF of two dairy products is caused by 'real' differences in impacts or simply by discrepancies in CF methodology. This is a challenge for farmers that need robust methods to properly identify and analyze improvement options, but also for policy-makers and consumers who need robust science as a basis for their decisions on regulations and on purchases. To be able to address these challenges, it is pivotal to gain a better understanding of the relationship between methodological choices and CF results. In relation to dairy and beef products, some key methodological challenges are identified in the present thesis: estimating CH_4, N_2O and CO_2 emissions, some simulation test of management and nutrition on the farm and the production system.

There is no 'silver bullet' in the mitigation of GHG emissions for dairy and meat productsI Instead many improvements which individually show little changes may together result in significant reductions. The difference in the CF of milk and meat between relatively similar dairy and beef farms indicates that there is scope for reducing GHG emissions by improving management practices. Mitigation strategies need to take the individuality of farms into account. Slight improvement at the farm level can result in relatively large reductions in the CF of dairy and meat products, because emissions before farm gate constitute the main source of the GHG emissions.

Finally, dairy and beef companies have an important role to play, representing the link between production and environment to encourage sustainable farming practices at the same time as promoting more sustainable environment. Even though the principal objective for a business is to make a profit, a strong engagement in the promotion of sustainable production (including mitigating climate change) is becoming more important for their image and therefore success especially in a long-term perspective.

CHAPTER 2: OBJECTIVES

The general objective of this study was:

1. To quantify and analyze the greenhouse gas emissions and carbon footprint from typical Spanish dairy and beef farms.
2. To evaluate the diet contribution on enteric methane emissions.
3. To evaluate the feasibility of management scenarios to reduce methane emissions.
4. To evaluate the impact of dietary modifications on methane emissions.

CHAPTER 3: MATERIALS AND METHODS

1. Models Description

1.1. The Integrated Farm System Model (IFSM)

The Integrated Farm System Model (IFSM) developed and validated by Rotz et al. (2007) was used in the present study to predict the GHG emission and C footprint from dairy and beef farms in Spain. IFSM was selected as a model to be applied in this study over others due to its integration, high feasibility and accuracy, as it integrates all processes inside the farms to give a full detailed data of greenhouse gas emissions. In addition, this model provides a comprehensive yet easy-to-use tool for estimating the emissions and C footprint of a wide range of dairy and beef production systems.

The model requires input data such as detailed information about soil characteristics, crop growth, tillage, planting, harvest, feed storage, feeding, herd structure and production, and manure storage. In addition, the model takes into account the prevailing local weather conditions and farm management practices. The input information is used in the model to predict the whole farm GHG emissions and the carbon footprint considering primary and secondary emission from dairy and beef farms (Figure18). Primary sources of GHG emissions include the net emission of CO_2 plus all emissions of CH_4 and N_2O during the on farm production of feeds, animals, and handling of manure. Secondary emissions are those occurring during the production of resources used in the farm, such as purchased feed, fuel, electricity, machinery, fertilizer, pesticides and purchased animals. Moreover, IFSM predicts the effect of different management scenarios on farm environmental pollution (Rotz et al., 2009).

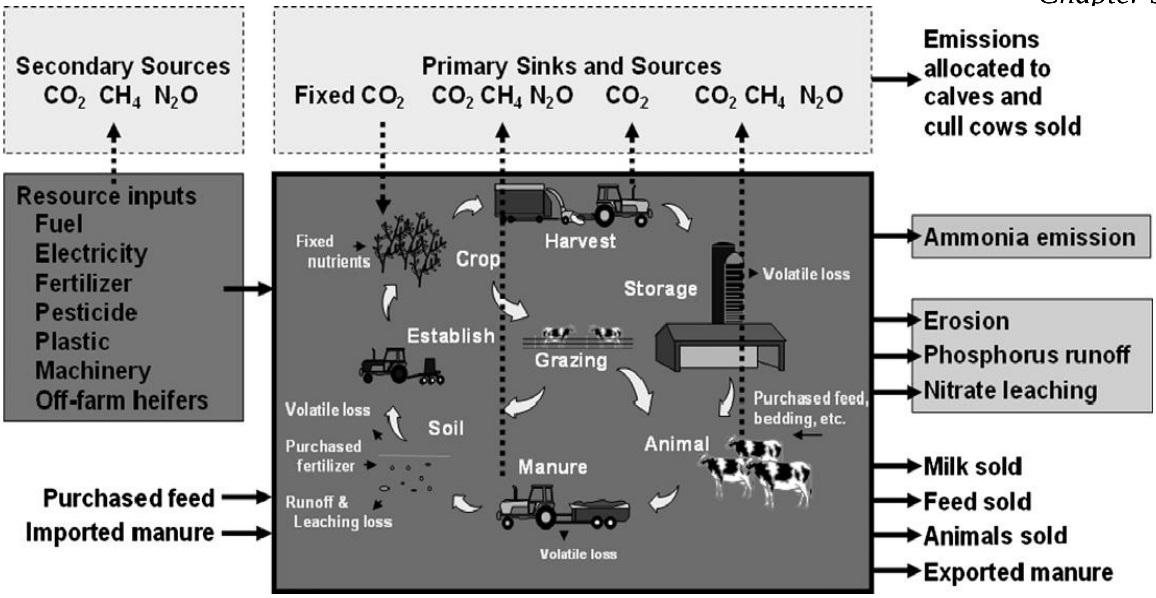

Figure 18. Processes on a dairy farm and their predicted GHG emission as simulated by the Integrated Farm System Model (USDA-ARS, 2009).

1.2. *The Cornell Net Carbohydrate and Protein System Model (CNCPS* 6.1*)*

The Cornell Net Carbohydrate and Protein System Model (CNCPS version 6.1; Fox et al., 2004) was used to evaluate the contribution of the diet to methane emissions of an average lactating cow and feedlot beef on each farm, and explore the impact of dietary modifications on methane emissions.

The CNCPS is a mathematical model that estimates cattle requirements and nutrient supply based on animal, environmental, and feed compositional information in diverse production situations. Predicted animal requirements account for different physiological states (lactation, pregnancy, and growth), body reserves and environmental effects. The CNCPS uses feed carbohydrate, and protein degradation and passage rates to predict extent of ruminal fermentation, microbial protein production, post ruminal absorption, and total supply of metabolizable energy and protein to the animal. The CNCPS has been used successfully on beef and dairy cattle farms to evaluate and formulate rations. The CNCPS is also designed to be used in the field to predict nutrient excretion as part of a nutrient management decision making process, including estimation of N and P excretion, methane emission and ammonia potential enabling integration with whole-farm nutrient management plans (Fox et al., 2004; Tylutki et al., 2008; Van Amburgh et al., 2010).

2. Scope of the Study

2.1. Dairy Farms

The three most important regions of dairy cattle production in Spain were selected: 1) Mediterranean (Catalonia, Valencia and Murcia) which represents 11 %; 2) Cantabrian Area (Galicia, Asturias and Cantabria) which represents 56 % of total dairy cattle; 3) Central zone (Castilla-La Mancha, Castilla-Leon, Madrid and Aragon) which represents 21 % of total dairy cattle production in Spain (MARM, 2011).

The default values of the model were used except when values deviated substantially from typical Spanish conditions, in such cases local values were used. So it was necessary to adapt the IFSM Model to the Spanish conditions including nutritional characteristics of forages and concentrates, and daily local weather data for ten years. We selected three geographic locations: 1) Mediterranean (Gerona: 41° 54' 42" N, 2° 45' 48" E); 2) Continental (Lerida: 41° 37' 42" N, 0° 35' 44" E); 3) Ocean (Galicia: 43° 21' 57" N, 8° 25' 17" O) to be used by the model. The average annual temperature, relative humidity, wind velocity, mean precipitation (mm) and solar radiation are depicted in Table 5.

Table 5. Local weather data of three point of the Spanish territory (State Agency of Meteorology, Spain).

Weather parameter	Annual Average Values		
	Gerona	Lerida	Galicia
Average High Temperature (°C)	20.2	20.8	17.4
Average low Temperature (°C)	8.4	8.6	11.4
Actual Average Temperature (°C)	14.3	14.7	14.4
Total Precipitation (mm)	724	369	1008
Average Solar Radiation (watts/m2)	8.8	7.6	8.9
Average Wind Velocity (MPH)	9.5	8.9	9.9
Average Relative Humidity (%)	72	66	77

2.1.1. Selection of Typical Farms and Data Collection

A typical dairy farm is defined as a farm which represents a significant number of dairy farms in a region in terms of size, forage and crops grown, livestock systems, labour organization and production technology used.

Typical farms were selected in a three step procedure. In the first step, the regions and locations which are most important for dairy production were identified. As a general rule, these are the main areas of production but, in some cases, they may be the regions with a particularly high potential for future expansion in milk production. In the second step, technical advisors with a sound knowledge of local conditions and with good contacts with farm managers were contacted. The main structural characteristics of the typical farms were discussed by these experts (e.g., type of farm, size of farm) with the aim to describe an average sized and large scale farm for each region.

Third data were obtained by visiting the farms and completing a structured questionnaire. The survey developed for the current study contained the following main points: crop and soil, grazing, machinery, tillage and planting, crop harvest, feed storage, herd and feeding, manure and nutrient.

Ration data for dairy cattle herds were also requested (types and amounts of forage and concentrate) together with nutritional management strategies (feeding groups for each herds, feeding system, mineral supplementation or grazing activity). Information on concentrate composition was obtained from the corresponding farm. Data regarding the land in relation to dairy activity (grassland or cropland), use of land (for homegrown forage production or slurry fertilization) and ownership (owned or rented) were also obtained from the survey a full questionnaire is presented in Appendices A. This approach has been used by international organizations to study country performance from different prospective (International Farm Comparison Network IFCN., 2013).

Four typical dairy farms from each region described above were selected. In addition, two other farms (one organic and one from Baleares Island were also selected) were simulated with IFSM and CNCPS Models (Table 6).The majority of the inputs into the model were determined during personal interviews with the manager of each farm.

2.2. Beef farms

The main beef production systems in Spain were divided into two types, the first type represents 90 % and is based mainly on concentrate feeding and straw (90:10) while the second type represents only 10 % and is based on corn silage (30%) and concentrate (70%).

Approximately 90 % of all beef produced in Spain are fattened on feedlot system. Of these, about 25% is produced from animals of dairy herds (mamones), and about 60% from beef breads (local or imported). A survey was conducted for beef farms, with a total of 3 feedlot beef farms selected and simulated with IFSM and CNCPS Models to reflect these different types of production systems. The major characteristics of these selected feedlot farms are represented in the Table 7.

3. Simulation of Mitigation Strategies to Reduce Methane Emission

Several strategies in this study were explored to reduce methane emissions. These strategies may be categorized as follows: Management and dietary strategies. Each will be addressed in the subsequent section.

A series of simulations were done in selected farm which had the highest non enteric methane and carbon footprint to study the effects of individual management changes. The 5 management changes were 1) increased milk production through genetic improvement, 2) manure type collection system, 3) bedding type, 4) use of anaerobic digester, and 5) storage type of manure.

A second series simulation was done in a selected farm which had the highest enteric methane emission to study the effects of nutritional changes. The 4 dietary changes were 1) modification of the ratio between forage / concentrate 2), improved forage quality 3) inclusion of fat in the diet, 4) addition of ionophores.

Table 6. Characteristics of the selected dairy farms in Spain.

Code farm	Region	Milk production(kg/cow/year)	Number of animals	Grazing	Farm area (Ha)
197MA	Mediterranean Area	9565	197	–	330
106MA	Mediterranean Area	11000	106	–	25
376MA	Mediterranean Area	11000	376	–	60
440MA	Mediterranean Area	10100	440	–	1
170CA	Cantabric Area	11000	170	–	26
64CA	Cantabric Area	8500	64	+	25
170CA	Cantabric Area	10800	170	+	82
240CA	Cantabric Area	12134	240	–	40
400CZ	Central zone	11000	400	–	3
365CZ	Central zone	12200	365	–	96
312CZ	Central zone	10500	312	–	60
189CZ	Central zone	11700	135	–	83
115BI	Baleares Island	10500	115	+	170
199OG	Organic	5800	199	+	70

+ Grazing; – No grazing

Table 7. Characteristic of the simulated beef farms in Spain.

Characteristic / Code farm	800 CAT	2400CYL			5000 ARA		
Province	Catalonia	Castilla -León			Aragon		
Size of farm(Ha)	0	0			150		
Number of animals	800	2400			5000		
Number of cycle during the year	1	2			2		
With or without corn silage	Without corn silage	Without corn silage			With corn silage		
Breed	Holstein	Limousin	Charlais	Spanish (Cross)	Limousin	Charlais	Spanish (Cross)
Growth period (month)	15	9	9	12	9	9	12
Starting and end weight (kg)	120-450	250-650	250-650	45-450	250-650	250-650	45-450
Average daily weight gain (Kg)	1.57	1.6	1.6	1.4	1.6	1.6	1.4

CHAPTER 4: RESULTS AND DISCUSSION

1. Gas Emissions by Spanish Dairy Farms

The results of the greenhouse gas emissions modeling of dairy cattle farms from Mediterranean Area, Cantabric Area, Central Zone and other two farms (one organic and one from Baleares Island) performed by the IFSM are shown in tables 8, 9, 10 and 11, respectively.

Gas emissions of an average Spanish dairy cow were 281.6, 4.5 and -3269 kg/cow/year for methane, nitrous oxide and the net emission of carbon dioxide including assimilation by land and feed production, respectively. Each kilogram of Spanish milk emits 0.83 kg of CO_2e. Several studies have determined C footprint for dairy production. Capper et al., (2008) found that a cow in the United States with a milk production of about 9050 kg/cow/year has a carbon footprint of about 1.52 kg CO_2e/kg of milk. Another study conducted in Canada by Verge et al. (2007) on cows with 9400 kg/cow/year of milk production has a carbon footprint of 0.98 kg of CO_2e/kg of milk. In addition, Thomassen et al. (2008) reported a carbon footprint of 1.28 kg CO_2e/kg of ECM in a Netherlands dairy farm with an annual production of 7991 kg/cow. It could be concluded from the previously reported results that Spain has lower C footprint than those reported in USA, Canada and the Netherlands.

By region the C footprint of the selected dairy farms used in this study was shown in Figure 19. It could be concluded that the C footprint was the highest by Mediterranean Area farms with average value of 0.98 kg of CO_2e/kg of ECM followed by Central zone farms with average value of 0.84 kg of CO_2e/kg of ECM, while the lowest values were detected in Cantabric Area farms when the average value was 0.68 kg of CO_2e/kg of ECM. Moreover, it is clear from the figure 20 that C footprint produced by organic farm was quiet high (0.89 kg of CO_2e/kg of ECM).In addition Baleares Island farm (115BI) has a relatively low carbon footprint (0.67 kg of CO_2e/kg of ECM). Similar results were obtained by Bellflower et al. (2012) in dairy farms with a carbon footprint varies from 0.79 to 0.87 kg of CO_2e/kg of ECM. Other published study have assessed the greenhouse gas emissions from dairy production systems using the IFSM (Rotz et al., 2011) farms with average value of 0.37 kg of CO_2e/kg of ECM.

The breakdown of total GHG emissions into component gases was examined in absolute terms and relative to each other for all farms (Figure 20). Methane emissions were the biggest share of GHG, accounting for more than 50% of the total emissions.

The prediction of CH_4 emission using the dairy IFSM was estimated to be the highest in Mediterranean Area; it ranged from 291.5 in the 440MA farm to 335.5 in the 197MA farm with an average of 328 kg/cow. About 70% of emissions were from enteric fermentation and manure. In the Central Zone, CH_4 emissions ranged from 223.4 in the 400CZ farm to 334.8 in the 365CZ farm with an average of 273.3 kg/cow. In the Cantabric Area farms, methane emission ranged from 156.6 in the 64CA farm to 284.2 in the 240CA with an average of 243.3 kg/cow. Nitrous oxide emissions were relatively low in all farms, but considering a greater effect on global warming, these low levels have a larger effect on overall GHG emissions.

Table 8. Greenhouse gas (GHG) emissions from four representatives Mediterranean Area.

	Mediterranean Area farms			
Greenhouse gas emission	**197MA**	**106MA**	**376MA**	**440MA**
Ammonia (kg of NH_3/cow)				
Animals and housing	87.3	34.6	85.4	82
Manure storage	10.9	18.5	16.4	16.1
Field-applied manure	25	84.7	118	21.2
Total	123	138	120	119
Methane (kg of CH_4/cow)				
Animals and housing	214	180	217	196
Manure storage	120	152	135	96
Field-applied manure	0.2	0.4	0.1	0.1
Total	335	333	352	292
Nitrous oxide (kg of N_2O/cow)				
Animals and housing	3.6	1.8	3.6	3.3
Manure storage	0.0	0	0	0.8
Cropland	4.8	2.4	2.4	3.1
Total	8.4	4.2	6	7.3
Carbon dioxide (kg of CO_2/cow)				
Animals and housing	6107	6161	6850	6444
Manure storage	450	361	503	357
Net Feed Production	-10776	-10600	-10680	-10155
Fuel combustion	313	169	252	221
Net Emission	-3218	-3700	- 3327	-3353
Total GHG (kg of CO_2e)				
Animal emissions	423374	287653	934701	1035996
Manure emissions	351776	181554	840921	840220
Feed production emissions	117890	35518	129715	203571
Secondary sources	325326	212946	711710	990553
Carbon footprint (kg of CO_2e/kg of ECM)	1.09	0.84	1.06	0.93

ECM= ECM = Energy Corrected Milk with 3.5% fat and 3.1% protein concentrations.

CO2e = CO2 equivalent.

Table 9. Greenhouse gas (GHG) emissions from four representative Cantabric Area farms.

Greenhouse gas emission	Cantabric Area farms			
	170CA(L)	240CA	170CA(C)	64CA
Ammonia (kg of NH_3/cow)				
Animals and housing	2.1	48.5	39	4
Manure storage	12.3	52.8	18	14
Field-applied manure	10.4	11.6	35	1
Grazing	50.5	0. 0	0	34
Total	75.3	113	92	53
Methane (kg of CH_4/cow)				
Animals and housing	34.4	194.3	187	30.8
Manure storage	28.1	89.8	90	14.2
Field-applied manure	0.1	0.1	0.2	0.0
Grazing	196.4	0.0	0	125.4
Total	259	284.2	278	171.6
Nitrous oxide (kg of N_2O/cow)				
Animals and housing	0.0	1.2	1.1	0.0
Manure storage	0.0	0.0	0.0	0.0
Cropland	5.7	1	1.2	2.7
Total	5.7	2.2	2.3	2.7
Carbon dioxide (kg of CO_2/cow)				
Animals and housing	1014	6618	6721	751
Manure storage	109	317	321.1	50
Net Feed Production	-10301	-10198	-10274	-7431
Fuel combustion	239	168	186.1	60.5
Net Emission	-3635	-3261	-3232	-2576
Total GHG (kg of CO_2e)				
Animal emissions	579231	527130	385684	161834
Manure emissions	81097	309848	234341	18596
Feed production emissions	171791	31837	29464	34270
Secondary sources	261419	309567	206836	96734
Carbon footprint (kg of CO_2e/kg of ECM)	0.67	0.73	0.75	0.59

ECM= ECM = Energy Corrected Milk with 3.5% fat and 3.1% protein concentrations.

CO2e = CO2 equivalent.

Table 10. Greenhouse gas (GHG) emissions from four representative Central Zone farms.

	Central Zone farms			
Greenhouse gas emission	**189CZ**	**312CZ**	**365CZ**	**400CZ**
Ammonia (kg of NH_3/cow)				
Animals and housing	71.9	80.2	27.6	73.1
Manure storage	4.8	19.2	45.0	5.5
Field-applied manure	21.8	18.0	57.0	20.3
Total	98.5	117.3	129.6	98.9
Methane (kg of CH_4/cow)				
Animals and housing	204.8	198.0	168.2	178.5
Manure storage	32.8	99.3	166.0	44.8
Field-applied manure	0.1	0.2	0.6	0.1
Total	237.7	297.5	334.8	223.4
Nitrous oxide (kg of N_2O/cow)				
Animals and housing	2.9	3.2	0.0	3
Manure storage	0.0	0.8	1.4	0.6
Cropland	0.8	1.6	0.6	1
Total	3.7	5.6	2.0	4.5
Carbon dioxide (kg of CO_2/cow)				
Animals and housing	5903	6474	6240	5806
Manure storage	137	415.2	649	131
Net Feed Production	-9291	-10191	-10400	-8843
Fuel combustion	89.3	237	372	119
Net Emission	-3250	- 3302	-3465	-2905
Total GHG (kg of CO_2e)				
Animal emissions	535607	899141	917103	1044694
Manure emissions	347872	743003	840654	5143399
Feed production emissions	4523	89771	35363	0.0
Secondary sources	167418	699179	771649	607864
Carbon footprint (kg of CO_2e/kg of ECM)	0.79	0.92	0.90	0.75

ECM= ECM = Energy Corrected Milk with 3.5% fat and 3.1% protein concentrations.

CO2e = CO2 equivalent.

Table 11. Greenhouse gas (GHG) emissions from simulated other farms

	Other farms	
Greenhouse gas emission	**115BI**	**119OG**
Ammonia (kg of NH_3/cow)		
Animals and housing	65.2	48.2
Manure storage	2.2	57.8
Field-applied manure	18.8	19.8
Grazing	10.1	8.0
Total	86.3	133
Methane (kg of CH_4/cow)		
Animals and housing	172	171
Manure storage	14.2	27.1
Field-applied manure	0.2	0.2
Grazing	10	25.5
Total	196	224
Nitrous oxide (kg of N_2O/cow)		
Animals and housing	0.0	1.3
Manure storage	0.4	1.3
Cropland	5.6	3.6
Total	6.0	4.4
Carbon dioxide (kg of CO_2/cow)		
Animals and housing	6274	5649
Manure storage	80.6	43.1
Net Feed Production	-8874	-8540
Fuel combustion	244.8	180
Net Emission	-2600	-2171
Total GHG (kg of CO_2e)		
Animal emissions	278220	491549
Manure emissions	27844	33095
Feed production emissions	94534	115822
Secondary sources	212499	0.0
Carbon footprint (kg of CO_2e/kg of ECM)	0.67	0.89

ECM= ECM = Energy Corrected Milk with 3.5% fat and 3.1% protein concentrations.

CO2e = CO2 equivalent.

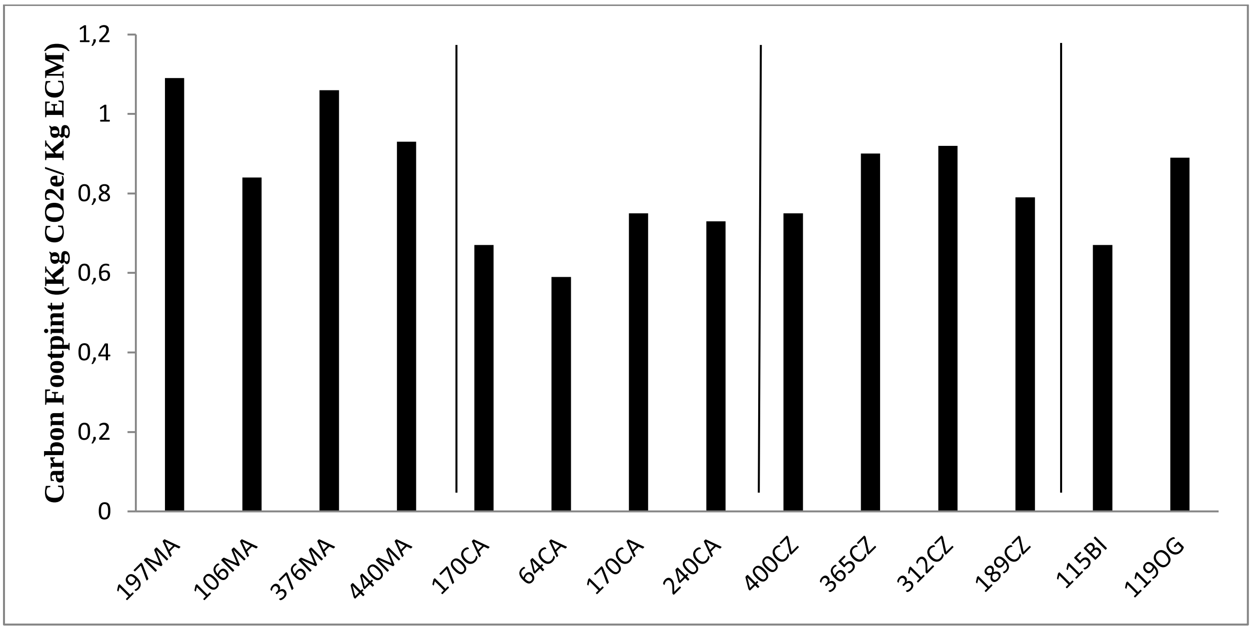

Figure 19. Carbon Footprint (Kg CO_2e /kg ECM) of the selected dairy farms.

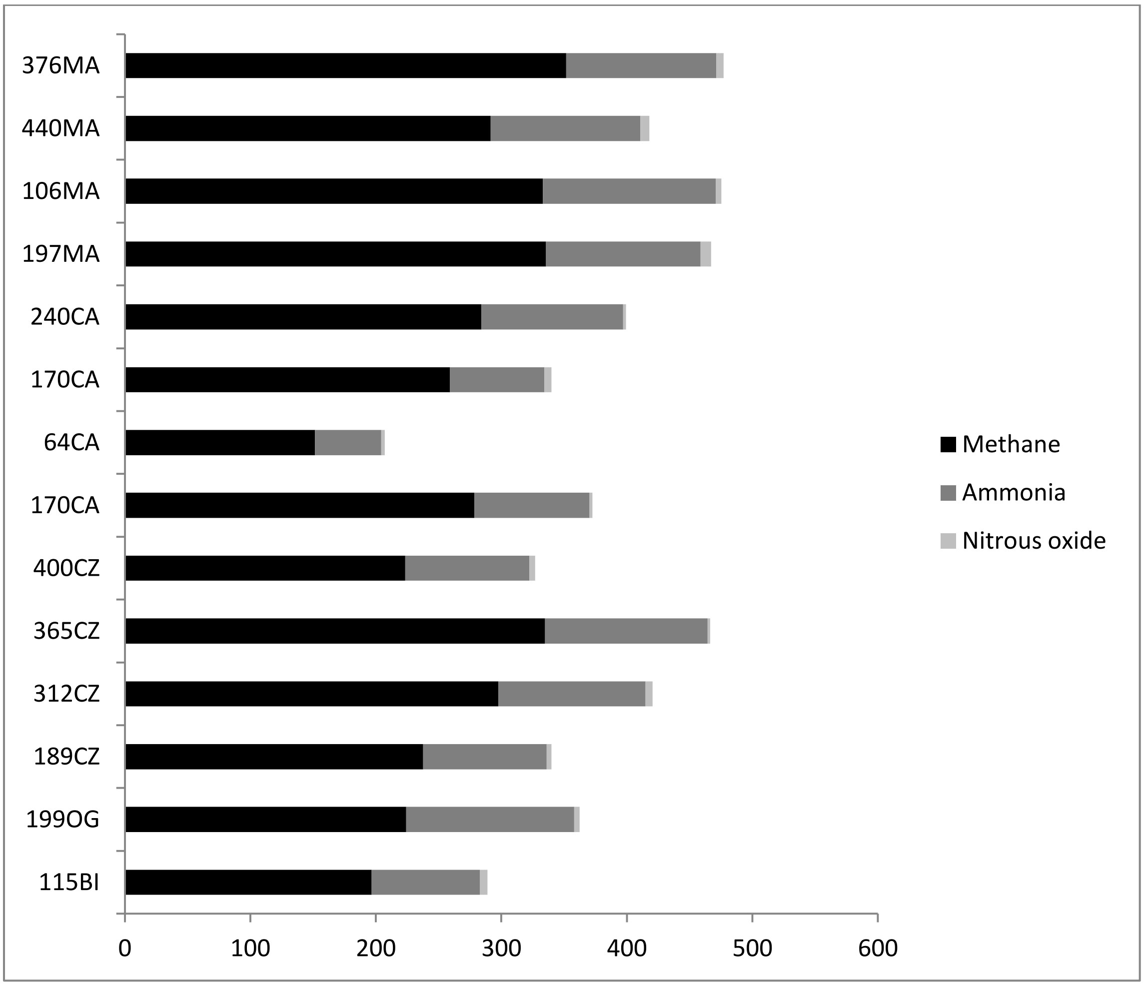

Figure 20. Annual emissions of important gases (kg/cow/year) in Mediterranean farms (197MA, 106MA, 376MA and 440MA), Cantabric (170CA, 240CA, 170CA and 64CA) farms, Central zone (400CZ, 365CZ, 312CZ and 189CZ) farms and to two other farms one organic and one from Baleares Island (OG and BI).

1.1. Diet Evaluation with the CNCPS Model and its Contribution to Enteric Methane Emissions.

Table 12 shows the results of diet evaluation of each farm with the CNCPS model and its contribution to enteric methane emission per unit of milk produced. It could be concluded from this table that the average values of enteric methane emissions per Kg of milk were 12.5, 13.5 and 12.4 g/Kg milk by Mediterranean Area, Cantabric Area farms, Central zone and two other farms, respectively.

Table 12. Diet contribution in methane production (Kg of milk) from the selected dairy farms.

Code farm	Number of milking cows	Milk yield (kg /day)	Enteric methane(g/kg milk) With CNCPS
Mediterranean Area farms			
197MA	82	32.0	12.3
106MA	59	36.5	11.2
376MA	180	34.5	13.1
440MA	220	33.0	13.3
Cantabric Area farms			
170CA(C)	85	36.5	12.2
64CA	42	28.5	16.2
170CA(L)	102	36.0	13.4
240CA	112	40.0	12.4
Central Zone Farms			
400CZ	220	36.5	14.4
365CZ	200	40.0	11.2
312CZ	190	34.0	13.2
189CZ	130	38.0	10.7
Other Farms			
115BI	65	34.0	12.8
119OG	101	19.0	24.7

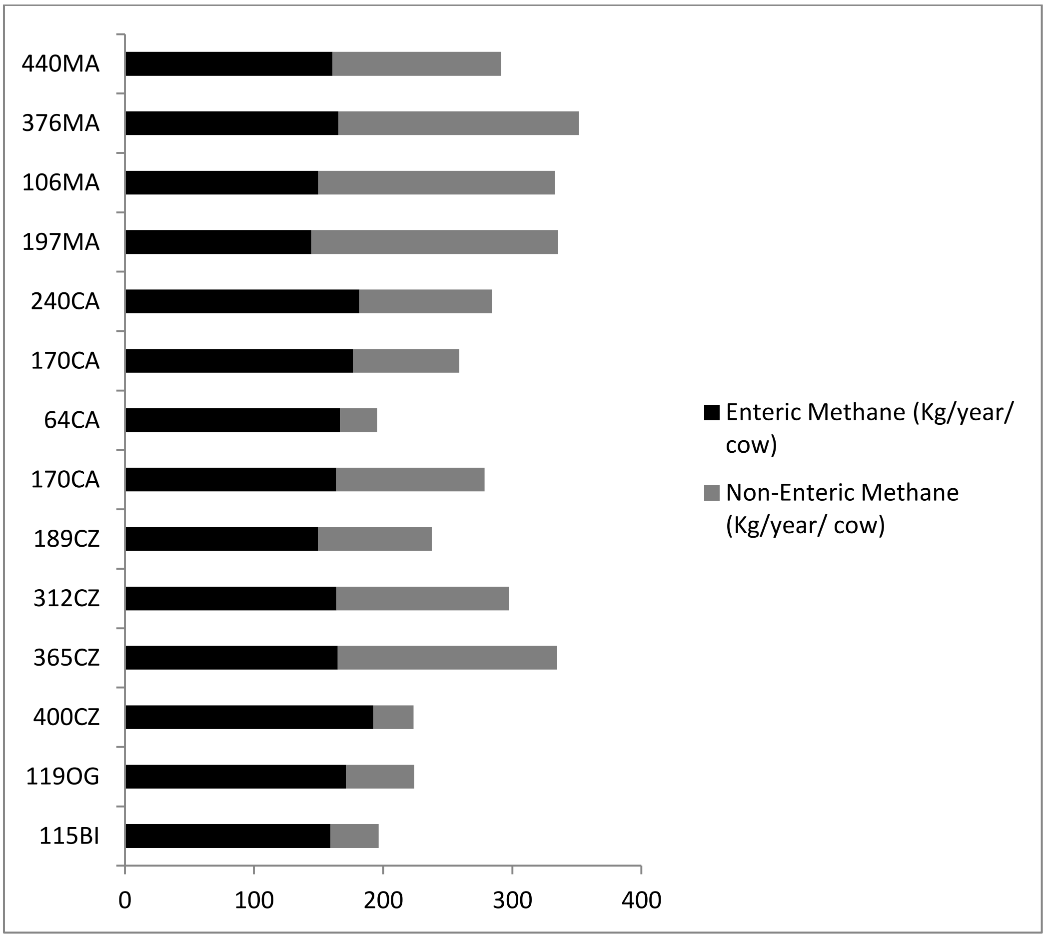

Figure 21. Production of methane (Enteric + Non-Enteric) in the selected dairy farms.

The production of enteric and non-enteric methane in the selected dairy farms is shown in Figure 21. It was clear that the enteric and non-enteric methane emission in Mediterranean Area farms was about 50 and 50 %, respectively, while in Central Zone farms it was 60 and 40 %, respectively, in the Cantabric Area farms it was 70 and 30 %, respectively and in the organic and the Baleares Island farm it was 70 and 20%, respectively. The farm 197MA has the highest non-enteric methane emission (153 Kg/cow/year) which explains its high C footprint. For this reason, such farm was selected to be modeled by the IFSM for reduction of non-enteric methane by application of different management strategies. The farm 64CA has high value of enteric methane and the lowest value of C footprint, and was selected to be modeled with the CNCPS for the reduction of enteric methane by application of different dietary change scenarios.

1.2. Characteristics of the Two Selected Extreme Farms

Two dairy farms, one with the largest non-enteric methane emissions (197MA, Gerona) and the other with the largest enteric methane emissions (64CA, Lugo). The first one was used to simulate changes in the management using IFSM model. The second one was used to simulate changes in diet composition using CNCPS model. The two farms are described in more detail.

The 197MA farm has 197 head, 82 of which are dairy cows, 54 young stocks over one year and 40 young stocks under one year. All animal in the herd were 100% Holstein. The average mature cow body weight was 650 kg, milk production estimated average around 9500 kg per cow per year, with 3.9% the milk fat, 3.2% milk protein concentration. Lactating cows were milked twice daily in a double 8 herringbone milking parlor. Calves on the farm were maintained in calf-hutches for about five weeks. Cows were bred year round using artificial insemination. All animals were maintained in free-stall barns with straw bedding (2 Kg /cow). Manure was collected every day and was stored for a period of 6 month in a top-loaded lined earthen basin. All animals were fed with similar amounts of forage coming from corn silage, mixed wheat and rye-grass silage, and alfalfa hay. The annual lactating cow replacement rate was 47%, with calves born randomly throughout the year. The major emission for this production was CH_4 generated by the animals (43%) and the bedded pack manure in the animal facility (57%). Nitrous oxide emissions were relatively small (8.4 Kg of N_2O/cow), but considering their large effect on global warming, these small levels had an effect on overall GHG emissions. About half of the total GHG emission for the production came from CO_2 emitted by the animals and manure in their housing facilities. This emission source was more than offset by the assimilation of CO_2 in feed production, so overall the farm was a net sink for CO_2. Emissions through the combustion of fuel were relatively small compared with other sources. The total from secondary sources was high, making up 20% of the net total of all sources and sinks. The C footprint for this production was 1.09 kg of CO_2e/kg of ECM.

The second farm (64CA) was relatively small, with 64 animals (42 of which are dairy cows, 14 young stocks over one year, and 9 young stocks under one year). Dry cows and heifers were maintained on about 20 ha. Annual milk production was 8.500 kg/cow, with 4.1% fat and 3.1% protein concentrations. During this time, lactating cows received about 30% of their forage from pasture over the full year and 50 % of ryegrass silage produced in the farm. Enteric methane in this farm was high and represented more than 85%, while non-enteric methane represents less than 15%.

1.3. Management Change Scenarios to Reduce Greenhouses Gases Emissions.

Sensitivity analyses have been conducted to suggest ways to reduce the carbon footprint and methane emission of dairies (Chianese et al., 2009a, 2009b, 2009c, 2009d and Rotz et al., 2010). Suggested improvements in management have included increased production per animal, reduced manure storage time, covering the manure storage and burning the biogas produced, incorporating managed rotational grazing into confinement operations, and reducing the resource inputs to the farm. The IFSM was used to analyze five potential changes in management on the 197MA farm to determine how these management changes affected methane emission. The following four management changes were modeled:

- Change in milk production (8000, 9565 and 11000 kg/cow) assuming that changes in cattle genetics and management could provide this increase in production.
- Selection of manure collection system among a solid (20% DM), semi-solid (12-14% DM), slurry (8-10% DM), or liquid slurry (1-7% DM).
- Selection of the type of manure storage used on the farm from no storage, top loaded tank or pit, bottom loaded tank or pit, covered tank, or enclosed tank.
- Selection of the type of bedding to be used in animal stalls: manure solids, sand, sawdust, or chopped straw.
- Installation of a anaerobic digester.

1.3.1. Improving Productivity

Figure 23 shows the effect of increasing milk production on methane emission in the 197MA farm. It was clear that as milk production increases the methane produced per cow per day increases slightly. Increasing productivity is an effective strategy to mitigate GHG emission, which may allow a reduction in animal numbers providing the same edible product output at a reduced environmental footprint. With time, increasing animal productivity can significantly reduce the number of animals needed for the national herd. Such reduction in animal numbers was the single most influential mitigation strategy which reduced significantly the C-footprint of the United States dairy industry from 1944 to 2007 (Capper et al., 2009). Similarly, in the Netherlands with a milk quota system, milk production per cow increased from 6270 kg to 8350 kg in 2008, with a CH4 decrease from 17.6 to 15.4 g/kg, respectively (Bannink et al., 2011). However, on the short term, high producing herd have a limited range of improvement of about 1% (Figure 23).

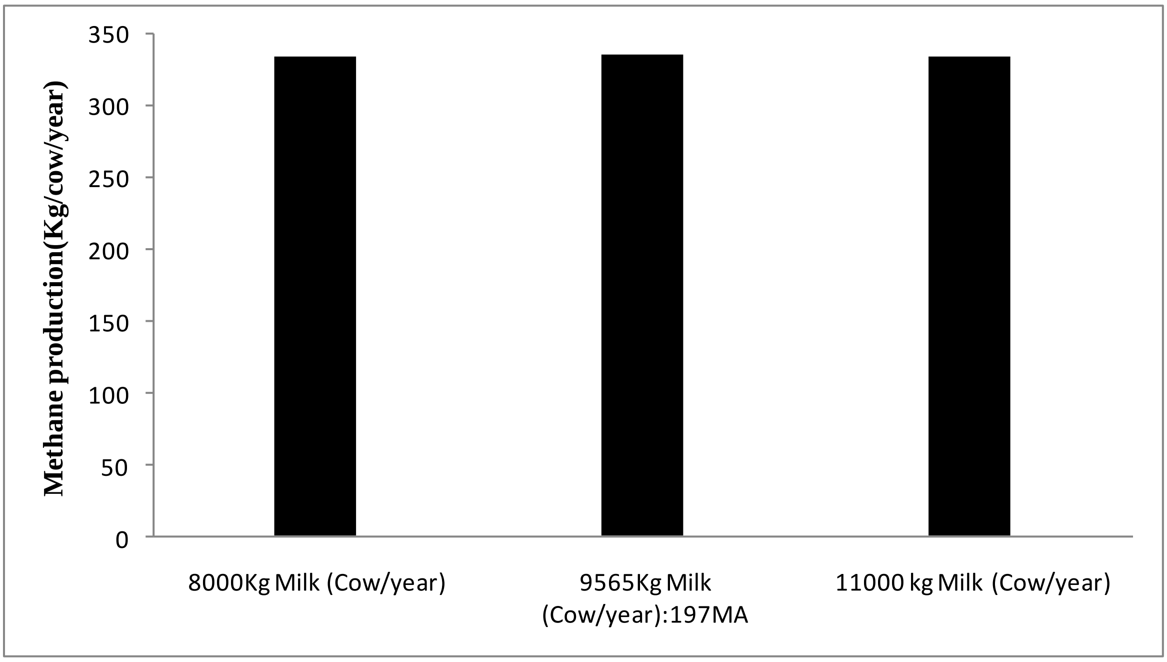

Figure 22. Effect of increasing milk production on methane production in 197MAfarm.

1.3.2. Manure Type

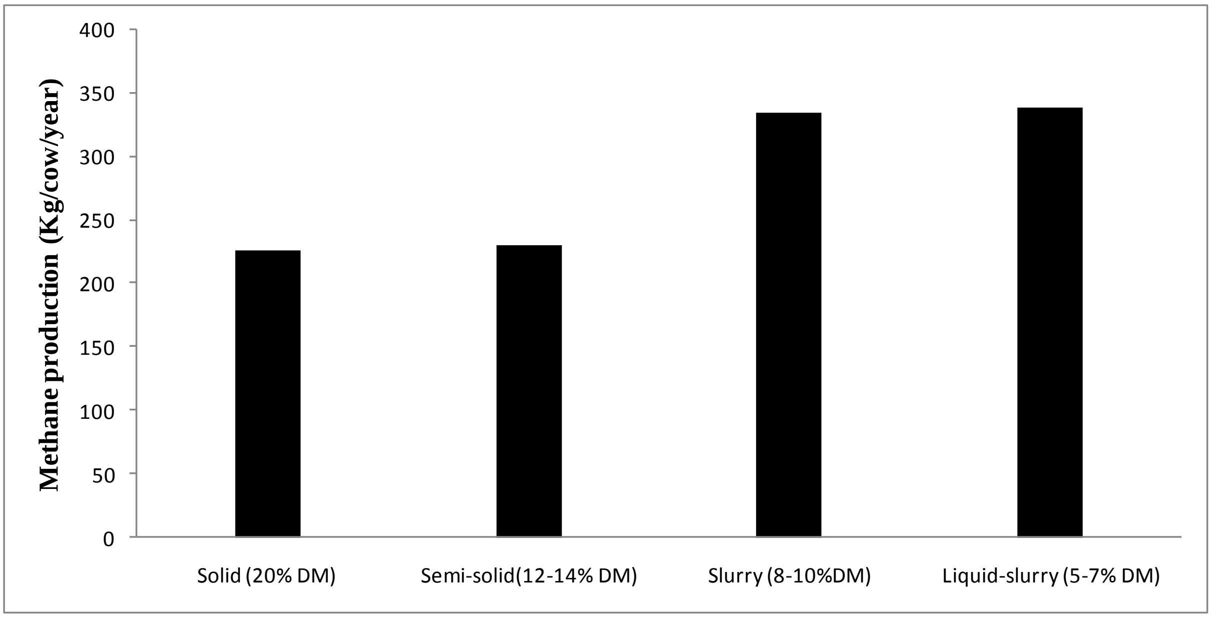

Figure 23. Effect of manure type on methane production in 197MA farm

1.3.3. Bedding Type

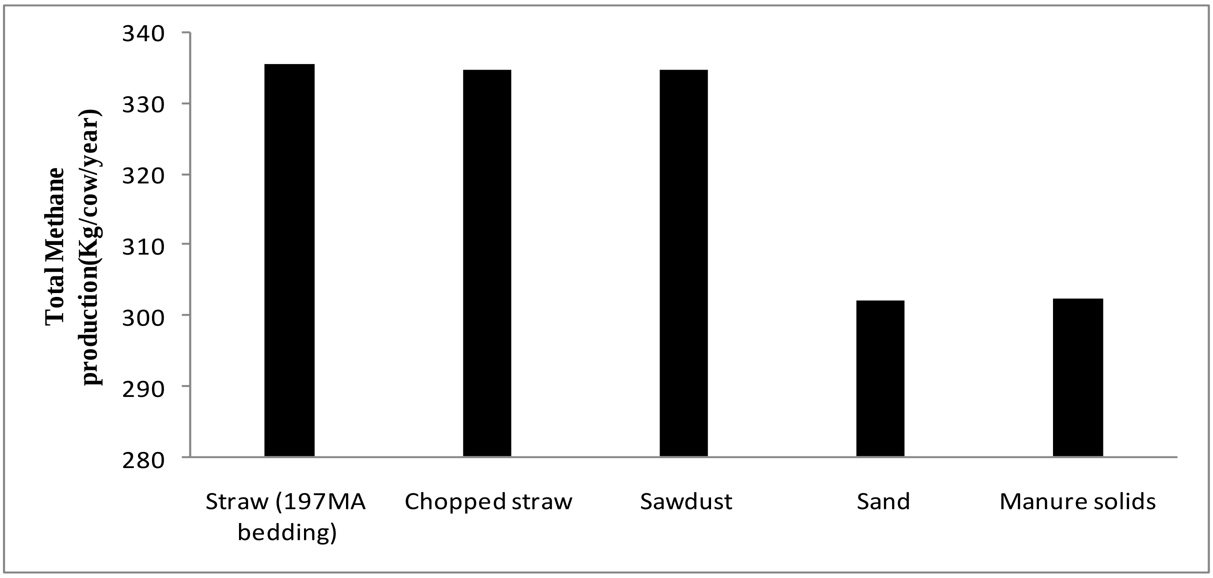

Figure 24. Effect of bedding type on methane production in 197MA farm.

1.3.4. Aneorobic Digestor

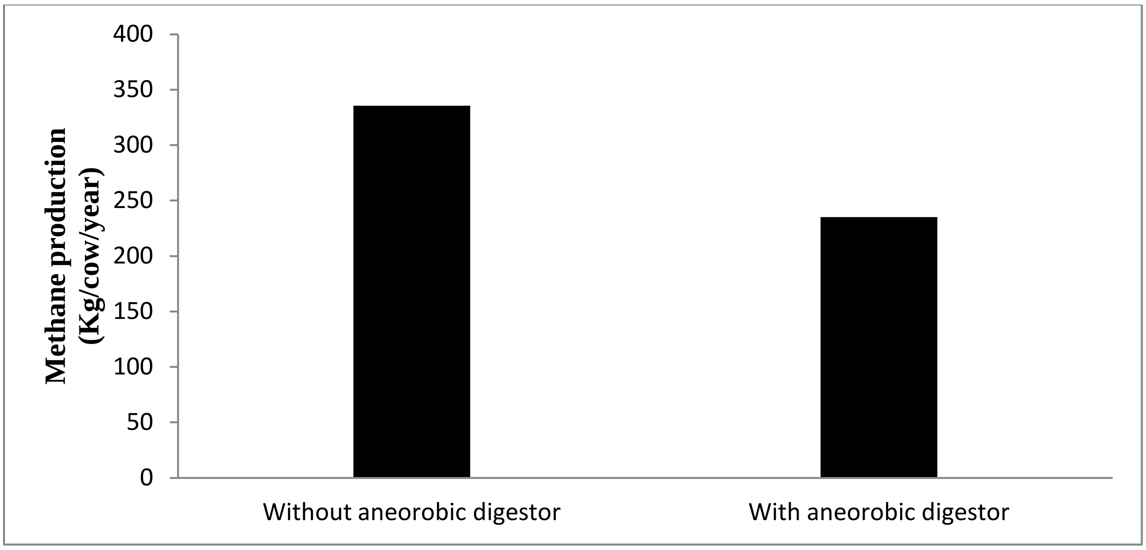

Figure 25. Effect of the installation of an anaerobic digester on methane production in MA farm.

1.3.5. Storage Type of Manure

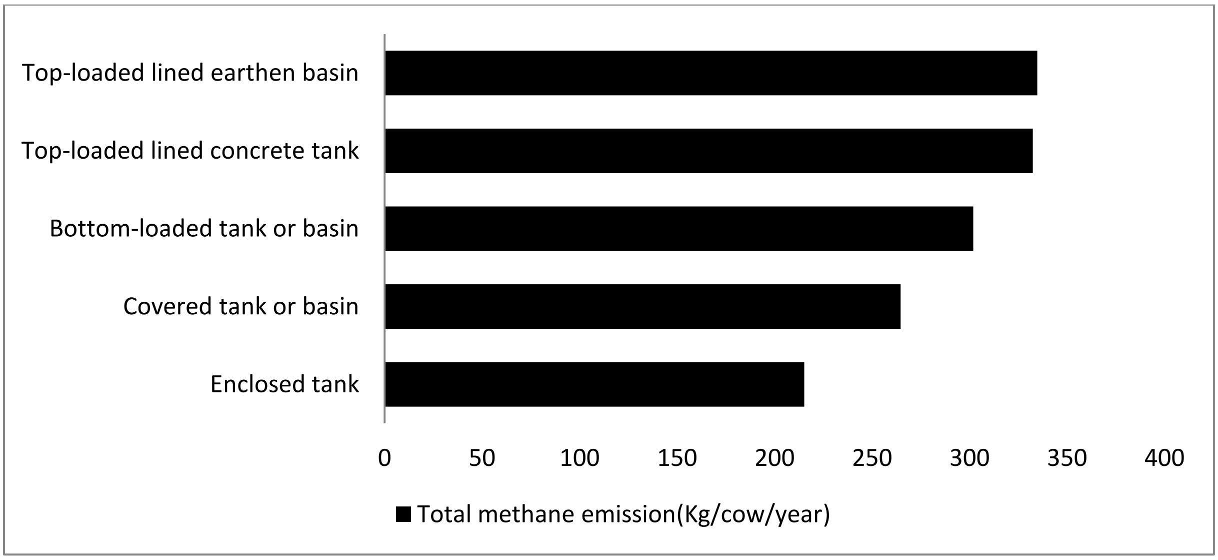

Figure 26. Effect of storage type of manure on methane emission in MA farm.

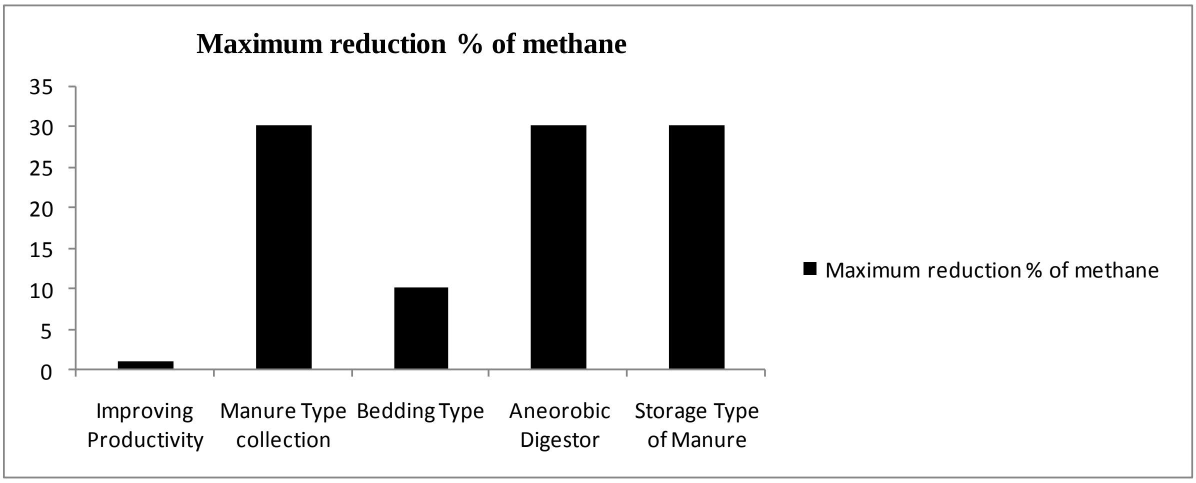

Figure 27. Summary of the various changes in management on the methane emission of the 197MA farm.

Data illustrated in Figure 28 indicate that the application of different management scenarios changes may have a large effect on methane emission reduction. The change in manure type collection (figure 24), anaerobic digestor (Figure 26) and storage type of manure (Figure 27) had the highest percent of methane emission reduction (30 %), while improving productivity and bedding type reduced methane emission from 1 to 10 %, respectively. According to Dhingra et al. (2011), which found that the use of an anaerobic digestor can reduce GHG emissions between 23 percent and 53 percent when compared with households without biogas, depending on the condition of the digester, technical assistance and operator ability. In addition, Sommer et al. (2009) simulated several manure management scenarios using data from four European countries and suggested that solids and liquid separation followed by incineration of the solids can reduce overall GHG emissions by 49% to as much as 82%. In the same context, Rotz et al., (2010) found that enclosing manure storage with a flare to burn the escaping biogas, almost eliminated CH_4 emission from the storage, but CO_2 emission increased. With the enclosed storage, the net result of this change was a 39% reduction in the net GHG emission and C footprint.

1.4. Dietary Change Scenarios to Mitigate Greenhouses Gases Emissions

The CNCPS model was used to analyze four potential changes in management on the 64CAfarm to determine how these changes affected their enteric methane emission. The diet composition of the 64CA farm is presented in Table 13.

Table 13. Ingredients diet of lactating cows.

Composition	**Kg DM /day**
Forages	
Rye Grass Silage	9.00
Grass Pasture	5.60
Concentrate	
Corn grain	1.53
Canola Meal	1.15
Soybean meal	1.4
Wheat Ground	0.87
Barley	0.72
Corn Dist Solubles	0.2
Wheat Bran	0.58
Molasses Cane	0.14
Sodium bicarbonate	0.04
Calcium Carbonate	0.07
Salt	0.04

Table 14. Diet evaluation and contribution en methane emission in the 64CA farm.

Intake DM (Kg/day/cow)	21.59
Number of lactating cows	42
Milk yield kg / cow / day	28.5
CH4 (g / kg milk)	16.37
Total methane production (kg / cow / year)	170
% Forage / concentrate	68/32

1.4.1. Modification of the Ratio Forage / Concentrate

Results displayed in Table 15 show the change in methane production by increasing the proportion of concentrates in the diet by 10 %. It was found such increase in concentrate led to a reduction in methane production from 16.37 to 13.07 g/Kg milk and decreased total methane emission (cow/year) by 5%. Feeding grain tends to increase ruminal propionate while lowering acetate levels from microbial fermentation (Grainger and Beauchemin, 2011). Previous work indicated that methane emissions increase as rumen acetate levels increase. This agrees with by Benchaar et al. (2001) who replaced beet pulp with barley, decreasing methane emissions by 22%.

Table 15. Effect of increasing the proportion of concentrates on the methane emission

% Forage / Concentrate	68/32 (control)	58/42
Milk yield kg / cow / day	28.5	31.2
CH_4 (g / kg milk)	16.37	13.07
Total methane production (kg / cow / year)	170	148.84

1.4.2. Improved forages quality

Data illustrated in table 16 shows effects of improving the nutritional value of Rye grass silage fed to lactating cows by harvesting at an earlier stage of physiological maturity on methane production. It was found that replacing Rye Grass Silage 1 (9 CP, 65 NDF and 8 LNDF) with Rye Grass Silage 2 (21 CP, 50 NDF and 7 LNDF) had a small effect on methane production (from 16.37 to 16.28 g/ Kg milk, respectively). A trial was conducted with lactating cows to evaluate methane production on two types of pasture (McCaughey et. al., 1999). An alfalfa-grass pasture (13% CP, 53% NDF) and a grass pasture (9% CP, 73% NDF) were used. Methane production was about 9% higher for cows on the grass pasture which is lower quality forage. Moreover, our results are in agreement with that reported by Boadi and Wittenberg (2002) which demonstrated that forage quality has a significant impact on enteric methane emissions. Cattle given hay of high (61.5 % IVOMD), medium (50.7% IVOMD) and low (38.5% IVOMD) quality differed ($P < 0.01$) enteric methane emissions ($P < 0.01$), as 47.8, 63.7 and 83.2 CH_4 L/ kg digestible organic matter intake was produced from cattle consuming the high, medium and low quality forages, respectively.

Table 16. Effect of improvement of the quality of ryegrass silage on methane emission

Ryegrass silage	Ryegrass silage farm	Ryegrass silage improved
Milk yield kg / cow / day	28.5	28.7
CH_4 (g / kg milk)	16.37	16.28
Total methane production (kg / cow / year)	170	170.34

1.4.3. The Inclusion of Fat in the Diet

Another practice of interest is to supplement diets with fats, which has been shown to lower enteric CH_4 production of dairy (Martin et al., 2008; Grainger et al., 2010) cattle. Several meta-analysis studies of numerous fat sources fed to sheep and cattle over a broad range of experimental conditions (Beauchemin et al., 2008; Eugène et al., 2008; Grainger and Beauchemin, 2011; Martin et al., 2010) showed that the inclusion of 40g fat/Kg dietary DM decline methane emission by an average 8–24%. In contrast, our study showed that including of linseed fat oil and canola fat oil in the diet of lactating cows lead to a higher methane emissions and milk production as compared with the control group (Table 17). Such result represents a critical point in this model as it is well accepted that increasing fat oil in the diet of lactating cows followed by reduction of methane gas emission.

Table 17. Effect of fat sources on methane and milk production

Fat type	**Control**	**Linseed Fat Oil**		**Canola Fat Oil**	
Fat Amount (g)	0	200	500	200	500
CH4 (g / kg milk)	16.28	16.52	17.01	16.49	16.99
Milk yield (kg /day)	28.5	29.4	30.8	29.3	30.1

1.4.4. The Addition of Ionophore

The results displayed in table 18 summarize the effect of addition of ionophore monensin on methane production. The addition of 300g/day monensin weakly reduced the methane emissions from 16.37 to 16.32 g/kg milk. This was in agreement with Appuhamy et al. (2013) that conducted a meta-analysis of literature data and showed that 32 mg/kg DM of monensin reduced CH_4 emissions and CH_4 conversion rate (Ym) in beef steers fed total mixed rations by 19 g/animal per d ($P < 0.001$) and 0.33 ($P = 0.047$), respectively. In dairy cows the reductions were 6 g/animal per day ($P = 0.065$) and 0.23 ($P = 0.095$) for monensin given at a dose of 21 mg/kg DM. In addition, Beauchemin et al. (2008) studied the effects of monensin on CH_4 emissions and found evidence of a dose response with monensin at 24–35 mg/kg DM intake reducing CH_4 emissions (as g/kg DM intake) by 3–8%.

Table 18. Effect of the addition of Rumensin 80 on methane production

Ionophore	Without monensin	With monensin
Milk yield kg / cow / day	28.5	28.6
CH_4 (g / kg milk)	16.37	16.32
Total methane production (kg / cow / year)	170	170.36

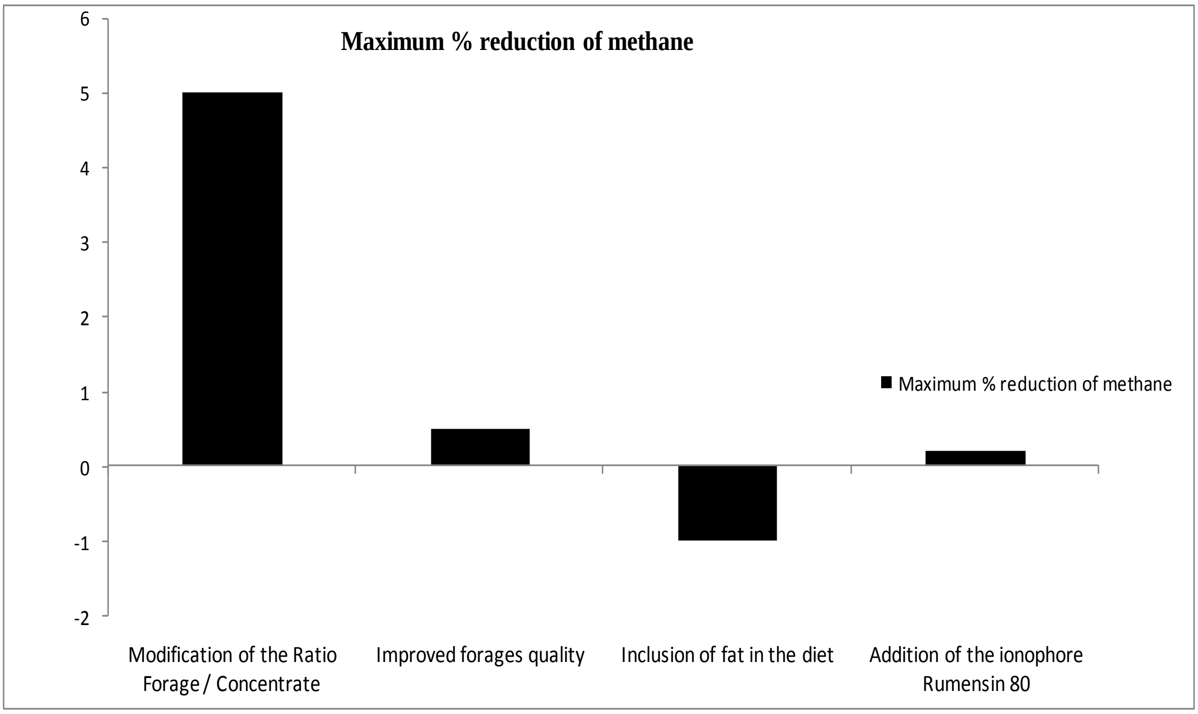

Figure 28. Summary of the various dietary changes on the methane emission of the 64CA farm.

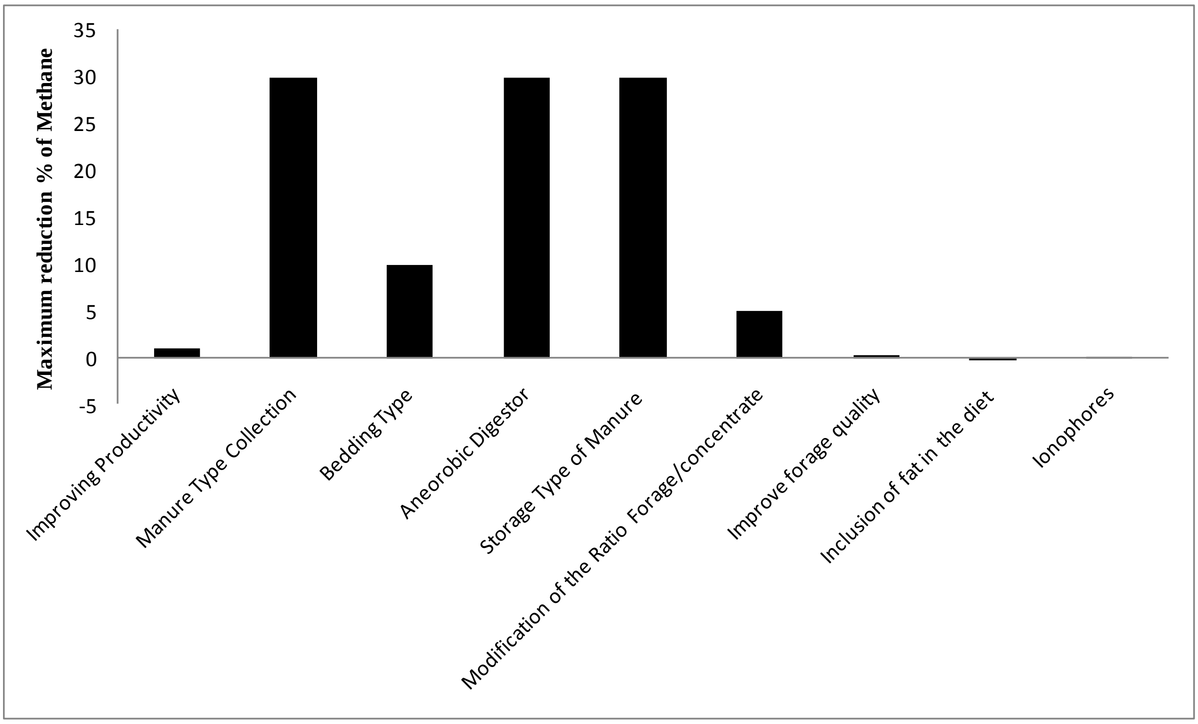

Figure 29. Comparison of reduction potential of different management and dietary strategies in the two selected dairy farms (197MA and 64CA).

From the aforementioned results in figure 29, it could be concluded that the dietary changes showed a weak reduction in methane emission. Of the four dietary changes, only those of modification of the ration forage / concentrate provided a substantial reduction in the methane emission (5 %). As comparing with changes in management scenarios, it could be recommended that management scenarios is more suitable to be used for methane emission reduction, as it provided a great reduction percent accordingly reduce C footprint with low cost.

2. Beef Farms

2.1. Gases Emissions per Kg of Body Weight

Each Kg live weight emits 6.86 kg of CO_2e in Spanish beef farms. Other studies have been carried out by other researchers regarding gas emissions from beef farms and reported that each Kg live weight emits 8.0 kg of CO_2e in Australia (Peters et al., 2010), 8.7 kg CO_2e per kg LW (Williams et al., 2006) in United Kingdom, 14.3 –18.3 kg CO_2e per kg LW in France (Veysset et al., 2010), and 14.8 kg CO_2e per kg LW in USA (Pelletier., 2010). It is clear that Spanish beef farms have the lowest values of C footprint as compared with the results which previously reported in other countries.

The data displayed in table 19 show GHG emissions from 800CAT feedlot farm. The total ammonia, methane, nitrous oxide, net carbon dioxide and carbon footprint were 21.3, 24.6, 0, -1426 Kg /head and 6.38 Kg CO_2e / Kg BW, respectively.

Table 19. Greenhouse gas (GHG) emissions from 800CAT feedlot farm.

	800CAT farm
Greenhouse gas emission	**Holstein**
Ammonia (kg of NH_3/head)	
Animals and housing	5.9
Manure storage	15.4
Field-applied manure	0.0
Total	21.3
Methane (kg of CH_4/head)	
Animals and housing	24.4
Manure storage	0.2
Field-applied manure	0.0
Total	24.6
Nitrous oxide (kg of N_2O/head)	
Animals and housing	0.0
Manure storage	0.0
Total	0.0
Carbon dioxide (kg of CO_2/head)	
Manure storage	15
Fuel combustion	20
Net emission	-1426
Total GHG (kg of CO_2e)	
Animal emissions	442842
Manure emissions	50361
Feed production emissions	0.0
Secondary sources	1196765
CF Without biogenic CO_2 (kg/kg BW)	6.38

BW= Body Weight sold; CO2e = CO2 equivalent.

The data illustrated in table 20 display GHG emissions from 2400CYT feedlot farm without corn silage. The total ammonia, methane, nitrous oxide, net carbon dioxide and carbon footprint were 44, 52, 6, -1614 Kg/head and 7.03 Kg CO_2e/Kg BW, respectively in Limousin breed, while they were 21.4, 24.8, 2.6, -1527 Kg/head and 6.90 Kg/ Kg BW, respectively in Charlais breed and 20.5, 25.2, 2.6, -1682 Kg /head and 7.01 Kg CO_2e / Kg BW, respectively in Spanish cross-breeds.

Table 20. Greenhouse gas (GHG) emissions from simulated 2400CYT feedlot farm without silage corn (Pasteros).

	2400CYT farm (Without silage corn)		
Greenhouse gas emission	**Limousin**	**Charlais**	**Spanish (Cross)**
Ammonia (kg of NH_3/head)			
Animals and housing	15	15.7	15.8
Manure storage	2	1.2	0.9
Field-applied manure	9	4.6	3.8
Total	44	21.4	20.5
Methane (kg of CH_4/head)			
Animals and housing	45	21.6	21.7
Manure storage	7	3.2	3.5
Field-applied manure	0	0.0	0.1
Total	52	24.8	25.2
Nitrous oxide (kg of N_2O/head)			
Animals and housing	5	2.3	2.3
Manure storage	1	0.3	0.3
Total	6	2.6	2.6
Carbon dioxide (kg of CO_2/head)			
Manure storage	0	0.0	0.0
Fuel combustion	39	36.9	39.5
Net emission	-1614	-1527	-1682
Total GHG (kg of CO_2e)			
Animal emissions	394373	392836	524810
Manure emissions	67259	48154	83098
Feed production emissions	0	0	0
Secondary sources	1138564	1115980	1513609
CF Without biogenic CO_2 (kg/kg BW)	7.03	6.90	7.01

BW= Body Weight sold; CO2e = CO2 equivalent.

Data in Table 21 show GHG emissions from 5000ARA feedlot farm with silage corn. The total ammonia, methane, nitrous oxide, net carbon dioxide and carbon footprint were 7.9, 12.9, 1.1, -900 Kg/head and 6.99 CO_2e Kg/Kg BW, respectively in Limousin breed, while they were 7.9, 12.8, 1, -796 Kg/head and 6.77 Kg CO_2e /Kg BW, respectively in Charlais breed and 7.3, 12.9, 1.1, -935 Kg/head and 6.95 Kg CO_2e/ Kg BW, respectively in Spanish (Cross).

Table 21. Greenhouse gas (GHG) emissions from simulated 5000ARA feedlot farm with silage corn (Pasteros)

	5000ARA farm (With silage corn)		
Greenhouse gas emission	**Limousin**	**Charlais**	**Spanish (Cross)**
Ammonia (kg of NH_3/head)			
Animals and housing	4.6	4.6	4.6
Manure storage	1.9	1.9	1.6
Field-applied manure	1.5	1.5	1.1
Total	7.9	7.9	7.3
Methane (kg of CH_4/head)			
Animals and housing	11.6	11.6	11.6
Manure storage	1.3	1.1	1.3
Field-applied manure	0.0	0.0	0.0
Total	12.9	12.8	12.9
Nitrous oxide (kg of N_2O/head)			
Animals and housing	1	0.9	1.0
Manure storage	0.1	0.1	0.1
Total	1.1	1.0	1.1
Carbon dioxide (kg of CO_2/head)			
Manure storage	20	20.2	20
Fuel combustion	80.1	80.0	79
Net emission	-900	-796	-935
Total GHG (kg of CO_2e)			
Animal emissions	399998	400128	533158
Manure emissions	63410	66072	45700
Feed production emissions	2526	2526	2526
Secondary sources	788391	788391	788391
CF Without biogenic CO_2 (kg/kg BW)	6.99	6.77	6.95

BW= Body Weight sold; CO2e = CO2 equivalent.

The highest level of C footprint was in 2400CYT feedlot farm without corn silage followed by 5000ARA feedlot farm with corn silage, while the lowest C footprint was detected in 800CAT feedlot farm. Usually, dairy farms produce a large percentage of their feed needs, while beef farms purchase all of their feed needs from outside. Therefore, the secondary GHG emissions and C footprint in beef farms are very high as compared with dairy farms due to crop production assimilatation of. The pervious sentence explains the high C footprint determined in 2400CYT feedlot farm without corn silage compared with 5000ARA feedlot farm with corn silage. In regard to cattle breeds, differences in breed have a very small effect on the C footprint.

Regarding the diet evaluation with CNCPS of the three feedlot beef farms, the methane produced from the diet was ranged between 5 and 8 g CH_4 / kg of BW. It was concluded that in the feedlot system (without feed production) the scenarios of mitigation of methane and carbon footprint in feedlot production should be directed to the secondary emission sources, because the manure is sold and their contribution in GHG emission is low. Moreover, it was found that the proportion of concentrates in beef farms diet is high which gives low enteric methane in comparison with dairy cattle farms.

General conclusions

Let us to conclude from the current study that:

1. Relationships for predicting all of the important primary and secondary GHG emissions in dairy production were integrated IFSM model to provide a software tool for estimating the net GHG emissions and C footprint of dairy and beef production.
2. The cradle-to-farm gate average carbon footprint in the selected dairy farms was found to be about 0.83 kg of CO2/kg of ECM.
3. By region, it could be concluded that the C footprint was the highest by Mediterranean Area farms with average value of 0.98 kg of CO_2e/kg of ECM followed by Central zone farms with average value of 0.84 kg of CO_2e/kg of ECM, while the lowest values were detected in Cantabric Area farms when the average value was 0.68 kg of CO_2e/kg of ECM.
4. Methane emissions were the biggest share of GHG in all the selected farms.
5. In beef farm,
6. Our study allows us to estimate and to see the profile of greenhouse gas emissions in each farm and to locate the sources of emissions and propose mitigation strategies with an objective way to reduce GHG emissions, estimate the reduction potential of each strategy and make decisions.

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APPENDICES

Survey of dairy cattle farms

Encuesta de explotaciones de ganado bovino lechero	
Objetivo Estimar la producción total de gases de efecto invernadero en explotaciones de diversas áreas geográficas españolas y sistemas de producción	
Nombre	……………………………………………..
E-mail	……………………………………………
Número de teléfono	……………………………………………
Provincia	……………………………………………..
Superficie total de la granja	…………………………………………..Ha
Tamaño del rebaño bovino (total bovino lechero)	……………………………………....cabeza
Datos sobre los cultivos y el suelo	
Tipo de suelo	…………………………………………….
Topografía de la granja	Casi el nivel (A, 0-3% pendiente) ☐ Pendiente suave (B, 3-8%) ☐ En pendiente (C, 8-15%) ☐ Moderadamente empinada (D, 15-25%) ☐ Empinado (E o F, > 25%) ☐
Nivel de fósforo en el suelo	Bajo ☐ Optimo ☐ Alto ☐ Muy alto ☐ Excesivamente alto ☐
Área de cultivo <u>Alfalfa</u> • Área de alfalfa • Aplicación de fertilizantes • Tipo de fertilizantes • Cantidad • Fertilización con estiércol	…………………………………………………….Ha Si ☐ No ☐ ……………………………………………..…Kg/Ha Si ☐ No ☐ …………………………………………………………… …………%

• Porcentaje aplicada de estiércol que está disponible	
Pasto • Área de pasto • Aplicación de fertilizantes • Tipo de fertilizantes • Cantidad • Fertilización con estiércol • Porcentaje aplicada de estiércol que está disponible Maíz • Área de Maíz • Aplicación de fertilizantes • Tipo de fertilizantes • Cantidad • Fertilización con estiércol • Porcentaje aplicada de estiércol que está disponible Cereales de grano pequeño Cebada, Avena, Trigo, Centeno • Área de cultivos • Aplicación de fertilizantes • Tipo de fertilizantes • Cantidad • Fertilización con estiércol • Porcentaje aplicada de estiércol que está disponible	……………………………………………….Ha Si ☐ No ☐ …………………………………………..… …………………………………………… Kg/Ha Si ☐ No ☐ …………………………………………………… …………% ……………………………………………….Ha Si ☐ No ☐ ……………………………………………… …………………………………………..…Kg/Ha Si ☐ No ☐ …………………………………………………… …………% ……………………………………………….Ha Si ☐ No ☐ ……………………………………………… …………………………………………..…Kg/Ha Si ☐ No ☐ …………………………………………………… …………%
Datos sobre la maquinaria **(debe indicarse también si la maquinaria es alquilada)**	
Operación	Número de máquinas
Cosecha / alimentación Siega Rastrillo	 ………………………………………. ……………………………………….

Empacar	………………………………………………
Secado de los forrajes	………………………………………………
Cosecha	………………………………………………
Mezcladora de alimentos	………………………………………………
	………………………………………………
Laboreo / plantación	
Manejo del estiércol	………………………………………………
Labranza	………………………………………………
Disqueo	………………………………………………
Aireación	………………………………………………
Sembradora	………………………………………………
Pulverización	………………………………………………
Riego	………………………………………………
Diversos	
Tractores de transporte	………………………………………………
Suministro / cargadores de estiércol	………………………………………………
Cargadores de balas	………………………………………………
Bomba de estiércol / agitador	………………………………………………
Bomba auxiliar de estiércol	………………………………………………
Número de remolques de transporte	……………………………………………...
Número total de tractores	………………………………………………
	………………………………………………..
	………………………………………………
Datos sobre el pastoreo	
Área de pastoreo	……………………………………………Ha
Área de pastoreo en primavera	……………………………………………Ha
Área de pastoreo en verano	……………………………………………Ha
Área de pastoreo en otoño	……………………………………………Ha
Animales pastaban	Novillas ☐
	Novillas y vacas secas ☐
	Vacas secas ☐
	Vacas en lactancia ☐
	Todas las vacas ☐
	Todos los animales ☐
Tiempo en el pasto	Cuarta parte del día durante temporada de pastoreo ☐
	Medios días durante la temporada de pastoreo ☐
	Días completos durante la temporada de pastoreo ☐
	Días completos durante todo el año ☐
Datos sobre el almacenamiento de alimentos	
<u>Estructura de almacenamiento; Silos</u>	
<u>Forraje de alta calidad</u>	No hay almacenamiento ☐
	Silo sobre el suelo ☐
	Silo bunker-trinchera ☐
	Silo “salsicha” ☐
	Silo en bolas ☐

Capacidad del silo	……………………………………………Toneladas
Número de silo	…………………………………………………..
<u>Forraje de baja calidad</u>	No hay almacenamiento ☐ Silo sobre el suelo ☐ Silo bunker-trinchera ☐ Silo “salsicha” ☐ Silo en bolas ☐
Capacidad del silo	……………………………………………Toneladas
Número de silo	……………………………………………
<u>Grano de cultivos ensilado</u>	No hay almacenamiento ☐ Silo sobre el suelo ☐ Silo bunker-trinchera ☐ Silo “salsicha” ☐ Silo en bolas ☐
Capacidad del silo	……………………………………………Toneladas
Número de silo	……………………………………………
<u>Grano de alta humedad</u>	No hay almacenamiento ☐ Silo sobre el suelo ☐ Silo bunker-trinchera ☐ Silo “salsicha” ☐ Silo en bolas ☐
Capacidad del silo	……………………………………………Toneladas
Número de silo	……………………………………………
Heno seco	Cubierto en cobertizo ☐ Exterior, en pìlas ☐ Exterior, (sin tocar a suelo) cubierto con plástico ☐ Exterior, (sin tocar a suelo) sin cobertura ☐ Exterior, contacto con el suelo, sin cobertura ☐
<u>Tratamientos de conservación</u> • Secado del heno de alta humedad	Ninguno ☐ Secado al aire en pequeñas pacas rectangulares ☐ Deshidratado artificial en pequeñas pacas rectangular ☐ Secado al aire en grandes pacas redondas ☐ Deshidratado en grandes pacas redondas/cuadradas ☐
• Preservación del heno	Acido propiónico / otras soluciones de ácidos orgánicos ☐ Buffer / solución diluida de ácido ☐ Microbiano ☐ Inoculante ☐

• Tratamiento del ensilaje • Cultivo de cereales	Otros Conservantes ☐ Acido fórmico (corte directo del ensilaje) ☐ Inoculante bacteriano (inactivo) ☐ Aditivo enzimático (inactivo) ☐ Ningún ☐ Amoníaco anhidro ☐
Datos sobre el ganado de vacuno lechero y el alimentación	
Raza	Holstein ☐ Brown swiss ☐ Ayrshire ☐ Guernsey ☐ Jersey ☐ Otros ☐
Producción lechera anual	…………………………………… Litros / vaca
Número de animales en lactación	………………………………………
Porcentaje de animales de primera lactación	………………………………………
Terneras de reposición de más de un año	………………………………………
Terneras de reposición de menos de un año	………………………………………
Características de los animales	Peso corporal medio de vacas maduras…………….Kg Contenido medio de grasa en la leche……………. % Contenido medio de proteína en la leche…………..%
Estrategia de parto	Todo el año ☐ Partos en primavera ☐ Partos en otoño ☐
Tipo de sala de ordeño	…………………………………………………
Alojamiento de las vacas	Ninguno ☐ Lote seco ☐ Estabulación fija ☐ Estabulación libre con cama caliente ☐ Estabulación libre con cubículos ☐ Estabulación con ventilación natural ☐ Estabulación con ventilación mecánica ☐ Estabulación libre con suelo de de bajas emisiones ☐
Alojamiento de las novillas	Ninguno ☐ Estabulación fija ☐ Estabulación libre con cama caliente ☐ Estabulación libre con cubículos ☐

	Estabulación libre, con ventilación natural ☐ Estabulación libre, con ventilación mecánica ☐ Estabulación libre con suelo de de bajas emisiones ☐
Manejo de la alimentación	
Método de alimentación	<u>Grano</u> No alimentados con granos ☐ Alimentación manual ☐ Cargador y el carro mezclador ☐ Mezcladora estacionaria y transportador ☐ Alimentación individual computarizado ☐
	<u>Ensilaje</u> No alimentados con ensilaje ☐ Alimentación manual ☐ Cargador y el carro mezclador ☐ Mezcladora estacionaria y transportador ☐ Alimentación individual computarizado ☐
	<u>Heno</u> No alimentados con heno ☐ Alimentación manual ☐ Auto-alimentado en el alimentador del heno ☐ Pacas a moler ☐
<u>Composición de la dieta</u> Porcentaje mínima de heno seco en la dieta de la vaca Nivel de alimentación en proteína Nivel de alimentación en fósforo	 …………………………% forraje …………………………% de recomendación de NRC …………………………% de recomendación de NRC
Ratio: forraje / grano	Alto ☐ Bajo ☐
Suplemento de proteína cruda	Ninguno ☐ Harina de colza ☐ Gluten de maíz ☐ Semilla de algodón ☐ Harina de soja 44% ☐ Harina de soja 48% ☐ Urea ☐ Otros (indicar) ☐
Suplemento energético	Concentrado restringido ☐ Cereal ☐ Grasa animal / vegetal ☐ Otros; ☐

Datos sobre el manejo de estiércoles	
Método de recogida de estiércol	Sin estiércol recogido ☐ Raspado manual con canalones de limpieza ☐ Rascador con rampa de carga ☐ Raspador con bomba de estiércol ☐ Sistema de descarga ☐
Tipo de estiércol	Sólido (20% MS) ☐ Semi-sólido (12-14% MS) ☐ Estiércol (8-10% MS) ☐ Estiércol- líquido (5-7% MS) ☐
Incorporación de estiércol al suelo respecto a la labranza	Mismo día ☐ Dentro de dos días ☐ Dentro de una semana ☐ No incorporación ☐
Distancia media de transporte de estiércol	……………………………………….. Km
Almacenamiento	No hay almacenamiento ☐ 4 meses de almacenamiento ☐ 6 meses de almacenamiento ☐ 12 meses de almacenamiento ☐
Tipo del almacenamiento	Apilar ☐ Cuenca perforada en la tierra ☐ Tanque de acero de baja carga ☐ Tanque de cemento ☐ Tanque o cuenco cubierto ☐ Tanque cerrado ☐
Características	Diámetro medio……………………………… M Profundidad media ……………………………..m Capacidad de almacenamiento ………………….t
Digestor anaeróbico	Si ☐ No ☐
Tipo de cama	Ninguno ☐ Estiércol sólido ☐ Arena ☐ Aserrín ☐ Paja ☐ Paja picada ☐
Cantidad de cama por animal maduro	………………………………………………/Kg/Día
<u>Importación / exportación</u> Cantidad importada a la granja Tipo de estiércol importado	 …………………………………………T Bovino ☐ Aves ☐

	Porcino ☐ Otro ☐
Cantidad exportada de granja	……………………… % de estiércol sólidos recogidos
Forma de estiércol	Estiércol crudo ☐ Sólidos separados ☐ Compost ☐

Además, necesitaríamos las dietas de todos los grupos animales (lotes de producción, secas, grupos de novillas,…) indicando el número medio de animales en cada lote. En lo posible, sería conveniente conocer la MS de los silos, la proteína de los forrajes y la composición detallada (ingredientes) de los concentrados (en %).

Muchas gracias por sus colaboraciones