Greenhouse Gas Emissions from the Dairy Sector

A Life Cycle Assessment

A report prepared by:
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Animal Production and Health Division

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This report is a result of a collaboration between the International Dairy Federation (IDF) and the Food and Agriculture Organization of the United Nations (FAO), to assess GHG emissions from the dairy food chain. The analysis forms part of a wider initiative conducted by FAO to assess GHG emissions from a range of animal food chains. We wish to acknowledge the following persons and institutions for their contributions.

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Abbreviations

AFC	Age at first calving
CF	Carbon footprint
CO_2-eq.	Carbon dioxide equivalent
CSA	Central and South America
DM	Dry matter
FPCM	Fat and protein corrected milk
GHG	Greenhouse gas emissions
GIS	Geographic information system
GPP	Gross primary production
GWP	Global warming potential
HDPE	High density polyethylene
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life cycle inventory
LPS	Livestock production systems
LUC	Land use change
MMS	Manure management system
NENA	Near East and Northern Africa
NFMP	Non- fat milk powder
NIRs	National inventory reports
SSA	Sub-Saharan Africa
UNFCCC	United Nations Framework Convention for Climate Change
WMP	Whole milk powder

Symbols/units

CH_4	Methane
CO_2	Carbon dioxide
CO_2-eq.	Carbon dioxide equivalent
Ha	Hectare
Kg	Kilogram
MJ	Megajoule
N_2O	Nitrous oxide

Glossary of Terms

Carbon footprint: is the total amount of GHG emissions associated with a product, along its supply-chain, and sometimes includes emissions from consumption, end-of-life recovery and disposal. It is usually expressed in kilograms or tonnes of carbon dioxide equivalent (CO_2-eq.).

CO_2-equivalent emission: is the amount of CO_2 emissions that would cause the same time-integrated radiative forcing, over a given time horizon, as an emitted amount of a long-lived GHG or a mixture of GHGs. The CO_2 equivalent emission is obtained by multiplying the emission of a GHG by its Global Warming Potential (GWP) for the given time horizon. The CO_2 equivalent emission is a standard and useful metric for comparing emissions of different GHGs, but does not imply the same climate change responses (IPCC, 4 AR 2007).

Dairy herd: for the purposes of this assessment, includes milking animals, replacement stock and surplus calves that are fattened for meat production.

Dairy sector: includes all activities related to the feeding and rearing of dairy animals (milking cows, replacement stock and surplus calves from milked cows that are fattened for meat production), milk processing and the transportation of milk to dairy processing plants, and transportation of dairy products from dairy to retailers.

Fat and protein corrected milk (FPCM): is milk corrected for its fat and protein content to a standard of 4.0% fat and 3.3% protein. This is a standard used for comparing milk with different fat and protein contents. It is a means of evaluating milk production of different diary animals and breeds on a common basis.

Global warming potential (GWP)*:* is defined by the Intergovernmental Panel on Climate Change (IPCC), as an indicator that reflects the relative effect of a GHG in terms of climate change considering a fixed time period, such as 100 years, compared to the same mass of carbon dioxide.

Geographic information system: is a computerized system organizing data sets through the geographical referencing of all data included in its collections.

Grassland-based livestock systems: **are** livestock production systems in which more than 10 percent of the dry matter fed to animals is farm-produced *and* in which annual average stocking rates are less than ten LU per hectare of agricultural land (Seré and Steinfeld, 1996).

Mixed farming systems*:* are those systems in which more than 10% of the dry matter fed to livestock comes from crop by-products and/or stubble or more than 10% of the value of production comes from non-livestock farming activities (Seré and Steinfeld, 1996).

Milking cows: are defined as all females at reproductive age, comprising both specialized and non-specialized dairy animals actually milked during the year.

Secondary energy: comes from the transformation of primary or secondary energy. The generation of electricity by burning fuel oil is one example. Other examples include petroleum products (secondary) from crude oil (primary), coke-oven coke (secondary) from coking coal (primary), charcoal (secondary) from fuel wood (primary), etc.

Tier levels: according to the IPCC, correspond to a progression from the use of simple equations with default data (Tier 1 emission factors), to country-specific data in more complex national systems, (Tier 2 & 3 emission factors). Tiers implicitly progress from least to greatest levels of certainty, as a function of methodological complexity, regional specificity of model parameters, spatial resolution and the availability of activity data.

Executive Summary

This study assesses the greenhouse gas (GHG) emissions from the global dairy cattle sector. The overall goal of this report is to provide estimates of GHG emissions associated with milk production and processing for main regions and farming systems of the world. These results will help to inform the public debate on GHG emissions, and will support research, development and extension efforts to improve the sustainability performance of dairy farming.

The specific objective of the study is two-fold:

- to develop a methodology based on the Life Cycle Assessment (LCA) approach applicable to the global dairy sector; and
- to apply this methodology to assess, and provide insights about, GHG emissions from the dairy cattle sector.

The assessment follows up on FAO's work presented in *Livestock's Long Shadow* on livestock's contribution to GHG emissions, by refining and elaborating on the emission estimates for the dairy cattle sector.

It focuses on the entire dairy food chain, encompassing the life cycle of dairy products from the production and transport of inputs (fertilizer, pesticide, and feed) for dairy farming, transportation of milk off-farm, dairy processing, the production of packages, and the distribution of products to retailers. Emissions, including those taking place after the farm-gate are all reported in per kg of fat and protein corrected milk (FPCM) units at the farm gate.

The study quantifies the major greenhouse gas emissions associated with dairy farming, namely, carbon dioxide, methane and nitrous oxide, and includes all animals related to milked cows, including replacement animals and surplus calves from dairy cows, fattened for their meat. It excludes emissions related to:

- land use under constant management practices;
- capital goods such as farm equipment and buildings;
- on-farm milking and cooling; and
- retail stage activities (e.g. refrigeration and disposal of packaging).

The emissions related to manure outside the livestock systems and to draught animals, are separated from other dairy sector emissions. The remaining emissions are allocated to milk and meat on the basis of their proportional contribution to total protein production.

For the preparation of this global assessment, numerous hypotheses and methodological choices were made, most of which introduce a degree of uncertainty in the results. Furthermore, a lack of data forced the research team to rely on generalisations and projections. A sensitivity analysis was thus conducted to test the effect of these approximations, and results were compared to

existing literature in specific locations/farming conditions. This allowed the computation of a confidence interval (±26 percent) within which the results are reported.

Overall sectoral contribution to global GHG emissions.

In 2007, the dairy sector emitted 1 969 million tonnes CO_2*-eq [±26 percent]* of which 1 328 million tonnes are attributed to milk, 151 million tonnes to meat from culled animals, and 490 million tonnes to meat from fattened calves.

The global dairy sector contributes 4.0 percent to the total global anthropogenic GHG emissions [±26 percent].

This figure includes emissions associated with milk production, processing and transportation, as well as the emissions from meat production from dairy-related culled and fattened animals.

The overall contribution of the global milk production, processing and transportation to total anthropogenic emissions is estimated at 2.7 percent [±26 percent].

This figure includes emissions associated with milk production, processing and transportation of milk and milk products only.

Global emissions per unit of product

The global average of GHG emissions, per kg of FPCM at the farm gate, is estimated at 2.4 kg CO_2*-eq. [±26 percent].*

Regional variations

Average regional emissions, per kg of FPCM at farm gate, range from 1.3 to 7.5 kg CO_2*-eq. per kg of FPCM [±26 percent].*

In comparing the total average life cycle emissions across different world regions, the highest emissions per kg of FPCM were found in developing regions with sub-Saharan Africa, South Asia, North Africa and the Near East with an average of 7.5, 4.6 and 3.7 kg CO_2-eq. per kg of FPCM, respectively. Industrialized regions such as North America and Europe, on the other hand, were found to exhibit the lowest emissions per kg of FPCM.

Variations between production systems and agro-ecological zones

The level of GHG emissions, per kg of FPCM, is higher in grazing systems than in mixed systems. However, within these two systems there are distinct differences between the agro-ecological zones.

On average, grassland systems have higher emissions than mixed farming systems. Grassland systems contribute about 2.72 kg CO_2-eq./kg FPCM, compared to mixed systems which on average contribute 1.78 kg CO_2-eq./kg FPCM.

Food chain contribution to overall emissions: cradle to farm-gate versus post farm emissions

Along the entire dairy food chain, cradle-to-farm gate emissions contribute the highest proportion of emissions from the sector

Globally, cradle to farm gate emissions contribute, on average, 93 percent of total dairy GHG emissions. The study reveals a similar trend across all regions of the world, where on-farm activities (including land use change) contribute most significantly to overall GHG emissions. In industrialized countries, the relative contribution ranges between 78 and 83 percent of total life cycle emissions, while in developing world regions the contribution is much higher – ranging between 90 and 99 percent of total emissions.

Contribution to total emissions by greenhouse gas

Methane contributes most to the global warming impact of milk - about 52 percent of the GHG emissions – from both developing and developed countries

Nitrous oxide emissions account for 27 and 38 percent of the GHG emissions in developing and developed countries, respectively, while CO_2 emissions account for a higher share of emissions in developed countries (21 percent), compared to developing countries (10 percent).

Scope of this assessment

In 2006, the Food and Agriculture Organization published *Livestock's Long Shadow*: *Environmental Issues and Options*, which provided the first-ever global estimates of the livestock sector's contribution to GHG emissions. Taking into account the entire livestock food chain, the study estimated this contribution to be about 18% of total anthropogenic emissions.

In the wake of the current global climate crisis, it has become increasingly clear that there is an urgent need to not only better understand the magnitude of the livestock sector's overall contribution to GHG emissions, but to also identify effective approaches to reduce emissions, and to identify where in the food chain to target these efforts. Addressing these needs has provided the impetus to re-examine the global livestock food chain emissions, based on the Life Cycle Assessment (LCA) approach.

This technical report is the first product of a wider study implemented by FAO and aiming at identifying low carbon development pathways for the livestock sector. The report follows two broad objectives: firstly it aims to disaggregate the initial estimates of livestock sector's contibution and assess the dairy sector's contribution to GHG emissions, and secondly, identify the major GHG "hotspots" along the dairy food chain.

This report does not present a model for estimating the full environmental impact from the entire livestock sector, rather it focuses on GHG emissions, notably carbon dioxide, methane and nitrous oxide, from the dairy cattle sector. The assessment takes a food chain approach in estimating emissions generated during the production of inputs into the production process, dairy production, land use change (deforestation related to soybean production), and milk transport (farm to dairy and from processor to retailer) and processing. Given the global scope of the assessment and the complexity of dairy systems, several hypotheses and generalisations have been used to overcome the otherwise excessive data requirements of the assessment. The uncertainties introduced by these assumptions were estimated and used to compute a confidence interval for the assessment results.

In this assessment, post farm gate emissions are related to a kg of milk equivalent at the farm-gate, rather than to each processed dairy product. Further, emissions related to the processing, the production of packaging material and transport for the various dairy products are attributed to the milk at the farm gate, even though they occur in the post farm gate stage of the commodity chain.

Although estimating GHG emissions from the sector provides an important starting point for understanding the sector's potential for mitigating emissions, the real challenge lies in identifying approaches to reduce emissions. However, the purpose of this current study is not to provide recommendations regarding appropriate mitigation options for the dairy sector. This will be done at a later stage, when the programme of biophysical and economic analysis of mitigation options is completed. Nevertheless, the emission estimates from this system-wide assessment provide a useful platform for identifying intervention opportunities to address mitigation at specific stages of the dairy food chain.

While this study deals solely with GHG emissions, it is important to highlight the importance of assessing a broader range of environmental issues, including water resource degradation, biodiversity loss, erosion and other non-GHG impacts. The sustainability of the dairy sector needs to be understood within this broader context, and analysed considering the synergies and trade-offs among competing environmental, social and economic objectives.

1 Introduction

1.1 Context

Recent studies such as *Livestock's Long Shadow*, by the United Nations Food and Agriculture Organization (FAO) have drawn attention to the considerable environmental footprint of the global livestock industry (FAO, 2006a). Taking into account the entire livestock commodity chain – from land use and feed production, to livestock farming and waste management, to product processing and transportation –*Livestock's Long Shadow* attributes about 18 percent of total anthropogenic GHG emissions to the livestock sector.

Without concerted action, emissions are unlikely to fall. On the contrary, they are rising, as global demand for meat, milk and eggs continues to grow rapidly. Projected population growth and rising incomes are expected to drive total consumption higher--with meat and milk consumption doubling by 2050 compared to 2000 (FAO, 2006b).

Improving the carbon footprint of the dairy sector[1] is a key element of sustainable milk production. To achieve this, policy makers, producers and consumers require clear and objective information. A review of recent literature and databases reveals that while more information has become available in recent years, it is still largely fragmented and not based on a consistent or comparable set of methodologies. Getting a clear, global picture from published data is therefore impossible.

The private dairy sector, represented by the International Dairy Federation (IDF), decided to support FAO's environmental research to redress this shortcoming and provide a system-wide assessment of GHG emissions of the dairy sector, as an important first step in identifying mitigation opportunities for the sector.

Technical guidance and expertise during this assessment has been provided by an advisory group of eight leading independent experts in life cycle assessment, environmental impact assessment and livestock production systems, from renowned academic and research institutions and the private sector (IDF representatives). The group's contribution centred on methodological design, model development, review of preliminary results, and identifying and accessing data, particularly from on-going parallel research. The group convened twice in Rome, to review progress on the assessment work and provide overall guidance. Members of the advisory group also provided technical support to the study team.

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[1] By dairy sector, we include all activities related to the feeding and rearing of dairy animals (milking cows, replacement stock and surplus calves from milked cows that are fattened for meat production), milk processing and the transportation of milk to dairy processing plants, and transportation of dairy products from dairy to retailers.

1.2 Goal of this report

The purpose of this study is to quantify the main sources of GHG emissions from the world's dairy cattle sector, and to assess the relative contribution of different production systems and products to total emissions from the dairy sector.

This assessment produces estimates of GHG emissions for:

- major dairy cattle products and related services;
- predominant dairy production systems (e.g. grass-based, mixed crop-livestock);
- main world regions and agro-ecological zones; and
- major production stages along the dairy food chain.

By providing the most accurate information available, this assessment will help IDF and FAO to design cost-effective policy and technical options that can mitigate greenhouse gas emissions from the dairy sector. Options for reducing GHG emissions range from improving practices within a given system, to shifting to a lower-impact production system, where feasible.

The intended beneficiaries of the report include the private sector, the consumers, policy-makers and technicians in governmental and nongovernmental organizations (NGOs), international organizations, academia and LCA practitioners.

2 Methodology

2.1 Choice of Life Cycle Assessment (LCA)

The analysis in *Livestock's Long Shadow* (FAO, 2006a) was an initial step in the food-chain approach for assessing GHG emissions from the global livestock sector. While the study analyzed emissions from enteric methane and manure management along lines similar to the 3rd Intergovernmental Panel on Climate Change (IPCC) assessment (IPCC, 2001), *Livestock's Long Shadow* assessed all emissions along the livestock food chains including those that IPCC reports under other categories such as energy, industry or transport. While useful, *Livestock's Long Shadow* did not disaggregate emission estimates by region, nor did it estimate and compare GHG emissions per kilogram of animal product.

A more comprehensive assessment that systematically analyses different commodities, processes and production systems, was therefore needed. The Life Cycle Assessment (LCA) provides the analytical tool for such a study.

The Life Cycle Assessment (LCA) approach is widely accepted in agriculture and other industries as a method to evaluate the environmental impacts of production, and to identify the resource and emission-intensive processes within a product's life cycle. The method is defined in the ISO standards 14040 and 14044 (ISO, 2006). The main strengths of LCA lie in its ability to provide a holistic assessment of production processes, in terms of resource use and environmental impacts, as well as to consider multiple parameters (ISO, 2006).

The methodology also provides a framework to broadly identify effective approaches to reduce environmental burdens. Further, the approach is recognized for its capacity to evaluate the effect that changes within a production process may have on the overall life-cycle balance of environmental burdens. This enables the identification and exclusion of measures that simply shift environmental problems from one phase of the life cycle to another.

However, LCA also presents significant challenges, particularly when applied to agriculture. First, the data intensive nature of the method places limitations on the comprehensive assessment of complex, interconnected food chains. Limited data availability can force the practitioner to make simplifications, which can lead to losses of accuracy.

A second difficulty lies in the fact that methodological choices and assumptions - such as system boundary delineation, functional units, and allocation techniques - may be subjective and affect the results. These complications call for a thorough sensitivity analysis.

2.2 General principles of LCA

Life Cycle Assessment was originally applied to analyze industrial process chains, but has been adapted over the last 15 years to assess the environmental impacts of agriculture. The LCA method involves the systemic analysis of production systems, to account for all inputs and outputs associated with a specific product within a defined system boundary. The system boundary largely depends on the goal of the study. The reference unit that denotes the useful output of the production system is known as the functional unit, and it has a defined quantity and quality. The functional unit can be based on a defined quantity, such as 1 kg of product, alternatively it may be based on an attribute of a product or process, such as 1 kg of fat and protein corrected milk (FPCM). The application of LCA to agricultural systems is often complicated by the multiple-output nature of production, as major products are usually accompanied by the joint production of by-products. This requires appropriate partitioning of environmental impacts to each product from the system according to an allocation rule, which may be based on different criteria such as economic value, mass balances, product properties, etc.

2.3 The use of LCA within the framework of this assessment

In the last five years, an increasing number of LCA studies have been carried out for livestock production, mostly in OECD countries (Casey and Holden, 2006; Cederberg and Mattsson, 2000; de Boer, 2003; Eide, 2002; Haas et al., 2001; Thomassen, van Calker et al., 2008). Although the methods of LCA are well defined, the studies vary considerably in their level of detail, their definition of system boundaries, the emission factors they use, and other technical aspects such as the allocation techniques and functional units they employ.

This assessment sets out to perform a complete LCA for the global dairy sector, using consistent calculation methods, modelling approaches, data and parameters for each production system within the sector. In contrast to previous LCA studies carried out for the dairy sector, which have primarily concentrated on either farm level or the national level emissions in OECD countries, this study is global in scope and includes both developed and developing countries. As a consequence of its global scope, the approach developed for this study has had to overcome onerous data requirements by relying on some simplifications that result in a loss of accuracy, particularly for systems at lower levels of aggregation.

Nevertheless, the broad scope and consistency of assessment allows, for the first time, direct comparisons between regions and between systems.

This assessment follows the attributional approach, which estimates the environmental burden of the existing situation under current production and market conditions, and allocates impacts to the various co-products of the production system. This is in contrast to the consequential LCA approach, which considers potential consequences of changes in production technologies, and relies on a system expansion analysis to allocate impacts of co-products (Thomassen et al, 2008b).

2.3.1 Compliance with LCA guidelines

This assessment is based on the methodology for LCA, as specified in the following documents:

- *Environmental management – Life Cycle Assessment- Requirements and guidelines* - BS EN ISO 14044 (ISO, 2006).
- British Standards Institute PAS2050; 2008. Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (BSI, 2008).

The assessment follows the principles outlined in PAS2050:

a) ***Relevance:*** select GHG sources, carbon storage, data and methods appropriate to the assessment of the GHG emissions from products.
b) ***Completeness:*** include all specified GHG emissions and storage that provide a material contribution to the assessment of GHG emissions from products.
c) ***Consistency:*** enable meaningful comparisons in GHG-related information.
d) ***Accuracy:*** reduce bias and uncertainties as far as is practical.
e) ***Transparency:*** where the results of life cycle GHG emissions assessment carried out in accordance with this PAS are communicated to a third party, the organization communicating these results shall disclose information sufficient to allow such third parties to make decisions related to GHG emissions with confidence.

2.3.2 Functional unit

Dairy-cattle production systems produce a mix of goods and services:

- Edible products: meat and milk.
- Non-edible products and services: draught power, leather, manure and capital.

In this assessment, the functional units used to report GHG emissions are kg of carbon dioxide equivalents (CO_2–eq.) per kg of FPCM and carcass weight, at the farm gate.
All milk was converted to FPCM with 4.0 % fat and 3.3 % protein, using the formula:

FPCM (kg) = raw milk (kg) * (0.337 + 0.116 * Fat content (%) + 0.06 * Protein content (%))

Milk is either consumed fresh or enters the transport and processing sectors of the post–farm gate dairy chain. To compare milk production chains all over the world, GHG emissions related to processed and transported products (e.g. cheese or milk powder) are reported in kg of CO_2 – eq. per kilogram of FPCM equivalent, at the farm gate. In each region, average post harvest emissions are thus estimated and added to emissions taking place before farm gate (cf. Annex 3).

2.3.3 System boundary

The assessment encompasses the entire production chain of cow milk, from feed production through to the final processing of milk and meat, including transport to the retail sector (cf. Figure 2.1).

The cradle to retail system boundary is split into two sub-systems:

1. *Cradle to farm-gate* includes all upstream processes in livestock production up to the point where the animals or products leave the farm, i.e. production of farm inputs, and dairy farming.
2. *Farm-gate to retail* covers transport to dairy plants, dairy processing, production of packaging, and transport to the retail distributor.

Note: All aspects related to the final consumption of dairy products (i.e. consumer transport to purchase product, food storage and preparation, food waste and waste handling of packaging) lie outside the defined system, and are hence excluded from this assessment.

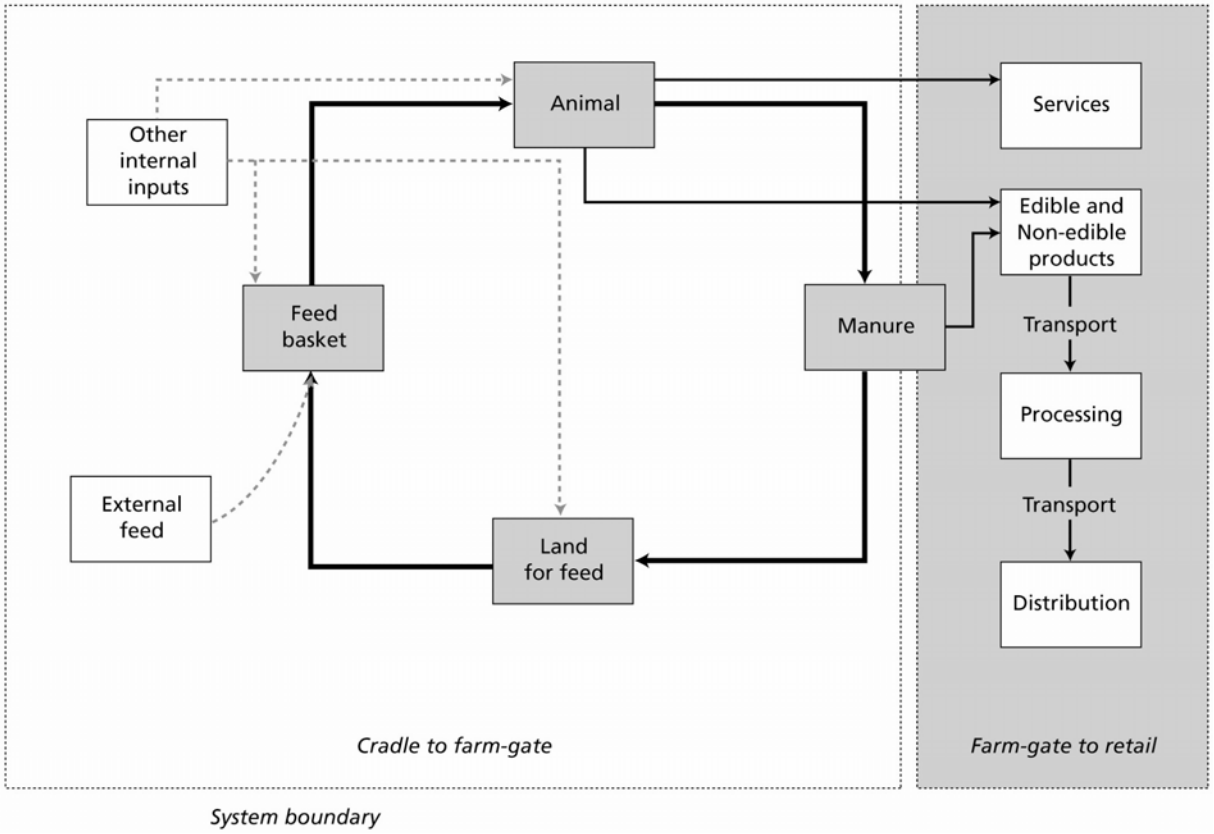


Figure 2.1. System boundary as defined for this assessment

To calculate greenhouse gas emissions, a simplified description of livestock production systems, derived from Oenema *et al.*, 2005; Schils *et al.*, 2007a; Del Prado and Scholefield, 2008, was developed (Figure 2.1).

- "*Land for feed*" is the land used for feed production, on the farm itself or nearby (with negligible emissions related to the transport of feed to the animal rearing site).
- "*External feed*" originates from off-site production. It includes by-products from the food industry and feed crops produced and transported over longer distances. In most situations, the external feed is concentrate feed.
- "*Manure*" is shown partly outside the 'cradle-to-farm gate' system boundary. This is to illustrate situations where manure is used as a fertilizer for food crops, either on- or off-farm, or where manure is used as fuel.
- "*Other external inputs*" refers to the inputs into production such as energy, fertilizer, pesticides, etc.

A novel aspect of this assessment (in comparison to Livestock's long shadow) is that these four compartments are connected, which requires the development of specific models and attribution techniques. (See Annex 1) These compartments in turn:

1. link feed requirements (energy and protein), herd parameters (genetics, management) and the production of manure and edible products;
2. define a feed basket that matches the feed requirements of animals, by combining locally available and imported feedstuff; and
3. partition manure excreted between feed production, food production and losses.

2.3.4 Sources of GHG emissions

This study focuses on emissions of the major greenhouse gases associated with animal food chains, namely, methane, nitrous oxide, carbon dioxide, and GHGs related to refrigerants (FAO, 2006a). The following emission sources were included and grouped as pre- and post-farm-gate sources.

From cradle to farm gate

- Processes for producing grass, feed crops, crop residues, by- products, and concentrates, including:
    - production of N fertilizer (CO_2);
    - application of manure and chemical fertilizers to crops, accounting for both direct and indirect emissions (N_20);
    - deposition of manure and urine on pasture crops, accounting for both direct and indirect emissions (N_20);
    - energy used for fertilization, field operations, drying, processing of feed crops and fodder (CO_2) ;
    - processing of crops into by-products and concentrates;
    - transport of feed from the production site to the feeding site;
    - changes in carbon stocks as a result of land use change (mostly from deforestation) in the previous 20 years (IPCC, 2006); and
    - nitrogen (N) losses related to changes in carbon stocks(N_2O).
- Enteric fermentation by ruminants (CH_4).
- Direct and indirect emissions from manure storage (CH_4 and N_2O).

From farm gate to retail point

- Transport of milk and animals to dairies and slaughterhouses.
- Processing of raw milk into commodities such as cooled milk, yoghurt, cheese, butter, and milk powder.

- Production of packaging.
- Refrigeration (energy and leakage of refrigerants).
- Transport of processed products to the retail point.

The assessment does not include GHG emissions related to:

- land use under constant management practices;
- capital goods such as farm equipment and infrastructure;
- on-farm milking and cooling;
- production of cleaning agents, antibiotics and pharmaceuticals; and
- disposal of packaging.

2.3.5 Allocation of emissions

Dairy herds produce a mix of goods and services that cannot easily be disaggregated into individual processes. For example, a dairy cow produces milk, manure, capital services, and eventually meat when it is slaughtered. In LCA, we need to use specific techniques to attribute relative shares of GHG emissions of to each of these goods and services.

The ISO recommends avoiding allocation by dividing the main process into sub-processes, or by expanding the product system to include additional functions related to the co-products (ISO, 2006). In situations where allocation cannot be avoided (as often is the case in biological processes such as dairy), GHG emissions can be allocated on the basis of casual and physical relationships.

Where physical relationships alone cannot be established or used as a basis for allocation, emissions should be allocated in a way which reflects other fundamental relationships. In the latter case, the most commonly used approach is economic allocation which, in the context of jointly produced products, allocates emissions to each product according to its share of the products' combined economic value. Other indexes, such as weight or protein content can also be used (Cederberg and Stadig, 2003).

The following paragraphs outline the allocation techniques used in this assessment, to apportion emissions to both the edible and non-edible products. They are summarised in Table 2.1.

Table 2.1. Summary of the allocation techniques used in this assessment

Products	Source of emissions	Allocation Technique
Milk	All system related emissions	Protein content
Meat	All system related emissions	Protein content
Manure	Emissions from storage	100 % to livestock system
Manure	Emissions from application	Sub-division: when crop or crop residue is used for feed in the livestock system. *See grass, feed-crops and residues below*.
Animal draught power		Sub-division:
Grass and feed-crops	Emissions related to cultivation and application of manure and chemical fertilizer	100 % to livestock
Crop residues, by-products and concentrate components	Emissions related to cultivation, application of manure and chemical fertilizer, processing, transport, land use change (only soybean)	Economic allocation (in the case of crop residues digestibility as a proxy)
Capital functions		Not taken into account

Meat and milk

Emissions related to goods and services other than meat and milk (e.g. manure, draught power) are first calculated separately and deducted from overall dairy system emissions, before emissions are attributed to meat and milk (cf. section below on attribution).

Within the dairy herd, some animals only produce meat (fattened calves), others contribute to the combined production of meat and dairy products (milked cows, reproduction bulls and replacement stock).

For the latter group, we chose to allocate GHG emissions on the basis of their protein content. This method reflects the fact that a primary function of the dairy sector is to provide humans with edible protein. Advantages of using protein content are that it enables direct comparison with other food products, and that it is also relatively stable in time (as opposed, for example to the relative prices of meat and milk) and it can be applied in situations where markets are absent or where they are highly localized and not comparable across regions. A disadvantage though, is that other nutritional properties, such as minerals, vitamins and energy, essential fatty acids are not captured. The validity of the different allocation techniques (such as economic allocation, mass allocation, energy-based allocation) on the results are analyzed through a sensitivity analysis (cf. 4.6).

Emissions related to surplus calves fattened for meat production, were computed and entirely attributed to meat production. However, the emissions related to the production of calves, i.e. the pregnancy of the dairy cows and female replacement stocks, are allocated to milk as they are an essential input for milk production.

No emissions are allocated to the other parts of the slaughtered animal (e.g. skin, horns), although these are utilized and represent an economic yield. This may result in a slight overestimation of the emissions per kg of carcass weight.

Manure

Manure is another by-product of milk production. The emissions related to manure are allocated through the subdivision of production processes:

- *Emissions related to manure storage* are fully allocated to the livestock system.
- *Emission from manure applied on the land used for feed, food and cash crops production*: These emissions are allocated to livestock in situations where the crop as a whole or in part is used for animal nutrition. In situations where manure is entirely deposited on grassland and feed crops, no allocation is required because the manure remains within the livestock system. On the other hand, where parts of the crop (e.g. crop residues) are used for feed, emissions are allocated according to the relative weight of harvested products used as feed, corrected for digestibility. Digestibility is treated as a proxy for economic value. And in cases where the crop is not used for animal nutrition, emissions are not allocated to livestock.
- *Emissions from manure used for fuel* leave the livestock system and therefore emissions from burning are not allocated to the livestock system.
- *Emissions from manure discharged into the environment*. Emissions are solely attributed to livestock activities (the discharge obviously causes other environmental impacts as well).

Animal draught power

Herd structure is affected by the use of animals, usually oxen, for labour. Oxen must grow to maturity before they can be used for traction, and this usually takes four years. The animals are then generally used for a decade before they are slaughtered. The adult male to female ratio is substantially higher than normal when animals are used for draught, since males are slaughtered at a higher age.

To allocate emissions to draught services, we first calculate total emissions and meat output from draught animals alone. In a subsequent calculation step, emissions related to the meat produced from these animals are estimated as being identical to those of meat produced from non-draught animals, slaughtered at a younger age. The difference (accruing from the extra lifetime and the energy need for the labour of draught animals) is then attributed to draught services.

Capital functions of cattle

In any cattle production system, animals constitute a form of capital, and can be sold or bought according to investment and cash flow requirements. In many pastoral systems, the capital functions of cattle are a particularly important, as they enable the accrual of savings to manage cash needs, insure against risk, and manage crises in the absence of adequate financial institutions. Therefore, low replacement rates are often a feature in these systems, as cattle are often kept even after their productivity drops. While the provision of these capital functions affects the herd structure and emission profiles of these systems, no emissions were allocated to capital services, due to difficulties in obtaining relevant information.

2.3.6 Emissions related to land use change

Changes in land use, such as the conversion of forest to pasture, or the conversion of rangeland to cropland are associated with the release of GHG into the atmosphere. Organic matter, both above and below ground is progressively oxidized and the resulting gases (mostly carbon dioxide, but also some nitrous oxide) are released. The pace of this process follows an asymptotic curve, initially it is very rapid, and it virtually ceases after 30 to 50 years, depending on soil characteristics management practices and climate. On the other hand, the abandonment of agricultural land or the shift from cropping to pastoral rangelands or forestry leads to carbon sequestration in soil and vegetation. In this assessment, we follow the methodology established by the IPCC, which assumes that all carbon losses or gains occur during the first 20 years following the land use change, at a constant rate (IPCC, 2006).

The methodology also assumes that there is no change in soil organic carbon stocks under constant land use (IPCC, 2006), although recent publications indicate that changes in soil organic carbon stocks may occur at certain scales on rangelands, considering their wide coverage (see for example Conant, 2009; Reijneveld et al., 2009; Schipper, 2007; Soussana et al., 2007; Bellamy et al., 2005; Sleutel et al., 2003). There is however no sufficient consensus on the underlying factors (e.g. management practices, climate change), neither on the direction and rate of change (net sequestration or release) nor on the permanence of these changes (prolonged droughts, crop and pasture cycles) to support the modelling of changes in soil organic carbon on a global scale.

The GHG emissions related to the expansion of soybean production into forest, shrub land or pasture were estimated. This required assessing (i) land use change emissions related to soybean production in its main cropping areas, (ii) the share of soybean cake in animal rations (see annex 2), and (iii) the origin of soybean cake used in each country, as provided by trade-flow data (FAOSTAT, 2009). Emissions were allocated to the soybean joint-products, soybean cake and oil, by using the economic allocation technique.

Land use change emissions related to other feed crops were omitted: it was assumed that these feed crops are only marginally associated with land conversion, and that the expansion of pastureland into forestland is generally not driven by the dairy sector.

2.3.7 Post-farm-gate emissions

The "farm-gate to retail" part of the assessment focuses mainly on energy use and related greenhouse gas emissions. Major post-farm activities include:

- transport of raw milk from farm to dairy;
- processing of raw milk into milk products;
- production of packaging material; and
- distribution of products from dairy to retail point.

For each region, the share of raw milk entering processing chains is estimated from literature surveys, including information on the presence of a modern retail sector in the country or region.

The raw milk entering the dairy plants is processed into one or several of the following products:

- fresh milk;
- fermented milk (e.g. yogurt);
- cream (and related butter);
- cheese;
- whey; and
- milk powder.

Emissions related to processing

Emissions at the processing stage mostly come from the use of energy, whether electricity or fossil fuels.

An exhaustive literature review was conducted to gather data on energy consumption in dairy plants. Average energy consumption was then calculated for each type of product. The corresponding GHG emissions were computed by multiplying energy consumption with emission coefficients. Data on GHG emissions from electricity and other sources of energy, for different world regions and individual countries, were sourced from the statistical database of the International Energy Agency (IEA, 2009).

Emissions related to transport

GHG emissions from transport in the post–farm chain relate to the transportation of raw milk from the farm to a processing point, and to the transportation of products from the processing point to the retail point. Emissions relate to both energy use and the leakage of refrigerants.

The greenhouse gas emissions related to the *transport from farm to the dairy* were obtained from a literature review of data from six OECD countries (USA, Australia, Spain, UK, Norway and Sweden). Greenhouse gas emissions per kilogram of milk transported were averaged over the six countries.

Transport from dairy to retailer includes both ocean and road transportation. Emissions are estimated by obtaining information on the total distance, transportation mode, emissions per unit of distance travelled and emissions per time unit (cooling system). Transport emissions are estimated for milk, cream, cheese, butter and milk powder.

Emissions related to production of packaging material

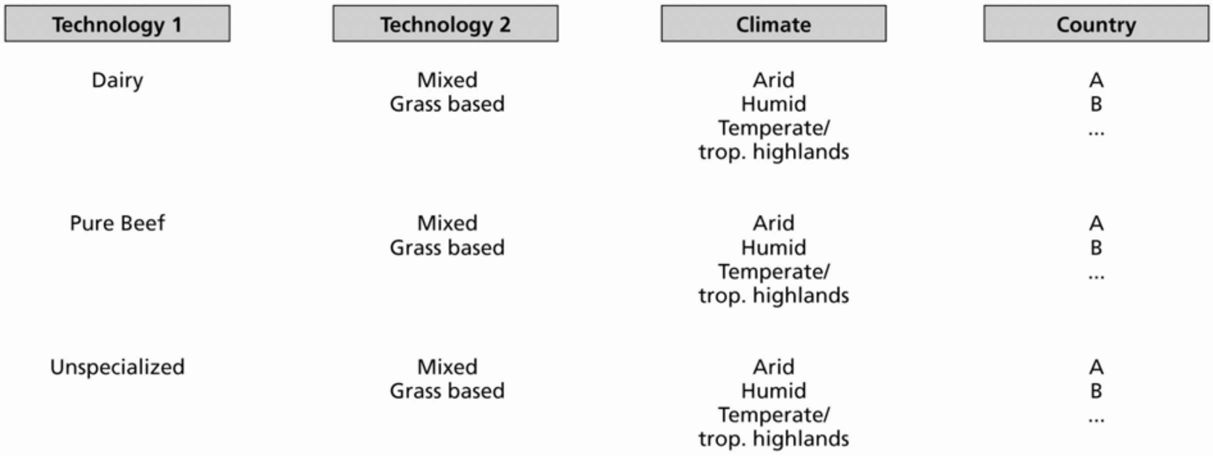
Producing packaging uses energy and creates GHG emissions. The packaging types assessed include plastic for cheese, aluminum and grease-proof paper for butter and cartons (gable top and brick), plastic for pouches and high density polyethylene (HDPE) for bottles.

Data on energy consumption related to the production of these packaging materials were obtained from literature reviews, and GHG emissions from energy consumption were derived from IEA statistics (IEA, 2009). Finally, region and country-specific GHG emissions were obtained by combining average energy use for packaging per kilogram of product and emissions factors per unit of energy used.

2.3.8 Production systems typology

This assessment aims to estimate emissions at global, regional and farming system levels. A farming system typology was thus adapted to provide a framework for examining GHG emission from different dairy farming systems. This typology is based on the classification principles set out by Seré and Steinfeld, 1996, namely, the feed-base and the agro-ecological conditions of production systems (Figure 2.2). The following three agro-ecological zones were used:

- *Temperate regions*, where for at least one or two months a year the temperature falls below 5^{O} C; and *tropical highlands*, where the daily mean temperature in the growing season ranges from 5^{O} to 20^{O} C.
- *Arid and semi-arid tropics and subtropics*, with a growing period of less than 75 days and 75 - 180 days, respectively.
- *Sub-humid tropics and subtropics* and *humid* where the length of the growing period ranges from 181 - 270 days or exceeds 271 days, respectively.



Technology 1	Technology 2	Climate	Country
Dairy	Mixed Grass based	Arid Humid Temperate/ trop. highlands	A B ...
Pure Beef	Mixed Grass based	Arid Humid Temperate/ trop. highlands	A B ...
Unspecialized	Mixed Grass based	Arid Humid Temperate/ trop. highlands	A B ...

Figure 2.2. Classification of cattle production systems used in the assessment

Using the widely used classification approach developed by Seré and Steinfeld (1996) has a number of advantages: it allows researchers to use the multiple databases developed using this structure (e.g. geo-referenced data on animal numbers in each livestock production system - LPS); it provides a conceptual framework to make estimates where data are lacking; and it enhances the compatibility of this work with other analyses using similar classification schemes.

2.3.9 Assumptions

The global scope of this assessment, as well as the complex and varied interactions within livestock production systems, called for a number of assumptions and simplifications. The main assumptions and methodological choices made in the study are summarized below:

- The farming of dairy and related meat animals is simplified to a model consisting of three modules: (i) feed production (within or external to the farming system being assessed), (ii) animal feeding and performance, and (iii) manure management.
- The herd model assumes a constant total herd count (no herd dynamics are considered).
- International trade in live animals is ignored.
- Dairy is assumed not to be a significant driver of pasture expansion into forest.
- Among feed crops, only soybean is significantly associated with land use conversion.

2.3.10 Emission coefficients

All emission calculations are based on the IPCC guidelines (IPCC, 2006), particularly the following chapters:

- Volume 4, Chapter 3: Consistent representation of land;
- Volume 4, Chapter 10: Emissions from livestock and manure management; and
- Volume 4, chapter 11: N_2O emissions from managed soils and CO_2 from lime and urea application.
- .

The assessment incorporates data from the IPCC National Inventory Reports (NIRs) where available (UNFCCC, 2009a, 2009b), however, for many processes such data is lacking.

For all calculations the Tier 2 level values are used. Country-specific emission factors as defined in the National Inventory Reports - which for many Annex 1 countries are Tier 3 approaches - were not used. This might compromise the accuracy of the results for these countries and cause discrepancies between the calculations in this assessment and the values reported in the NIRs. However, a unified approach was preferred for the assessment, to ensure consistency and comparability of results across regions and farming systems.

The Global Warming Potentials (GWP) with a time horizon of 100 years based on the 4th Assessment Report of the IPCC (IPCC, 2007) are used to convert nitrous oxide and methane to CO_2-eq terms. Consequently, GWP of 25 and 298 were used for methane and nitrous oxide, respectively.

Data on emissions related to the use of energy from fossil fuels and the electricity grid was retrieved from the EcoInvent database (EcoInvent, 2009).

3 Data

The availability of data varies considerably within and between key parameters. In general, the OECD countries possess detailed statistics, supported by several scientific and technical publications. In contrast, there is a severe paucity of data in non-OECD countries. Where detailed and accurate data are available, they are often outdated and/or lack supporting metadata.

3.1 Data collection

Data collection is particularly time consuming, especially for parameters that are highly variable, such as yields. FAO and other experts in production systems and other fields related to the assessment, contributed by recommending reliable sources of data, reviewing data collected and by providing estimates where data gaps existed. The study's main data sources include:

- Gridded Livestock of the World (FAO, 2007).
- National Inventory Reports of the Annex 1 countries (UNFCCC, 2009a).
- National Communications of the non-Annex 1 countries (UNFCCC, 2009b).
- Geo-referenced databases on feed availability from the International Food Policy Research Institute (IFPRI, 2009).
- Satellite data on gross primary production.
- Life Cycle Inventory (LCI) data from the Swedish Institute for Food and Biotechnology (Flysjö et al., 2008), and Wageningen University, the Netherlands (Imke de Boer, *Personal communication*).
- Reports from the CGIAR research institutes.
- Statistics from FAO (FAOSTAT, 2009).
- Peer reviewed journals.

The data have been organized into data groups or "basic data layers". Table 3.1 summarizes the data collection approach and sources for each main data group.

Table 3.1. Overview of the data sourced for the preparation of this assessment

Data groups	Data collection approach and sources
Herd (animal parameters)	Literature reviews and reports
Manure management	Literature reviews and reports
Feed basket	Literature reviews, reports; IFPRI (GIS based data)
LCI feed components	Literature reviews, reports; IFPRI (GIS based data), LCI databases Sweden and the Netherlands
Milk production	Literature reviews and FAOSTAT
Non-edible products	Literature reviews and reports
Carbon stocks	Use of model based on Gross Primary Production (GPP)
Deforestation	FAO Forestry statistics and own calculations
Animal numbers	Herd layer data, FAOSTAT and FAO, Gridded Livestock of the World

3.2 Data management

Data on farming activities and farming system parameters was collected at different levels of aggregation: production system, country level, agro-ecological zones, or a combination thereof (e.g., information on manure storage in developing countries was available for a combination of production systems and agro-ecological zones).

Additional data, such as livestock numbers, pasture and availability of feedstuff was available in the form of Geographical Information System (GIS) grids (raster layers), with a level of resolution not coarser than 5 Arc minutes (ca. 8.3 km x 8.3 km at the equator).

To preserve and manage spatial heterogeneity, both at the level of data management and at the level of calculation, we relied on GIS to create the database and develop the calculation model. In this way, emissions are estimated at any location of the globe, using the most accurate information available, and then aggregated along the desired category, e.g. farming systems, country group, commodity and animal species.

4 Results and Discussion

4.1 *Total emissions for milk production*

The amount of milk produced globally in 2007 was about 553 million tonnes (FAOSTAT, 2009). The amount of meat produced from slaughtered dairy cows and reproduction bulls slaughtered after their production period, is estimated to be 10 million tonnes. This meat production is a biologically inevitable co-product of the dairy production. The calculated meat production from surplus calves generated by milked cows, but not needed for replacement of milked cows and reproduction bulls and thus fattened for beef production, amounts to about 24 million tonnes.

The total meat production related to the global dairy herd is thus estimated to be 34 million tonnes, or 57 percent of the total cattle meat production in the world (60 million tonnes in 2007 - FAOSTAT, 2009) and almost 13 percent of the total global meat production (cattle, sheep, goats, buffaloes, pigs and poultry) in the world (269 million tonnes in 2007 - FAOSTAT, 2009).

The GHG emissions from the dairy herd, including emissions from deforestation and milk processing were estimated at 1,969 million tonnes CO_2-eq. [±26 percent][2], of which 1,328 million tonnes [±26 percent] are attributed to milk, 151 million tonnes [±26 percent] to meat production from culled animals and 490 million tonnes [±26 percent] to meat production from fattened animals (Table 4.1).

Milk and meat production from the dairy herd (comprising of milking cows, replacement calves and surplus calves and culled animals) plus the processing of dairy products, production of packaging and transport activities are thus estimated to contribute 4.0 percent [±26 percent] to total GHG anthropogenic emissions, estimated at 49 gigatonnes (IPCC, 2007). Milk production, processing and transport alone are estimated to contribute 2.7 percent [±26 percent] to total anthropogenic GHG emissions (Table 4.1).

Average global emissions per kg of milk are estimated to be 2.4 kg of CO_2-eq. [±26 percent].

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[2] See uncertainty analysis, section 4.6.4.

Table 4.1. Milk and meat production and related GHG emssions – global averages

Commodities	Total production (Million tonnes)	GHG emissions (Million tonnes CO_2 eq.) *	GHG emissions (kg CO_2 eq. per kg of product) *	Contribution to total anthropogenic emissions in 2007 (%) *
Milk: production, processing and transport	553	1 328	2.4	2.7
Meat: produced from slaughtered dairy cows and bulls (carcass weight)	10	151	15.6	0.3
Meat: produced from fattened surplus calves (carcass weight)	24	490	20.2	1.0

* [±26 percent]

4.2 *Regional trends*

Average emissions per kg of FPCM at the farm gate are shown in Figure 4.1. The highest emissions are estimated for sub-Saharan Africa, which has an average of about 7.5 kg CO_2-eq. per kg FPCM at the farm gate. The lowest values are estimated for the industrialized regions of the world, which have between 1 and 2 kg CO_2-eq. per kg FPCM at the farm gate. South Asia, West Asia & Northern Africa and Central & South America have intermediate levels of emissions, estimated to be between 3 and 5 kg CO_2-eq. per kg FPCM at the farm gate.

The largest portion of dairy sector emissions occurs at the farm level, which on average is 93 percent. In North America, Western Europe and Oceania, 78 to 83 percent of emissions are generated by activities on the farm and in all other parts of the world, these emissions are estimated to contribute to between 90 and 99 percent of the total emissions. Regional variations in emissions per kg milk are predominantly driven by differences in farming systems.

The average greenhouse gas emissions from land use change are relatively low. The highest values are estimated for Western and Eastern Europe, where they account for 0.11 and 0.04 kg CO_2-eq. per kg of FPCM at farm gate, respectively, representing 7 percent and 3 percent of the emissions per kg of FPCM at farm gate, respectively (cf. section 4.4).

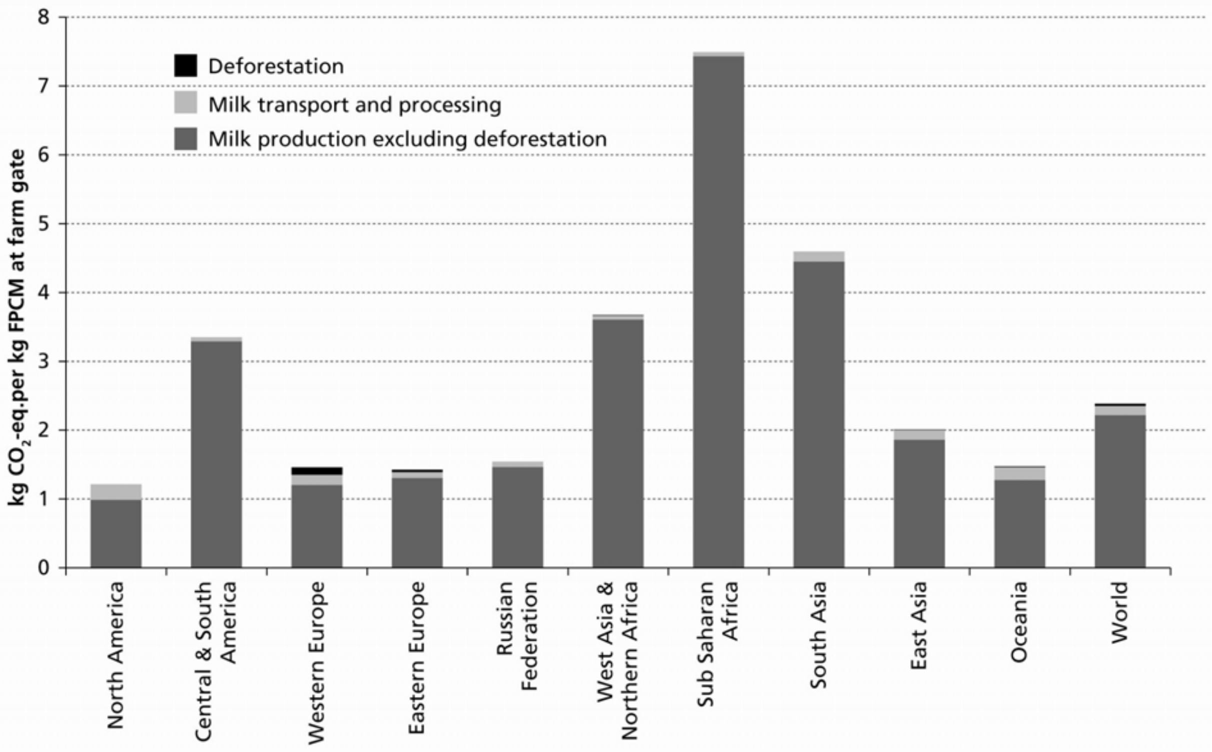


Figure 4.1. Estimated GHG emissions per kg of FPCM at farm gate, averaged by main regions and the world

Post-farm gate emissions range between 0.06 and 0.23 kg CO_2-eq. per kg of FPCM at the farm gate. Differences are due to variations in the fraction of milk processed and the emission intensity associated with energy generation and consumption (cf. section 4.5).

Milk production and GHG emissions associated with milk production, processing and transport are shown in Figure 4.2. Two groups of regions can be identified, according to their relative contribution to global milk production and related GHG emissions: those where production is more emission intensive than average (e.g. South Asia, Sub-Saharan Africa, and Central and South America) and those where it is less (e.g. Western Europe, North America, East Asia).

South Asia generates the largest share of emissions, combining large production of milk with relatively high emission per kg of milk. By contrast, Western Europe is ranked at third place for its share of global emissions, even though is the largest producer of milk.

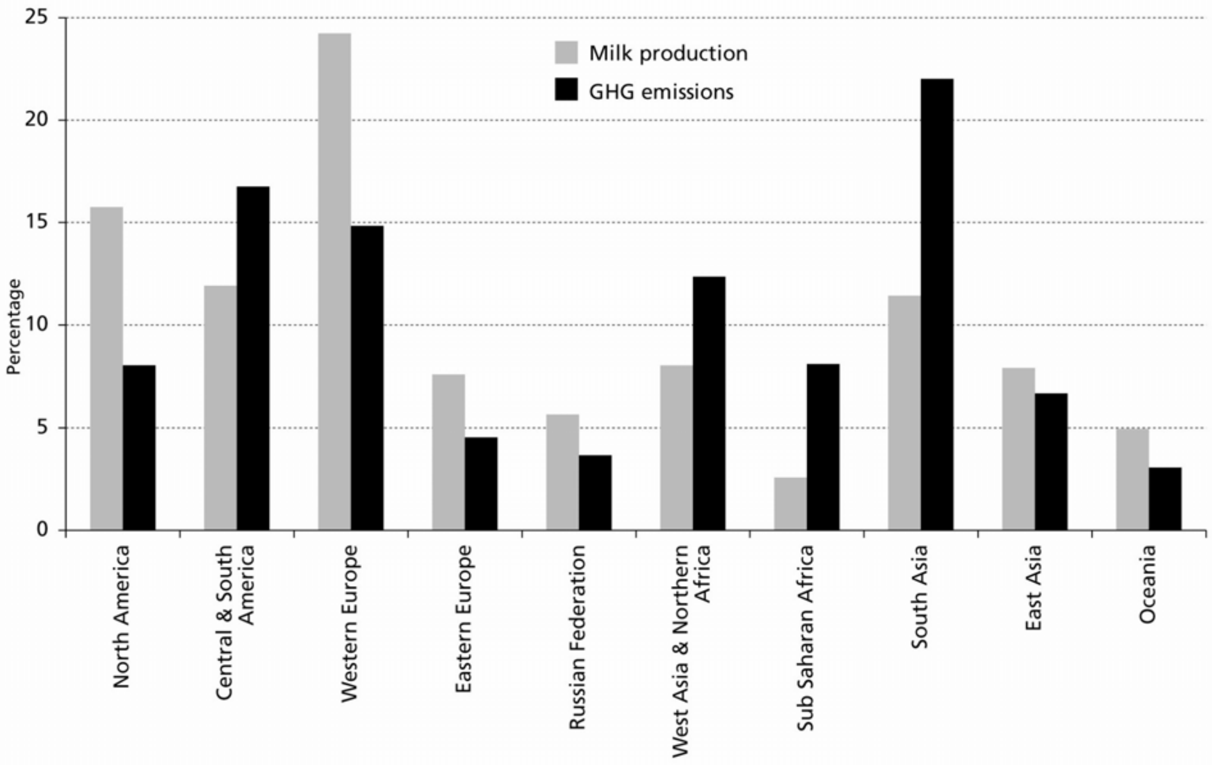
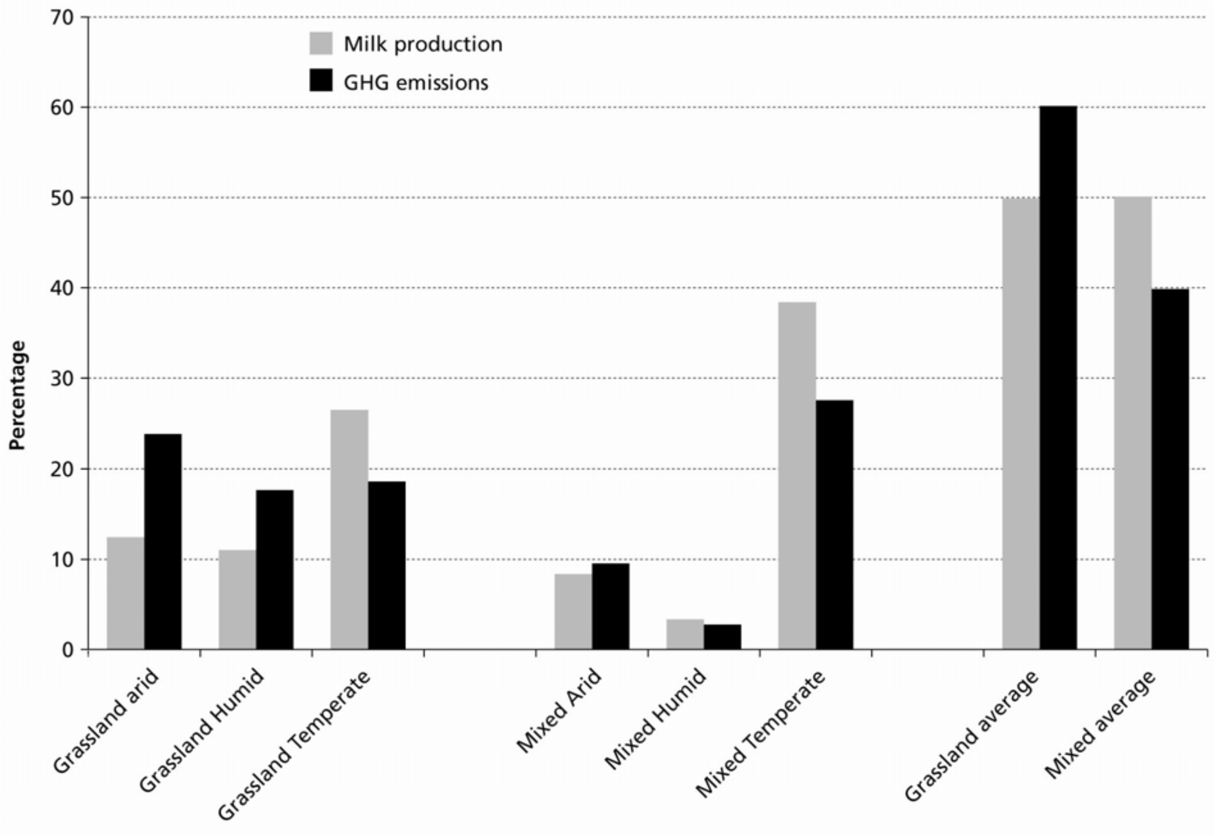


Figure 4.2. Relative contribution of world regions to milk production and GHG emissions associated to milk production, processing and transportation.

4.3 The partitioning of emissions by production systems and gases

The grassland based and mixed systems are both estimated to contribute around 50 percent to global milk production. However, grassland based systems, on average, account for 60 percent of the global sector's emissions, whereas mixed systems are characterised by a lower emission intensity, and are thus estimated to account for only 40 percent of emissions (Figure 4.3). The average emissions from grassland based systems are 2.72 kg CO_2-eq. per kg of FPCM, compared to an average of 1.78 kg CO_2-eq. per kg of FPCM, in the mixed systems (Figure 4.4).

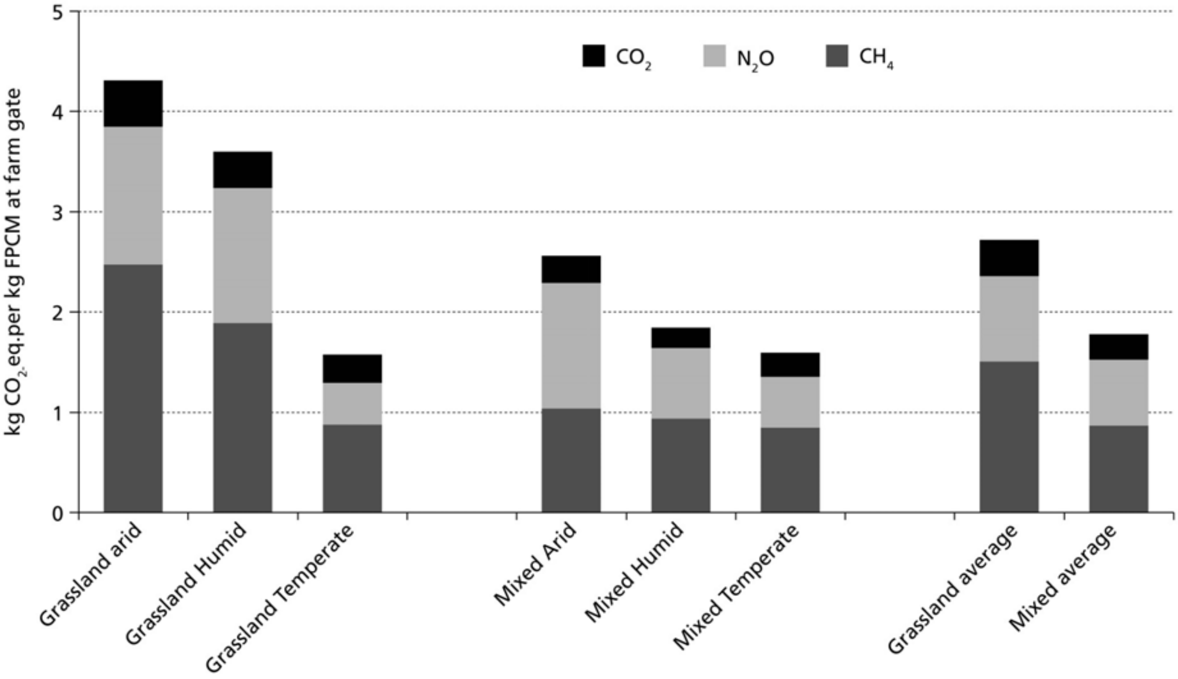
Within the grassland systems, most of the milk production is found in temperate regions, which also includes the tropical highlands. The share of milk production in the temperate regions (grassland and mixed) is larger than their share in the total emissions, indicating a lower emission per kg of milk than the average.



Note: Emissions related to processing and land use change are omitted.

Figure 4.3. Partitioning of milk production and greenhouse gas emissions over livestock production systems and climatic zones

The emissions are relatively high in the arid agro-ecological zones; this is especially the case in the arid grassland systems (Figure 4.4). The high emissions can be explained by the low milk production per cow, combined with the low digestibility of the feed in many of these systems. The lowest emissions per kg of milk are found in the temperate zones, where most industrialised countries are found.



Note: Emissions related to processing and land use change are omitted.

Figure 4.4. GHG emissions per kg of FPCM, by main farming systems and climatic zones

Methane is generally the most important contributor to the total greenhouse gas emissions from milk production, accounting for 50 percent or more of emissions. Its relative importance is particularly high in grassland systems of arid and humid climates, and in mixed temperate systems. The low digestibility of grass in the arid and, to a lower extent, humid regions is the main reason for the high methane emissions from grazing systems. Although methane emissions are considerably lower in other systems and agro-ecological zones, it is in all cases the most important contributor to total greenhouse gas emissions from milk production.

Nitrous oxide emissions range from 27 to 38 percent of the total emissions, and they are relatively high for the arid zones and for grassland systems in humid environments. This is mostly due to the deposition of manure on pasture (grassland systems) and the use of dry lots for manure storage, combined with manure application to crops (mixed systems) in these climatic environments. The fraction of nitrous oxide in the temperate zones is substantially lower than in the arid and humid zones, because grazing time is limited and manure storage systems prevent high nitrous oxide emissions.

Carbon dioxide plays a minor role in on-farm emissions, representing on average 5 to 10 percent of the total emissions. Carbon dioxide emissions are highest in the temperate zones (mostly found in industrialized countries) where milk production levels are highest and energy is used for feed production.

4.4 *Emissions related to land use change*

As discussed, the only emissions related to land use change that were included, were those associated with the expansion of soybean production into forested land. The total area of soybeans increased from about 24 million ha in 1961 to about 90 million hectares in 2007. The 8 largest producers of soybean account for 94 percent of the total cropped area, and the “big 4”: USA, Brazil, Argentina and China account for almost 80 percent of the total cropped area.

4.4.1 Soybean production and land use conversion

Among the “big 4”’, soybean areas have expanded significantly in recent decades in USA, Brazil and Argentina, while it remained fairly stable in China: areas increased by about 6, 10, 11 and 0.5 million hectares, respectively, between 1990 and 2007.

Table 4.2. Average annual land use change rates in Argentina, Brazil and the USA, 1990 to 2007

Land use type	Argentina (1000 ha)	Brazil (1000 ha)	USA (1000 ha)
Agricultural area	+351	+1 288	-929
Arable land & permanent crops	+358	+535	-860
Soybean area	+648	+534	+182
Grasslands	-7	+753	-69
Forest area	-149	-2 855	+280
Other land	-201	+1 567	+666

Source: FAOSTAT, 2009

In Argentina, the annual increase of area dedicated to soy is much larger than the increase of total arable land, indicating that there has been a shift in land use from other crops to soy. According to FAOSTAT statistics (Table 4.2), 44 percent of the new soy area was gained against other crops, while the rest was gained against forest (22 percent) and other land (31 percent). The latter category covers natural vegetation that does not include from forest and grazed natural grasslands.

The reported annual increase of soybean area in Brazil is 534,000 ha. We assumed a simplified pattern of deforestation in the Amazon, in which cleared land is first used as pasture and/or crop land, and then left as fallow land. The latter, classified as “other land” in FAOSTAT, is occupied by weeds, grasses, shrubs and partly by secondary forest. Under this assumption, every year roughly 2.9 million hectares are converted to arable land and grassland. At the same time, agricultural land is abandoned at a rate of 1.6 million hectares per year. The annual net increase of arable land and grassland is 0.53 and 0.75 million hectares respectively. We thus assume that all incremental soybean area is gained at the expense of forest area. The deforestation rates correspond to rates from published sources such as INPE, 2009.

In the USA, the annual increase in soybean area is much less than in Brazil and Argentina, and it is gained at the expense of other crops rather than forest. Under these circumstances, and consistent with the IPCC methodology, soil carbon stocks are assumed to be unchanged.

Annual emissions related to land use change were then calculated on the basis of BSI (2008):

- Deforestation in Brazil releases 37,000 kg CO_2-eq. per hectare;
- Deforestation in Argentina releases 17,000 kg CO_2-eq. per hectare;
- Clearing of shrubland in Argentina releases 2,200 kg CO_2-eq. per ha.

Following the economic allocation technique, 72 percent of the emissions related to land use change were allocated to the soybean cakes, which represent 80 percent of the soybean mass before processing (Table 4.3).

Table 4.3. Relative mass and economic value fractions of oil, meal and hulls resulting from the processing of soybean

Component	Mass fraction	Economic value fraction
Oil	0.17	0.27
Cakes	0.80	0.72
Hulls	0.03	0.01

Source: Flysjö *et al.* (2009) and Imke de Boer (personal communication)

Based on this analysis, we classified soybean cake into three categories:

1. Soybean cake from soybeans produced in Argentina, partially associated with the conversion of pasture and shrub land to cropland, for which land use change emissions are estimated at 0.93 kg CO_2 eq. per kg of soybean cake.
2. Soybean cake from soybeans produced in Brazil, entirely associated with deforestation, for which land use change emissions are estimated at 7.69 kg CO_2 eq. per kg of soybean cake.

3. Soybean cake from soybeans produced elsewhere not associated with land use change.

4.4.2 Relative contribution to farm gate emissions

Of the “big 4”, only USA, Brazil and Argentina are major exporters of soybean and soybean cake. Asia is the main importing region, importing 69, 47 and 93 percent of soybean exports from USA, Brazil and Argentina, respectively. The second largest importing region is Europe (EU-15, in particular), importing around 50 percent of the total exports of soybean from Brazil and 10 percent of exports from USA (Table 4.4). Brazil and Argentina export most of their soybean cake to the European Union, 74 and 61 percent, respectively (Table 4.5).

Table 4.4. Trade flow matrix of soybean in 2005, expressed in percentages of total trade

	Exporting country		
	USA (%)	Brazil (%)	Argentina (%)
Africa	3	1	3
America	18	1	3
Asia	69	47	93
Europe	10	51	1
Oceania	0	0	0
Total (%)	100	100	100
Total (Metric tonnes)	25	22	9

Source: FAOSTAT, 2009

Table 4.5. Trade flow matrix of soybean cake in 2005, expressed in percentages of total trade

	Exporting country		
	USA (%)	Brazil (%)	Argentina (%)
Africa	6	0	9
America	66	2	4
Asia	22	22	25
Europe	2	74	61
Oceania	3	2	0
Total (%)	100	100	100
Total (Metric tonnes)	6	14	21

Source: FAOSTAT, 2009

Based on the total use of concentrates in the dairy sector, GHG emissions from land use change related to the production of soybean cake are estimated to amount to 17 million tonnes. Europe is estimated to account for 94 % of these emissions, because the use of soybean in the diet of dairy cows is relatively high in the region (cf. annex 2) and because Europe sources most of its soybeans from South America (the weighted average CO_2-eq. per kg of soybean cake in the EU is 4.8 kg).

Average emissions attributed to land use conversion are estimated at 0.09 kg CO_2-eq. per kg of FPCM for Europe, and they are of the same magnitude for most OECD countries in Asia and Oceania, but they are negligible in the rest of the world.

4.5 Post-farm gate emissions

4.5.1 From raw milk to dairy products

The proportion of milk processed in dairy plants and the basket of commodities produced, varies by region. In industrialized countries, 95 to 100 percent of the milk is transported to the dairy plant for processing (IDF, 2009). The remainder is generally processed on-farm into cheese, butter and yogurt, and a limited amount of raw milk is sold fresh. In most developing countries, however, transport infrastructure and markets are limited: in most cases, all milk is sold locally or processed to butter and cheese by the milk-producing household.

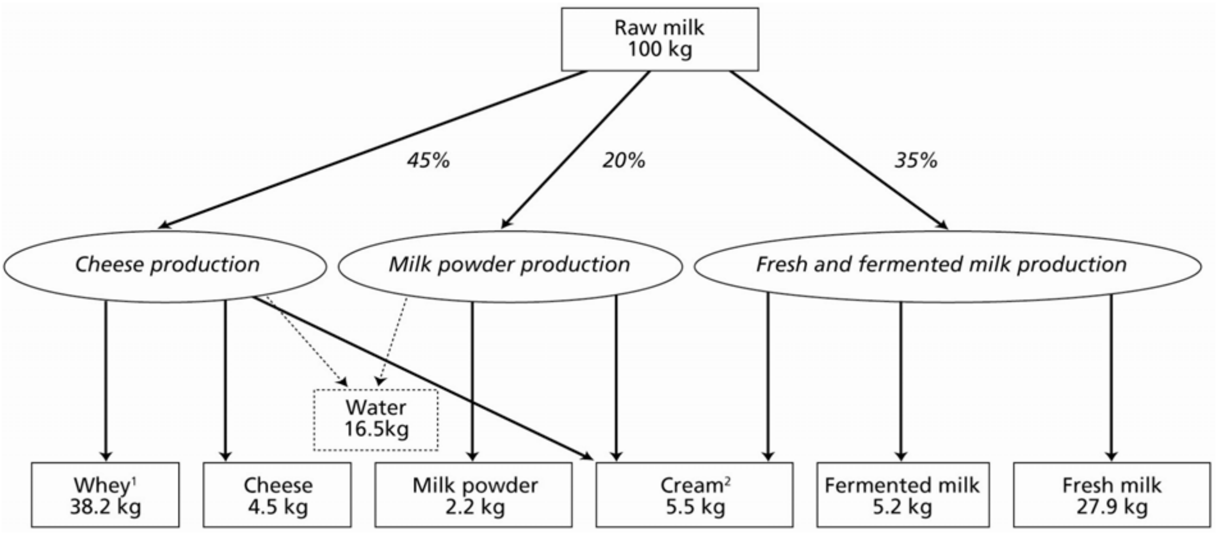
IDF provides data for a number of countries, mostly in the OECD, representing 74 percent of the global raw milk production. In these countries, 85 percent of all raw milk enters dairy plants for processing (Table 4.6).

This assessment considers six major dairy products: fresh and fermented milk, cream (and related butter), cheese, whey and milk powder. The processing chains and global average partitioning of milk is shown in Figure 4.5.

Table 4.6. Percentage of raw milk transported to dairy plant for processing in regions included in IDF reports

Region	Share of raw milk sent to dairy plant (%)
North America	96
South America	82
Asia	62
EU27	89
Other European countries	78
Africa	No data
Oceania	100

Source: IDF, 2009



Note: [1] Whey is sold as feed and as whey powder; [2] Cream is sold as such or processed into butter

Figure 4.5. Milk processing chains and related mass partition: a global average.

Significant regional differences exist in the relative importance of dairy products. For instance, cheese is quite important in the EU27 and North America, whereas in New Zealand and to some extent Australia, milk powder takes precedence (Table 4.7).

Table 4.7. Milk processing: regional variations in mix of end products

Region / country	Fresh milk	Fermented milk	Cheese	Condensed milk	Milk powder
	% of raw milk				
EU27	25	8	52	3	12
Australia	26	no data	33	no data	34
New Zealand	no data	no data	19	no data	52
Canada	37	4	45	2	11
USA	31	2	51	1	10
Average for countries and regions above	26	6	51	3	14

Source: IDF, 2009

4.5.2 Energy consumption

The amount of energy used for milk transportation and processing depends on:

- the distance between the production site and the dairy plant;
- the type of processing;
- the type of packaging;
- the distance and type of transport (e.g. cooled vs. non cooled lorries) between the dairy plant and the retailer; and
- the technical standards of the dairy plant.

Clearly, GHG emissions from a given dairy plant depend on the type of energy used, and how it is produced in the region. In Europe, on average, GHG emissions related to processing are estimated at 0.155 kg of CO_2-eq. per kilogram of milk at farm gate (0.155 kg CO_2-eq./kg milk). Of this, 0.086 kg of CO_2-eq. is from processing. Packaging accounts for 0.038 kg of CO_2-eq., and transport (from farm to dairy and dairy to retail) adds another 0.030 kg of CO_2-eq./kg milk (Table 4.8).

Table 4.8. Estimated energy use and GHG emissions for milk transport,processing and production of packaging: average values for Europe

	CO_2 emissions (kg CO_2-eq./kg milk at farm gate)
Transport from farm to dairy	0.016
Processing in dairy	0.086
Packaging	0.038
Transport from dairy to retail	0.014
Total	**0.155**

The production of packaging material is particularly energy intensive and therefore boosts emissions (Table 4.8).

GHG emissions in the post-farm gate phase vary by product. Table 4.9 presents post-farm gate GHG emissions from processing, transport and production of packaging, for major dairy products in Europe.

Table 4.9. GHG emissions from processing, transport and packaging for major dairy products - average values for Europe

Product	Greenhouse gas emissions (kg CO_2-eq./kg milk at farm gate)
Fresh milk and cream	0.153
Fermented milk and cream	0.304
Cheese and whey	0.126
Skimmed milk powder and cream	0.157
Whole milk powder and cream	0.171

Regional variations are considerable, related to differences in energy sources and energy efficiency. For example, emissions are relatively high in Australia and India due to a high percentage of coal use in energy production (Figure 4.6).

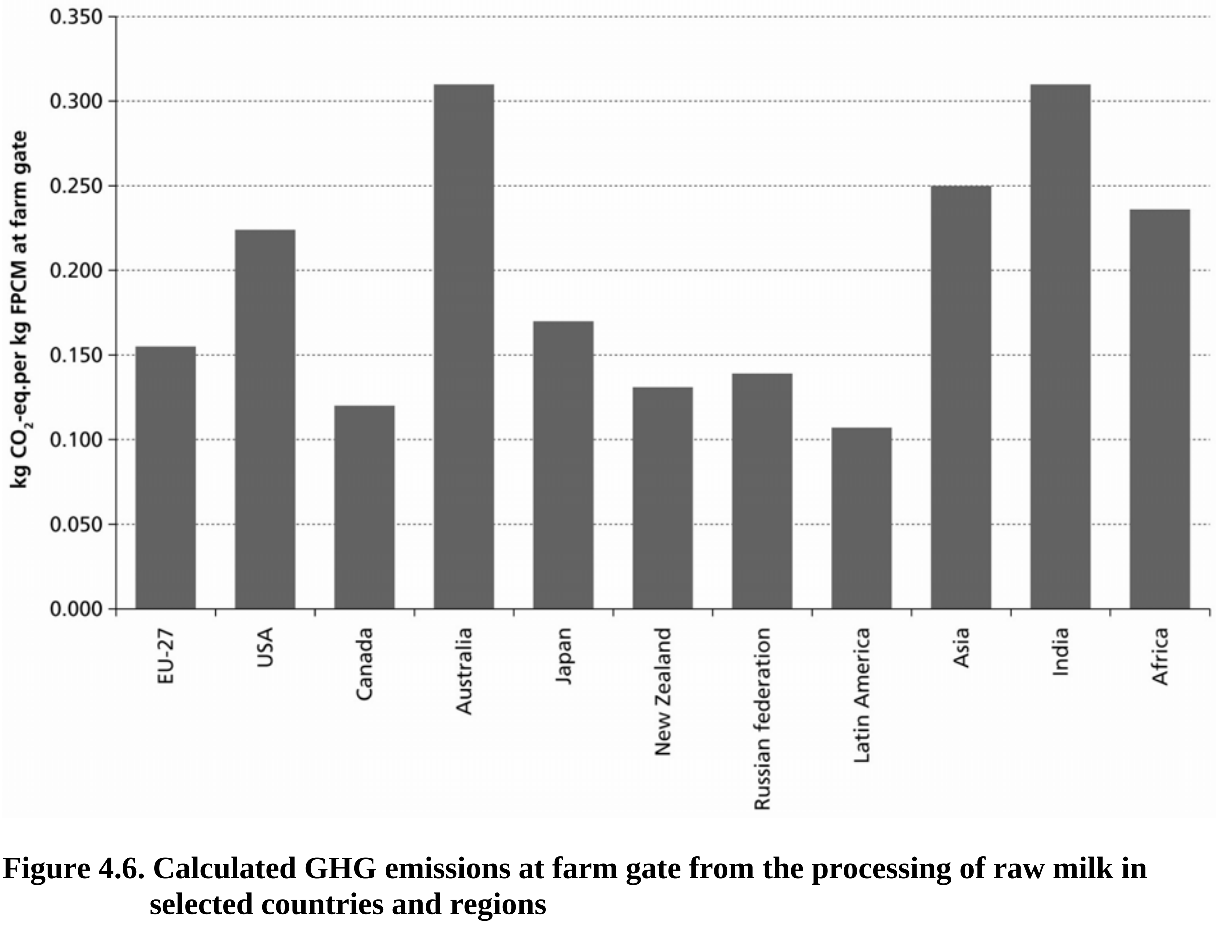


Figure 4.6. Calculated GHG emissions at farm gate from the processing of raw milk in selected countries and regions

4.6 Sensitivity and uncertainty analysis

Sensitivity analysis helps to provide an understanding of the relative importance of various input data on the results of a model. It is particularly important in the present case, since relatively arbitrary methodological choices had to be made, and limited data availability necessitated the use of several simplifications and assumptions. Uncertainty associated with the emission factors (IPCC, 2006) is an additional source of potential error.

4.6.1 Sensitivity to herd and feed characteristics

The effect of herd parameters (reproduction and production) and feed characteristics (digestibility and nitrogen content) was tested for extensive and intensive systems, using Nigeria and Sweden as examples. The herd parameters analyzed include: fertility, replacement rate, death rates, age at first calving and milk yield per cow. The age at first calving reflects the growth rate of animals; a lower age at first calving indicates a higher growth rate.

The effect of these parameters on greenhouse gas emissions and milk and meat production are tested by changing one parameter, by 10 percent at a time, while holding the others constant at average levels (Figure 4.7). The black bars indicate the effects of an increase of the parameter; the grey bars indicate the effects of a decrease.

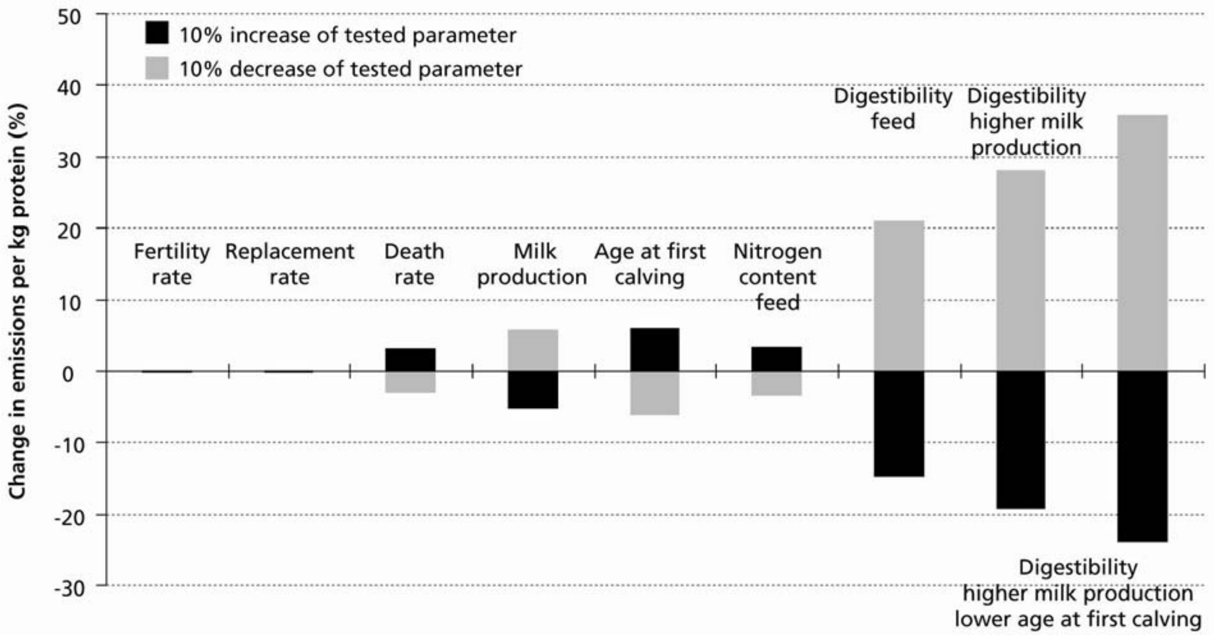


Figure 4.7. Sensitivity analysis: effect of a 10% change in key parameters on GHG emissions per kg of animal protein from a dairy system (including fattening calves)

The changes in the herd reproduction parameters (fertility, death and replacement rates) affect meat production proportionally, but the emissions per kg of animal protein (the sum of milk and meat protein) only change marginally.

The changes in the milk production per cow and the age at first calving (which is a proxy for the growth rate) clearly affect the emissions per kg of animal protein, but at a rate that is proportionally less than the actual changes in these production parameters. Increasing the nitrogen content of feed, without increasing milk production or growth rate causes a proportionally smaller increase in GHG emissions from both extensive and intensive systems.

The digestibility of feed has a strong effect on the GHG emissions per kg of product; a 10 percent increase in feed digestibility in the extensive system (5 units on an average digestibility of 56%) reduces GHG emissions by 14.8 percent. The increase in feed digestibility in the intensive system (5 units in, with a digestibility of 73%) is relatively less, and reduces GHG emissions by 10.1 percent. In practice, however, the quality of the feed is interrelated with milk production and growth, so looking at the combined effect of changes in feed quality, milk production and growth is more realistic. If we assume an increase in milk production by 10%, parallel to the increased digestibility, the GHG emissions are reduced by 19.2 percent in the extensive system and by 15.4 percent in the intensive system. In the situation where the growth rate is also increased, the GHG emissions are further reduced.

4.6.2 Sensitivity to manure management parameters

In the Nigerian extensive system, 75 percent of manure is estimated to be deposited on pasture, and 25 percent is stored in dry lots. If we assume 100 percent deposition on pasture, GHG emissions rise by 2.4 percent (Table 4.10). If solid storage is replaced by a liquid manure-management system, emissions increase by 5.8 percent.

Table 4.10. Sensitivity analysis: changes in greenhouse gas emissions due to changes in the manure management practice – a case of Nigeria

Manure management system	Standard management	100 % pasture	Liquid storage
pasture	75	100	75
solid storage	25	0	0
liquid	0	0	25
GHG emissions per kg of animal protein, indexed to 100 for standard management	100	102.4	105.8

In the Swedish intensive system, we estimate that 25 percent of manure is deposited on pasture, 20 percent is kept in solid storage, and 55 percent in liquid storage. Increasing the storage of manure in solid form to 40 percent reduces emissions (Scenario I, Table 4.11). However, the reduction is nearly eliminated by a 4 degrees Celsius temperature rise (Scenario II)

If solid manure is entirely replaced by liquid manure (Scenario III), emissions increase, and they increase even further with a 4 degrees Celsius temperature rise (Scenario IV).

Table 4.11. Sensitivity analysis: changes in GHG emissions due to changes in manure management– a case of Sweden

	Manure management system			Temperature	GHG emissions per kg of animal protein*
	Pasture	Solid storage	Liquid/slurry	(^{O}C)	Index
Standard management	25	20	55	8	100
Scenario I: more solid storage	25	40	35	8	97.7
Scenario II: more solid storage, high temperature	25	40	35	12	99
Scenario III: more liquid storage	25	0	75	8	102.3
Scenario IV: more liquid storage, high temperature	25	0	75	12	105.2

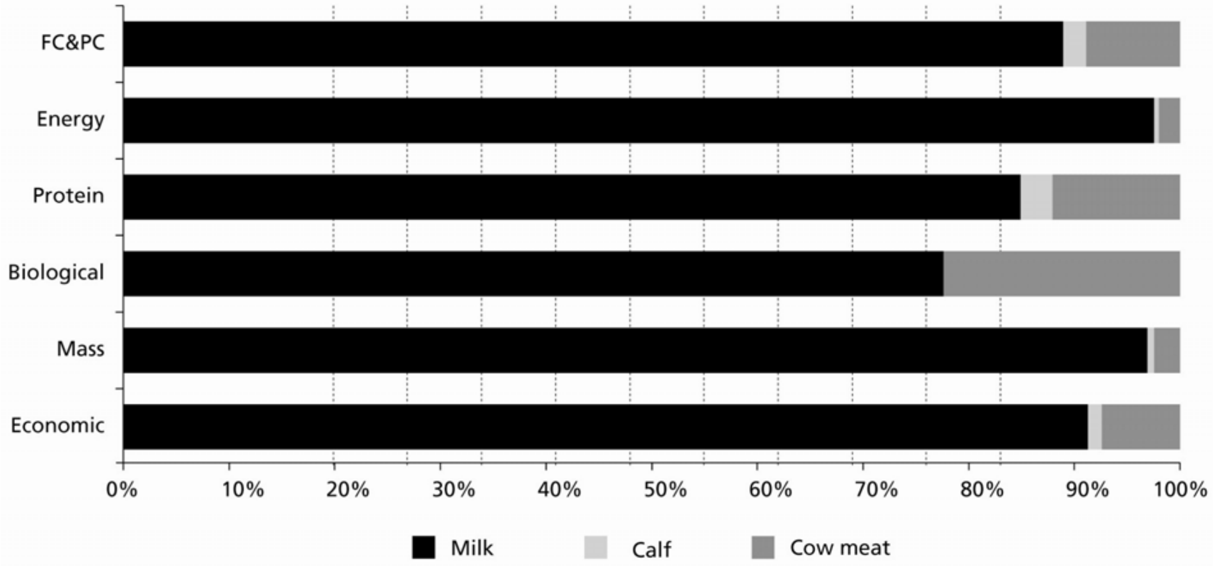
Note: * Indexed to 100 for standard management.

In general, it can be concluded that emissions are quite sensitive to variations in the feed digestibility and yield values, whereas they are relatively robust to uncertainties in the herd dynamics parameters and manure management practices.

4.6.3 Sensitivity to allocation rule

As discussed, GHG emissions associated with milk and meat production from the animals that are required to maintain the dairy herd (i.e. adult female and male and replacement female and male), were allocated on the basis of protein contents of milk and meat.

Jollé & Bertrand (2009) showed the effect of different allocation approaches on the partitioning of emissions between meat and milk (Figure 4.8). The allocation on the basis of protein production, protein and energy production (FC&PC), and economic value are quite similar. The mass (kilograms of fresh weight) and the energy allocation show lower emission fractions for meat, whereas the biological allocation shows a high fraction of the emissions for meat.



Source: Jollé & Bertrand, 2009

Figure 4.8. Effect of allocation techniques on partitioning of GHG emissions between milk and meat

The allocation approach strongly affects the emissions per kg of meat and, to a much lesser extent, the emissions per kg of milk. This is because meat production in specialised dairy systems is only a very limited part of the total output. Small changes in the allocation of emissions to meat can have relatively strong effects, as is shown in Figure 4.9. For Western European conditions, with 94 percent of proteins in milk and 6 percent in meat, increasing the allocation of emissions to meat by 10% almost doubles the emissions per kg of meat, but only increases the emissions per kg of milk by 5%.

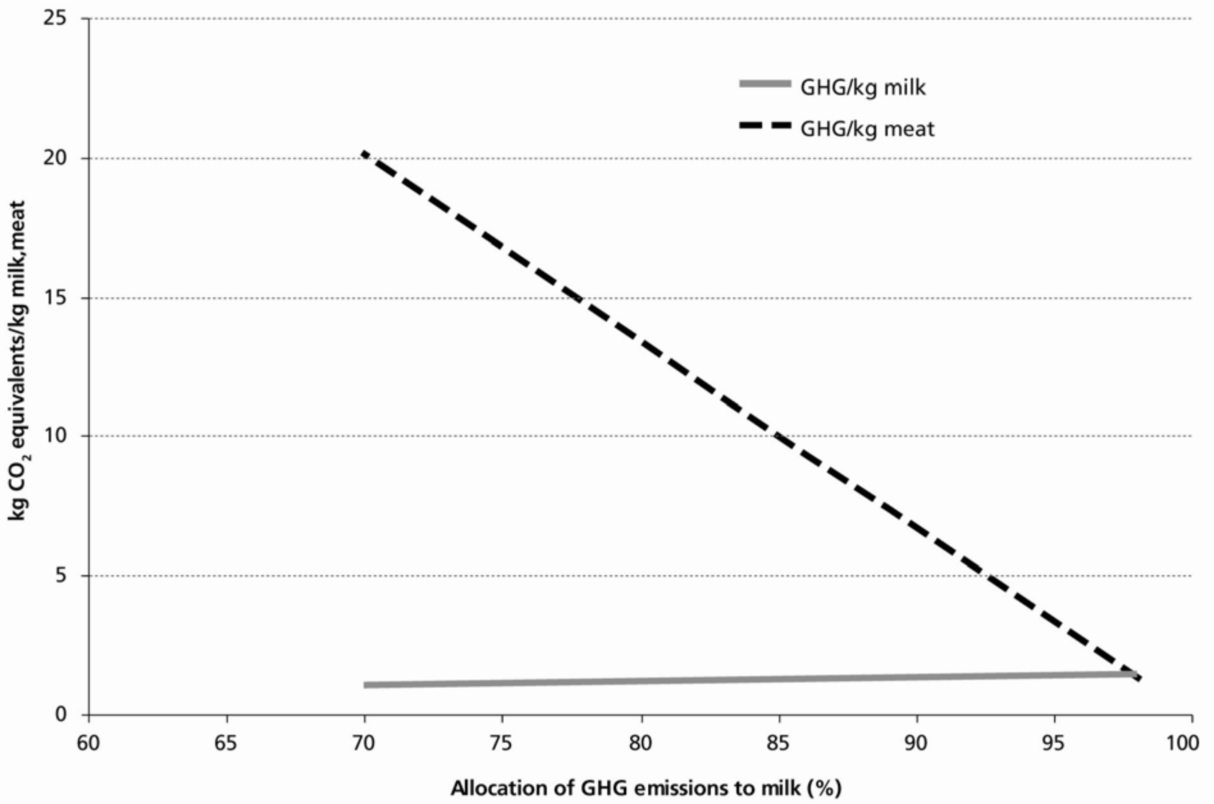


Figure 4.9. Sensitivity analysis: effect of protein based allocation rule on the partitioning of GHG emissions between milk and meat

4.6.4 Uncertainty analysis

In the previous section, changes in feed digestibility and related changes in productivity and manure management were shown to affect emission levels. It should also be noted that the emission factors that are used, have an uncertainty range (IPCC, 2006). A “Monte Carolo” uncertainty analysis was performed, to explore the combined effects of potential variations in input data and emission factors, according to the method used by Vellinga et al. (2001). Feed digestibility was set to randomly fluctuate by -/+ 10 %, the conversion for enteric fermentation by -/+ 15 %, emission factors regarding manure and N application by -/+ 50 %, and the energy use for feed production by -/+ 25 %. Three hundred model runs were performed under this “Monte Carlo” type analysis, the results of which are shown for the Swedish dairy system in Figure 4.10.

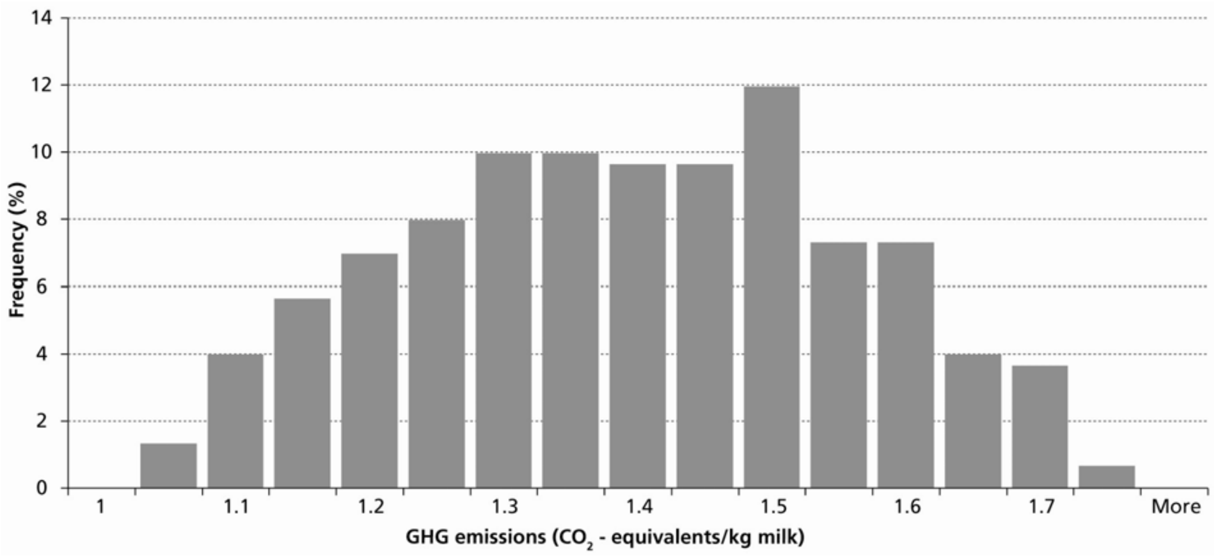


Figure 4.10. Distribution of the greenhouse gas emissions per kg milk for Sweden, resulting from a "Monte Carlo" uncertainty analysis conducted on key production parameters.

The average emission intensity is 1.36 kg CO_2-eq. per kg milk, and the standard deviation is 0.163 kg. The uncertainty analysis thus showed a standard deviation of 12 to 13 percent of the average value for meat and milk, in both Sweden and Nigeria. The variation in absolute figures is larger in Nigeria than in Sweden, which does not allow a simple extrapolation of the variation to the global average. The 95 % confidence interval is estimated to be two times the standard deviation, and calculations indicate that the variation around the average is plus or minus 26 %. This means that the range around the overall average GHG emissions per kg milk ranges from 1.8 to 3.0 kg of CO_2-eq. per kg milk.

4.7 Discussion

Accuracy

The use of GIS to store data and compute emissions has allowed this assessment to maintain the original spatial resolution of data sources, and to thus avoid generalising and averaging input data where spatially explicit sources were available. Two main methodological innovations have also been made compared to previous analyses. One is the development of a herd model that computes the "dairy related stock", consisting of the cattle required to maintain a population of milked cows and the "surplus" calves that are fattened for meat production. The second is a feed basket computation module that links locally available feed resources with animal numbers and productivity. These modules allow estimation of information which is required for the assessment, but is not available in statistical databases, and they also ensure coherence between the production parameters (e.g. reproduction and herd size, or feed intake and milk yields).

Despite these methodological advances, the assessment relies on numerous assumptions and simplifications, as well as methodological choices that influence the results. The sensitivity analysis has shown that the emissions, per kg of milk and meat, are mostly affected by digestibility, milk yield per cow and manure management. The supporting uncertainty analysis, which assessed random variations in input parameters and emissions factors, showed that emissions can range to plus and minus 26 % of the average emissions per unit of milk.

Validation

The slaughtered animals and total meat production figures calculated with the herd demography module were compared to FAO statistics (FAOSTAT, 2009) and were found to be very similar for all countries, except for a few countries where live animals are traded in large numbers.

Calculated GHG emissions were also compared to previous studies, based on similar methodologies. Methane emissions per animal from this assessment are comparable to figures obtained by Schils et al. (2007b), Cederberg et al. (2009) in OECD countries (ranging from 110 to 130 kg methane per cow per year) and by Herrero *et al.* (2008) in Africa (ranging between 21 and 40 kg methane per livestock unit per year).

Emissions per kg of milk also compare well with previous LCA studies for dairy production (Basset-Mens et al., 2009; Blonk et al., 2008; Capper et al., 2008; Cederberg et al., 2009; Foster et al., 2007; Herrero et al., 2008; Sevenster and DeJong, 2008; Thomassen, Dalgaard et al., 2008; Vergé et al., 2007). Some of the results from prior analyses are lower than those presented in this report, which in part is explained by discrepancies in emission factors (e.g. Basset Mens et al, 2007, Cederberg et al., 2009) or allocation technique (Cederberg et al., 2009). The choice to use the standard emissions factors of the IPCC at Tier 2 level, may also result in discrepancies if compared to studies that utilise country-specific emissions factors. As discussed, the use of IPCC standard emission factors at Tier 2 level, however, may not permit direct comparisons with other studies that utilize country-specific emission factors.

Table 4.12. Results from prior life cycle assessment studies of dairy production

Reference	Country/grouping	CO_2 eq. per kg of milk	CO_2 eq. per kg of meat	Remarks
Basset-Mens *et al.*, 2009	New Zealand	0.65 – 0.75	-	High maize yields, special emission factors
Foster et al., 2007	United Kingdom	1.14		
Vergé et al. 2007	Canada	1.0		
Blonk et al., 2008	Netherlands	1.2	8.9	
Sevenster & DeJong, 2007	Annex 1 countries	0.75 – 1.65	-	Based on national Inventory Reports /UNFCCC data
Thomassen et al., 2008a	Netherlands	1.5 – 1.6	-	
Capper et al., 2009	USA	1.35	-	
Cederberg et al., 2009	Sweden	1.00	19.8	Allocation milk/meat 85/15, meat including beef cattle

Intensification and implications for emissions and emissions reduction

A global trend emerging from the results is the lower level of emissions per unit of product in intensive compared to extensive systems. This is mainly driven by two factors: the higher digestibility of the animals’ feed, and the higher milk productivity level. These were also shown to be key factors in the sensitivity analysis. The CO_2 emissions associated with intensive systems, such as those from feed production, on-farm energy consumption, processing and transport are of a lower magnitude than methane and nitrous oxide emissions, and therefore do not change the overall picture.

It should be highlighted that this observation is true when broadly considering the range of production systems. However, it is possible that production systems in industrialised countries will experience increasing emissions with intensification, as the marginal reductions in emissions from enteric fermentation may not compensate for the increased emissions from manure, fossil energy and other inputs (Vellinga et al., 2009).

This assessment only considers the sector's contribution to climate change

The assessment presented here only looks at the GHG emissions of the dairy sector. It is obvious that GHG emissions are only one aspect of the environmental sustainability of the sector, which also includes issues such as water use and pollution, biodiversity erosion and air pollution. Furthermore, environmental performance is only one of the criteria against which the sustainability of production systems is measured, others being social issues, public health, and profitability.

The results and conclusions of this report need to be understood in this context, and analysed considering the synergies and trade-offs existing among environmental objectives and between environmental and other objectives. For example, although we estimated that the intensification of production is coupled with a reduction of GHG emissions per unit of output, its impacts on the eutrophication of water resources, biodiversity conservation and social arrangements may well be negative.

Efficiency and potential for mitigation

The combined production of milk and meat is particularly efficient in achieving low GHG emissions per unit of product. The fundamental biological reason for this is that milk is a "non extractive" product, which is harvested without any reduction of the productive biomass (stock). In dairy systems the emissions associated with growing a calf into an adult animal, and maintaining the animal until it is slaughtered are attributed to the production of both beef and milk, whereas they are entirely attributed to beef in specialised beef systems. Despite their comparative efficiency, there is still scope for emission reductions in dairy systems. In production, the main mitigation avenues are to limit methane and nitrous oxide emissions.

In intensive systems, enteric methane emissions per kg of milk are relatively low, compared to the extensive systems, leaving relatively little opportunity for improvement. In contrast, the fraction of methane coming from manure storage is relatively high (15 to 20 percent, compared to less than 5 percent in the extensive systems of the arid and humid zones). Anaerobic digestion of manure to produce biogas is a proven technique that has a significant potential. In the extensive systems of the arid and humid zones, marginal improvements of feed digestibility would achieve significant reductions in methane emissions per kg of milk, through a direct reduction of emissions and through the improvement of milk yields (Kristjanson and Zerbini, 1999).

The high contribution of nitrous oxide to the emissions of extensive systems in the arid and humid regions is mainly caused by the deposition of dung and urine in pastures, due to the long grazing time for the animals, and by the use of dry lot manure storage. Where feasible, changing manure management in these regions could be an effective way to reduce emissions.

Sequestering carbon by increasing soil organic matter content in grasslands is an effective way to offset emissions. Natural grasslands represent about 70 percent of the world's agricultural lands. Improving grazing land management is estimated to have the highest mitigation potential amongst all possible agricultural mitigation sources, at over 1.5 billion tonnes CO_2-eq./yr (IPCC, 2007). The restoration of degraded grasslands through erosion control, re-vegetation and improved fertility, also has significant potential to increase soil carbon sequestration rates. This can also generate additional ecosystem services relating to water quality and biodiversity management, and can improve the productivity and resilience of livestock enterprises.

Published overviews of mitigation options which provide useful information include Schils et al., 2006; Smith et al., 2008; and FAO, 2006a. When assessing mitigation options special attention should be paid to trade offs and displacement of emissions among steps in the production chain (van Groenigen et al., 2008; Wassenaar et al., 2007). A brief overview of these mitigation options can be found in Annex 4. The analysis in this report shows that the effectiveness of mitigation options depends on the specificities of the livestock systems.

In post farm activities, the mitigation options consist of opting for packaging material with lower production and disposal-related GHG emissions, as well as choosing energy sources with a lower emission levels.

Relevance of the methodology and database developed

The method developed to undertake this assessment is an important step in the direction of a standardised approach to assess and compare the environmental implications of food systems. In developing it, the research team benefited from comments and suggestions from a group of experts and consulted with other groups such as ISO, the IDF working group on LCA, and the World Resource Institute. Critical aspects of the methodology include the definition of functional units, the system boundaries, the attribution techniques and the approach to quantify land use change emissions. The method can be used as a framework from which further methodologies for local/product analyses can be developed. It also provides a useful starting point for the global-level assessment of dairy sector emissions, which can be refined as new data sources are made available and as new research needs arise.

The database developed and populated to underpin this assessment, is also of broader relevance to agricultural and environmental analysts. The data on emissions related to feed ingredients (life cycle inventories), and the information on feed rations, herd dynamics and productivity are relevant to other environmental and system analyses, at global, regional or national levels. They could serve as initial information to populate a shared database on dairy production and its related environmental impact.

5 Conclusions

The contribution of global milk production, processing and transportation to total anthropogenic emissions is estimated at 2.7 percent [±26 percent].

The global average of emissions from milk production, processing and transport is estimated to be 2.4 CO_2-eq. per kg of FPCM at farm gate [±26 percent].

The overall global emissions attributed to the dairy herd, are estimated to contribute to 4.0 percent of total anthropogenic emissions [±26 percent]. This includes the production of milk, the processing of milk products, transport activities, the production of meat from dairy related animals (old stock and young fattened stock), as well as the provision of draught power.

The combined production of milk and meat is particularly efficient in achieving low GHG emissions per unit of product, compared to pure beef production, due to the “non-extractive” nature of dairy production.

The study estimated large variations between the different world regions, with regional average emissions ranging from 1.3 to 7.5 kg CO_2-eq. per kg of FPCM [±26 percent]. From a system perspective, grassland systems were found to have the largest GHG emissions per kg of FPCM, estimated at 2.7 kg CO_2-eq. per kg of FPCM [±26 percent] compared to 1.8 kg CO_2-eq. per kg of FPCM [±26 percent] from mixed farming systems. Livestock systems in the temperate regions, mainly in industrialised countries, were found to have much lower emissions per kg of milk and meat than systems in the arid and humid zones in the developing countries.

Methane is by far the largest contributor to total GHG emissions from the dairy sector - accounting for over half of total emissions, while nitrous oxide contributes to between 30 and 40 percent of total emissions.

The method and database developed for this assessment effectively supported the calculation of GHG emissions related to dairy production on a global scale, and may be considered an important step towards a harmonised methodology for the quantification of emissions. Similarly, the global datasets collected for this assessment serve as useful initial data sources, which can be refined and updated by users over time.

Next steps

This assessment is part of an ongoing research programme to assess the environmental implications of animal food chains, and to analyse and recommend improvement options. The immediate next step is to use a similar approach to quantify the GHG emissions associated with specialised beef cattle and other major livestock species including buffalo, poultry, small ruminants and pigs.

This technical report is the first product of a wider programme implemented by FAO and aiming at identifying low emission development pathways for the livestock sector. The development of mitigation strategies, tailored to different development priorities and agro-ecological conditions, is the ultimate objective of this undertaking. This requires the use of technical data generated by studies such as this, combined with socio-economic data, to assess the cost effectiveness and social implications of a range of policy instruments to curb emissions.

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LIST OF ANNEXES

Annex 1: The LCA Model - Cradle to farm gate

The model structure

The Life Cycle Assessment model consists of 4 modules:

1. Herd demography module
2. Feed basket module, comprised of feed production and composition of the animals' ration
3. Animal energy requirements and GHG emissions module
4. Allocation module, where emissions are allocated to various goods and services

Table A1.1. Module input and output parameters

Input	Modules	Output
	Herd demography module	
- Number of cattle - Number of milked cows - Herd rates - Adult and slaughter weights	- Dairy cattle: herd structure and size; - Non-dairy cattle: herd structure and size	- Herd structure for dairy and non-dairy animals - Animals' live weights
	Feed Basket module	
- Number of cattle - Feed area and yield per component - LCI data structure: mechanization, fertilizer inputs, digestibility and N content of feed - Concentrate use	- Animals' ration - Weighted average of feed: yield per ha, digestibility, N content - Feed production: land use, emissions of N_2O and CO_2	- Feed basket: one average feed with quality (Digestibility, N content of feed), land use and emissions
	Emission module	
- Herd structure, dairy and non-dairy - Live weights - Feed basket - Manure Management System (MMS)	- Energy requirements - Feed intake - Calculates animal emissions: CH_4 and N_2O from enteric fermentation and MMS - Calculates feed emissions	- System production: protein and non-protein products - Emissions and land use
	Allocation Module	
- System production emissions - Land use	- Calculates meat and milk to protein - Allocates emissions and land use to products - Calculates emissions per unit of product	- Allocation results: - Protein production, - emissions and land use per unit of protein, milk and meat, - emissions and land use non edible products

The first step in the model is to compute a detailed herd structure, with different groups of animals and weights. Once the herd structure is determined, feed requirements are calculated and compared to locally available feedstuffs. If there is not enough feed available in the region, we assume that additional feed is imported.

The locally available and imported feed plus imported concentrate form the total feed basket. Information on feed inputs (e.g. fertilization of crops, energy use for production, harvesting and processing) and feed quality is attached to each feed basket.

Outputs from both the *herd* and *feed basket* flow into the *emission module*, where a detailed feed intake is first calculated for animal category. The detailed feed intake is then used to calculate methane emission from enteric fermentation, methane and nitrous oxide emissions from manure management, and nitrous oxide and carbon dioxide emission from feed production and land use.

Finally, the *allocation module* converts emissions into CO_2-eq. terms, totalling up enteric fermentation, manure and feed related emissions. It combines animal categories and allocates emissions to edible and non-edible products.

More detail on the modules follows.

The herd demography module

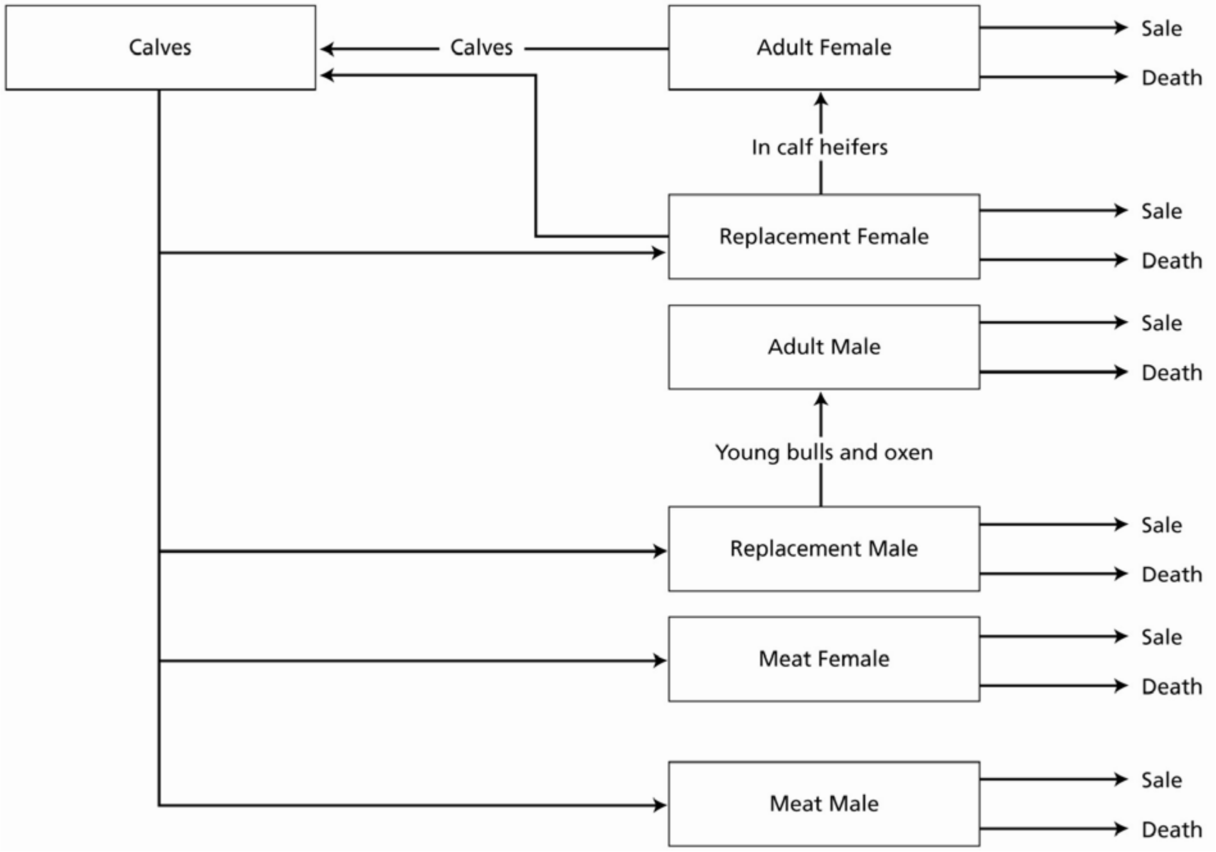


Figure A1.1. Structure of herd dynamics

Data on cattle herd structure is generally not available at the national level. A specific "herd demography" module was thus developed to partition the total number of cattle into complete dairy and beef herds. The module has a number of state variables and a number of rate parameters. The rate parameters are used in the model include:

- The *fertility rate* is the number of births per year per milked cow. It depends on the calving interval and percentage of cows culled due to fertility problems. Fertility rates differ between adult and young replacement females. The number of calves per birth is assumed to be one.
- The *death rate of calves* reflects the percentage of pregnancies that end with a dead calf. This may occur by abortion, still birth or death in the first 30 days after birth.

- The *death rate of other animals* reflects the annual death rate of all categories of animals, except calves.
- *Replacement rate* represents the number of adult animals replaced by younger adult animals per year. The replacement rate of female animals is taken from the literature. Literature reviews did not reveal any data on the replacement rate of male animals, so the replacement rate was defined as the reciprocal value of the age at first calving, on the assumption that farmers will prevent inbreeding by applying this rule.
- *The growth rate of animals* is based on the age at which they attain adult weight. For females, this depends on the age at first calving, although some growth takes place after the first calving. The age at which animals are sold for slaughter is based on the defined slaughter weight and the calculated growth rate.

The six animal categories are state variables:

1. Adult female (or milked cow)
2. Adult male (servicing bulls and draught animals)
3. Replacement female (not milked)
4. Replacement male
5. Meat female (these animals are not required for maintaining the herd and are kept for meat production only)
6. Meat male (these animals are not required for maintaining the herd and are kept for meat production only)

Calves are not counted *per se,* since they are immediately transferred to one of the four *replacement* or *meat* categories above (Figure A1.1).

The number of reproduction bulls is based on the male-to-cow ratio. Reproduction bulls and male animals for draught (oxen) are both part of the *adult male* category. The numbers of *replacement male* and *replacement female* animals that are needed to maintain the herd of adult animals, depend on the above defined rates.

A high replacement rate combined with a high death rate results in an increase of animal numbers in the *replacement* categories. A high age at first calving increases the total size of the *replacement* categories, since the animals remain for a longer time in these categories. The number of calves depends on the: (i) fertility rates of adult and replacement animals; (ii) replacement rate of females; and (iii) death rate of calves.

The calves that are not needed for maintaining the herd are fattened and slaughtered (*meat* categories). The animal numbers in these categories are calculated from the slaughter weight and the growth rate. The latter is assumed to be same as for *replacement* animals of the same sex.

To partition the total cattle numbers into complete dairy and beef herds, we perform two sequences of calculations (Table A1.2). The first sequence starts from the number of adult cows (input) and allows us to compute the numbers in the other five animal categories of the dairy herd. The total number of cattle in the dairy herd, subtracted from the total number of cattle in the country, gives the number of animals in the pure beef herd. The number of animals in the six beef categories can then be computed. In this assessment, meat production and the emissions related to the beef herd are not incorporated.

Table A1.2. Example of herd structure computation for the Netherlands

Animal type	Head		Head
Cattle – all included	**3 730 000**		
	Dairy herd		*Beef herd*
Milked cows (dairy herd) / reproductive cows (beef herd)	**1 450 000**	↓ ↑	139 500
Replacement female	1 025 032		43 860
Male for reproduction	14 500		5 580
Replacement male	15 117		5 695
Meat female	233 398		54 687
Meat male	682 998	*Total minus dairy related*	59 613
Dairy / Beef related herd	*3 421 045*	→	*308 955*

Note: Numbers in bold were taken from statistics; others are calculated.

→ : Calculation sequence

Feed basket module

Feed plays a key role in any animal production system. High quality feed is necessary for optimal productivity and growth levels. In many livestock production systems, feed quality and quantity is a major limiting factor. In this assessment, all feed ingredients are identified by three key parameters:

- dry-matter yield per hectare;
- net energy content (or digestibility); and
- nitrogen content.

Defining the animals' ration

Animal rations are generally a combination of different feed ingredients. The *feed basket module* computes a ration composed of different feed ingredients and calculates an average digestibility and nitrogen content of the ration, given the relative proportion of each ingredient.

Major feed ingredients include:

- *Grass*. Grass production ranges from natural pasture and roadsides to improved grasslands and leys.
- *Feed crops*. Crops specially grown to feed livestock, e.g. maize silage or grains.
- *Tree leaves*. Some livestock browse in forests, others are fed leaves.
- *Crop residues*. Plant material left over from food or other crops, such as straw or stover, left over after harvesting.
- *Agro-industrial by-products and wastes*. By-products from the processing of non-feed crops such as oilseeds, cereals, sugarcane, and fruit. Examples include cottonseed cakes, rape seed cakes and brans.
- *Concentrates*. High quality mixtures of by-products and feed that are processed at specialized feed mills into compound feed.

In all livestock production systems, the feed basket composition depends on the availability of rangelands, the crops grown and their respective yields. The fraction of concentrates in the ration varies widely, according to the need to complement locally available feed, the purchasing power of farmers, and access to markets.

Feed production

Feed is produced both on- and off-farm. When feed comes from outside the farm, the link between feed production and manure is broken: manure cannot be returned to the land on which feed has been cropped. Emissions related to the production of feedstuff are calculated from the following parameters:

- dry matter yield per hectare;
- for crop residues or wastes - the percentage of the total crop yield (e.g. grains and straw);
- manure and fertilizer use;
- energy used in farm processes, such as tillage, harvesting, processing and storage;
- energy used for the transport of feed to the livestock production site;
- energy use for the processing of feedstuffs into concentrates at the feed mill; and
- previous land use (land-use change is a major factor in GHG emissions).

Emission module

The energy and feed requirements of all animals are first calculated, taking into account the following parameters:

- *Weight*. Larger animals need more energy for maintenance than smaller ones.
- *Production*. The production of the animals can be milk and meat, but also non edible products and services. The figures for edible and non edible production of the animals are taken from literature and statistical databases. In general terms, a higher production or more labour per day requires more energy and thus more feed per day.
- *Type of feeding*: Grazing or stall feeding. Animals in ranging systems that have to search for their feed (often over long distances) have higher energy requirements than those in grazing systems or stall-fed systems.

The total net energy requirement and the digestible energy of the feed are used to calculate the gross energy requirement and the feed intake. A methane conversion factor is used to calculate the methane emissions from enteric fermentation. In all calculations the IPCC guidelines at Tier 2 level are applied. The IPCC (2006) defines the methane conversion factor (Ym) as 6.5 +/- 1%, indicating that Ym is at the high end of the range when digestibility of feed is low and *vice versa*. Considering the wide range in feed digestibility all over the world we incorporated a range of Ym values according to the following formula:

$$Ym = 9.75 - 0.05 * \text{Digestibility rate}$$

The Ym value of 6.5 is realized at a digestibility of 65 percent.

Ym is then used in the following formula:

$$CH4 \text{ emission} = (\text{annual feed intake} * Ym/100) * (18.55/55.65)$$

Table A1.3 shows the difference in methane emissions, calculated using the formula above, in intensive and extensive farming contexts.

Table A1.3. Calculated animal and management parameters, and related methane emissions from enteric fermentation in Sweden and Nigeria

Parameters	Sweden	Nigeria
Animal weight (kg)	650	250
Milk production (kg.year^{-1})	8400	240
Digestibility feed (%)	73	56
Feed intake (kg.animal^{-1}.year^{-1})	6416	2546
Methane conversion factor	6.10	6.95
Methane from enteric fermentation (kg.animal^{-1}.year^{-1}).	130	59

Methane emissions from manure storage depend on the type of storage and the composition and amount of manure produced. Manure composition and quantity are calculated on the basis of feed quality and feed intake. The digestibility of feed also determines the quantity of volatile solids in manure: low digestibility of feed corresponds to a high amount of volatile solids in manure. Methane emissions also depend on the nature of storage and its effect on the presence of oxygen in manure: anaerobic conditions, found at the bottom of deep lagoons, increase methane emissions.

Estimates of nitrous oxide emissions from manure are based on the nitrogen content in manure and the type of storage used. The quantity of N excreted is the difference between N intake via feed and N retention in meat and milk.

Feed intake is an input to the estimation of emissions from feed production. This is done by simply multiplying the LCI values of every feed item by their relative share in the feed basket, and then multiplying this figure by the overall amount of feed consumed by the animal.

The allocation module

The *allocation module* aggregates all the outputs of the previous modules. The production of meat and milk, and emissions from enteric fermentation, manure storage and feed production, are grouped for:

- adult and replacement females;
- draught animals; and
- meat animals.

Emissions of methane and nitrous oxide are converted into CO_2-eq. terms and then added to CO_2 emissions. GHG emissions are calculated based on their respective share in total protein production.

Annex 2: Overview of the database and data sources

This annex provides an overview of the database developed for the assessment and provides insights into the variability and quality of data.

Data collected for this study follows the data-quality preferences as defined (BSI, 2008). They are:

- Time-specific
- Location-specific
- Technology-specific
- The most accurate data
- The most precise data
- Complete and representative
- Consistent and uniform
- Sourced with clear references

Herd demography

Live weights and growth rates vary widely from region to region (Table A2.1). For instance, death rates for calves and other animals are especially high in Africa.

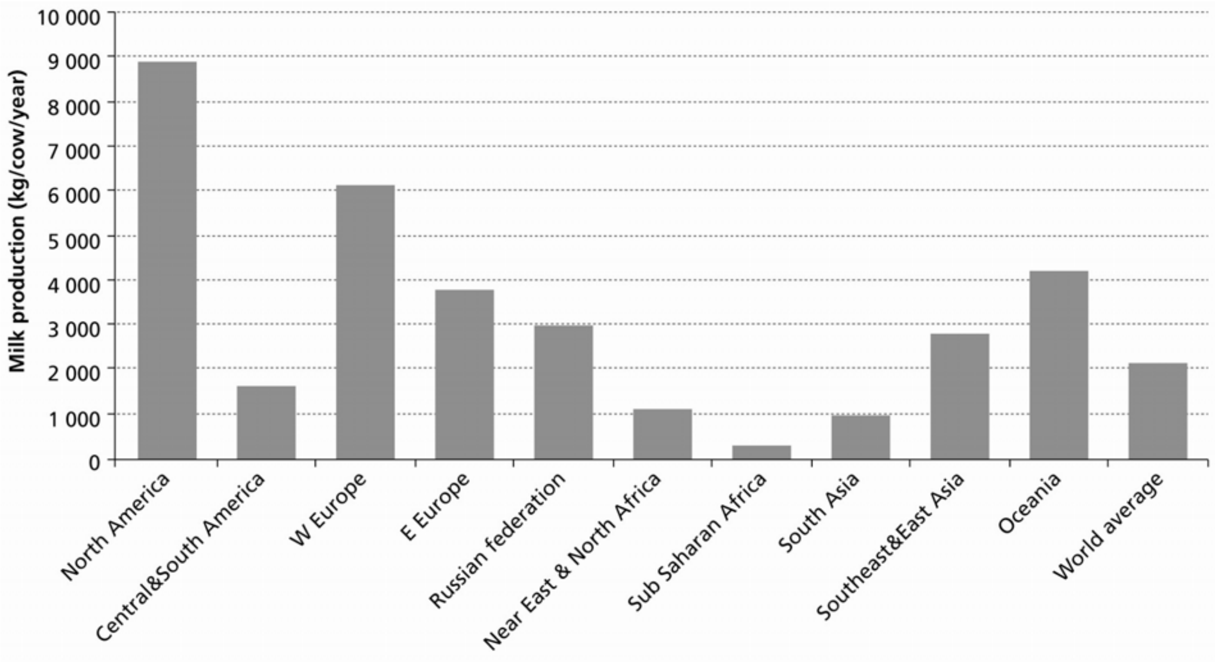
Table A2.1. Animal parameters used in the assessment for dairy cows

Parameters	North America	CSA	Western Europe	Eastern Europe	Russian Federation	NENA	SSA	South & SE Asia[1]	South & SE Asia[2]	Oceania
Weights (kg)										
Adult cow	700	565	570	538	500	259	231	296	613	467
Adult bull	863	735	741	699	650	343	301	398	776	607
Calve at birth	41	38	38	36	33	20	20	20	39	31
Slaughter female	583	550	535	532	530	259	231	296	540	403
Slaughter male	607	550	535	532	530	309	301	296	552	403
Rates (%)										
Replacement adult cow	34	24	30	29	31	13	10	21	31	22
Fertility	77	79	83	83	83	64	57	75	82	80
Death rate calves	8	9	8	8	8	20	20	20	8	8
Death rate other	3	2	4	4	4	7	7	8	4	4
Age at first calving	2.1	2.6	2.2	2.2	2.3	3.8	4.1	3.4	2.2	2.1

Note: 1=Unspecialized; 2=Specialized dairy cattle (Japan, China, South Korea, Israel)

Milk production per cow

Milk yield is a key input for computing emissions per kg of FPCM. Industrialized countries in Europe and North America have highest milk production. The lowest milk productivities can be found in South Asia and in Africa. (Figure A2.1) Data come from the FAO statistical database.



Source: FAOSTAT, 2009

Figure A2.1. Average milk production per cow, by FAO-region

Manure management

Manure can be stored in a number of ways. In the assessment, we use the predefined storage systems from the IPCC (summarized in Table A2.2). Deposition on the field during grazing or ranging is considered to be a type of storage.

Table A2.2. Overview of different manure storage systems used in the assessment

Practice	Management type
Inside/outside confinement	
– Time outside confinement (e.g., x % of the year)	scavenging, grazing, ranging
Manure storage during housing	
– Manure with wastewater, Storage in open ponds	Uncovered anaerobic lagoon
– *Manure with little or without wastewater*, Storage in ponds without crust cover	Slurry/liquid
– Manure with little or without wastewater, Storage in tanks or ponds with crust cover	Slurry/liquid
– Manure with little or without wastewater, Storage under confinement	Pit storage below confinements
– Manure without wastewater, Storage in open confinement area	Dry lot
– Manure without wastewater, Storage in open confinement area, removed daily	Daily spread
– Manure without wastewater, Storage in stacks, use of straw and/or evaporation	Solid storage
– Other storage system (e.g. above fish ponds)	Other

Source: IPCC, 2006

Manure storage relates to the time that animals spend outdoor, and therefore to the fraction of fresh grass in their ration. Manure storage is well defined for Annex 1 countries in their National Inventory Reports (NIRs). There is however very limited information on manure storage systems in developing countries; some qualitative information can be found in grey literature. Management practices were estimated based on: livestock production system, livestock density (i.e. the feed availability), importance of manure as a fertilizer, and use of mineral fertilizers (cf. Table A2.3. for Africa).

Table A2.3. Estimated manure storage systems in Africa

Livestock production system and agro ecological zone	Solid storage	Drylot	Pasture
Grass based, arid	0	25	75
Grass based, humid	0	25	75
Grass based, temperate	50	0	50
Grass based tropical highlands	67	0	33
Mixed Arid	0	60	40
Mixed Humid	0	60	40
Mixed Temperate	60	0	40
Mixed Tropical Highland	75	0	25

A worldwide summary of manure storage is shown in Table A2.4. Because nitrate leaching from manure storage is not defined in the IPCC guidelines, these data have been developed on the basis of information provided in Velthof et al., 2009.

Table A2.4. Average manure storage systems and the average percentage of nitrogen leaching from manure storage systems in the ten FAO regions

Region	Manure storage						N Leaching	
	Lagoon	Liquid/slurry	Solid storage	Drylot	Pasture/range	Daily spread	from liquid slurry	from solid manure
North America	12	32	31	0	16	9	2	4
CSA	0	0	29	19	52	0	19	8
W. Europe	0	38	36	0	22	4	3	4
E. Europe	0	22	61	0	14	3	4	4
Russian Federation	0	0	78	0	22	0	4	4
NENA	0	2	29	20	48	0	19	8
SSA	0	0	32	21	47	0	19	8
South Asia	0	4	26	18	48	0	18	8
East Asia	0	4	26	18	48	0	18	8
Oceania	4	0	0	0	94	2	15	2

Sources: *Manure storage*: Annex 1 countries taken from National Inventory Reports; Non-annex 1 countries based on own calculations. *Nitrate leaching*: Own calculations based on Velthof et al., 2009

Feed basket

Data on the main parameters of feed digestibility and nitrogen content were collected from an extensive literature review covering grass, crop residues, feed crops, agro-industrial by-products and concentrate feed. Digestibility and nitrogen content vary widely, particularly for grass and grass-legume mixtures across world regions. Grass digestibility was found to be highest in north and Western Europe and lowest in America, Asia and Africa (Table A2.5).

Table A2.5. Estimated average digestibility of fresh and conserved grass and grass legume mixtures, by FAO regions

Feed quality	Average digestibility of fresh grass and grass legume mixtures (%)	Average digestibility of conserved grass and grass legume mixtures (%)
North America	68	58
Central & South America	64	54
Western Europe	75	71
Eastern Europe	70	65
Russian Federation	70	65
West Asia & North Africa	64	54
Sub Saharan Africa	64	54
South Asia	64	54
East Asia	64	54
Oceania	70	65

Source: Literature review

The digestibility and N content of the feed ingredients showed much less variation between countries and regions. The average values that have been used are provided in Table A2.6.

Data on concentrate use was gathered from National Inventory Reports for Annex 1 countries, and calculated for other countries. The relationship between concentrates and milk was estimated from National Inventory Reports, as follows:

Concentrates (%) = 0.0065 * (Milk yield – 3000).

The use of concentrate was assumed to be nil for systems where milk production is less than 3000 kg per cow per year. High concentrate use in relation to milk production (top left part of the Figure A2.2) is observed in the Mediterranean countries, and can be explained by feed shortages. The concentrate composition is estimated as shown in Table A2.7.

Table A2.6. Estimated average digestibility and N content of feed ingredients used in the assessment

Feed component	Digestibility (%)	N content (g/kg)
Whole plant silage grains	59	19
Whole plant silage maize	75	14
Rice straw	43	6
Wheat straw	45	6
Barley straw	46	7
Maize stover	55	10
Millet stover	40	8
Sorghum stover	49	6
Sugarcane tops	61	8
Leaves from trees	68	22
Fodder beet	80	13
Grains (wheat, barley)	86	21
Corn (maize)	92	16
Soy meal	93	79
Rapeseed meal	75	63
Cottonseed meal	78	74
Palm kernel expeller	67	27
Maize gluten meal	92	106
Maize gluten feed	82	39
Beet pulp	81	16
Molasses (beet and cane)	80	11
Grain by-products dry (brans)	73	18
Grain by-products wet (brewers grains)	78	38

Source: Literature review

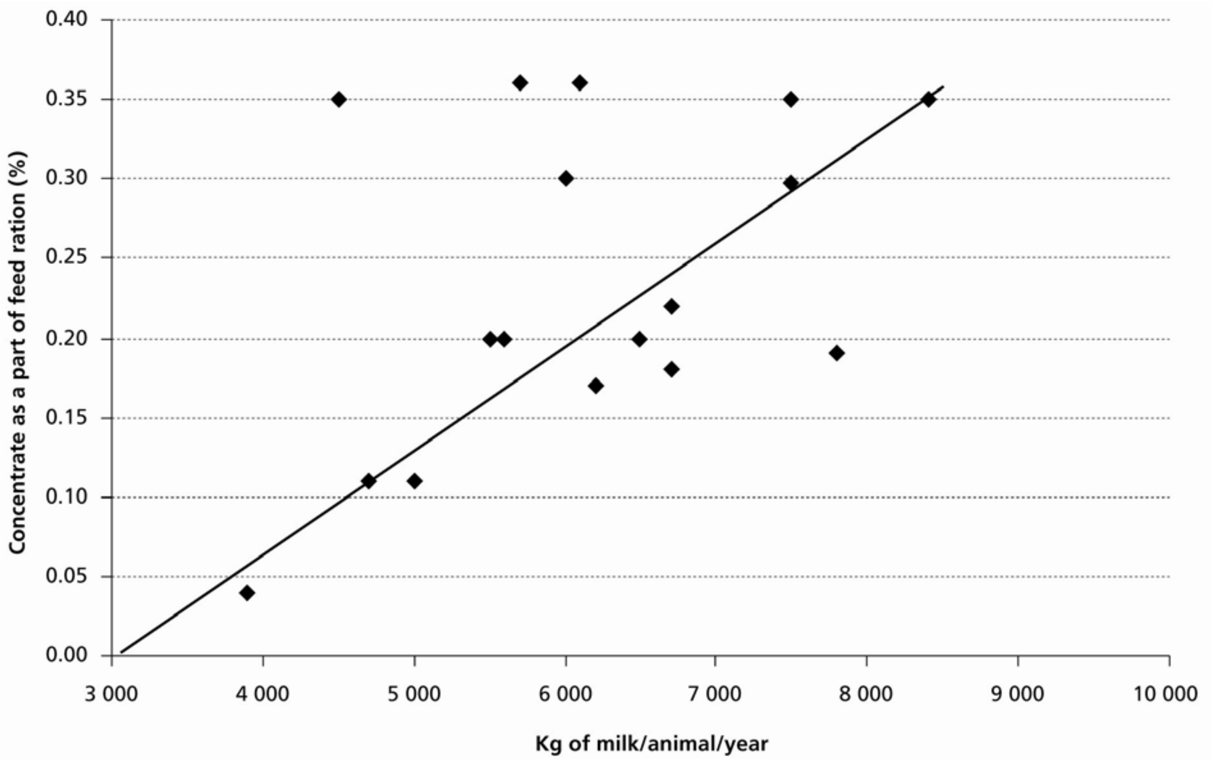


Figure A2.2. Relationship between concentrate feed use and milk production

Table A2.7. Estimated concentrate feed composition, by FAO region.

Component	Europe	Asia	Africa	Central and South America	North America	Oceania
Grains	40	50	50	50	30	90
Maize	20	20	20	20	20	0
Grain by products	2	5	5	5	15	0
Soy meal	13	10	10	10	5	5
Rape meal	13	0	0	0	15	0
Cottonseed meal	0	10	10	10	10	5
Maize gluten meal	12	5	5	5	5	0

Source: Literature review and own calculations

Crop management

Estimates of energy use for crop production, including tillage, harvesting, processing and transport is based on databases available for Sweden (Flysjö et al. 2008) and the Netherlands (de Boer, personal communication).

A key determinant of energy use is the level of mechanization. Four classes of mechanization have been assumed on a country level: 10 percent, 40 percent, 70 percent and 100 percent (expressed in percentage of the crop area cultivated with machinery). We assumed that draught animals were only used in mixed farming systems. From the level of mechanization, we calculated reliance on animal draught power in the country. A lower level of mechanisation means a higher fraction of (draught) bulls and oxen in the herd.

Mechanization levels were estimated to be 100 percent in Europe, North America, Japan, South Korea, Australia and New Zealand. In other countries, the mechanization level was estimated on the basis of two indicators available from FAOSTAT: the number of tractors used in agriculture and the labor per 1000 USD of Gross Agricultural Production (GAP). When the tractor to land ratio is less than 1 to 1000 ha, we assumed a 10% mechanization, in other situations where the ratio is between 1 and 5, a 40 percent of mechanization is assumed, and between 5 and 10 a 70% of mechanization is assumed. For values higher than 10, we assumed a full level mechanisation. When the amount of labour per 100 000 USD of GAP was lower than 0.1 person, the mechanization was adjusted one level higher than we assumed on the basis of the tractor to land ratio, to create a more plausible labour to capital ratio.

Based on this, the mechanization level in many countries in sub-Saharan Africa was estimated at 10 percent. In South and South East Asia the mechanization levels ranged from 10 to 70 percent, while the industrialized countries in Asia were set at 100%. Table A2.8 gives an indication of the average level of mechanization per region. From the level of mechanization, we also inferred reliance on animal draught power in the country, and therefore the bull to cow ratio in the herd

Table A2.8. Estimated average level of mechanization by region

Continent	Estimated rate of mechanisation (%)
Africa	16
Asia	78
Central and South America	96
Europe	100
North America	100
Oceania	100

Source: FAOSTAT, 2009

Chemical fertilizer use also affects emissions intensities through crop yields, and through carbon dioxide and nitrous oxide from fertilizer production and application. Data on crop fertilization are available for a limited number of countries and crops (FAO FERTIstat, 2009). Where available, these data were used to refine statistics on fertilizer consumption at country level. Unless more accurate information was found, it was assumed that no chemical N fertilizer is applied to grasslands in Central and South America, Africa and Asia.

Table A2.9. Average N application for all agricultural land, by continent and region, 2007

Region	Average fertilizer Nitrogen Use (kg/ha/year)
North America	32
Central & South America	21
Western Europe	71
Eastern Europe	46
Russian Federation	46
West Asia & North Africa	35*
Sub Saharan Africa	3
South Asia	47
East Asia	52
Oceania	15

Note: * West Asia 65, North Africa 4
Source: FAOSTAT, 2009

The quantity of N applied through manure was estimated by multiplying animal numbers by standard levels of Nitrogen excretion obtained from IPCC guidelines.

Annex 3: Post-Farm Gate Emissions

Post farm gate emissions estimated in this study, include emissions related to milk transport and processing, to distribution, and to the production of packaging. This annex presents the underlying data and data sources, used in the estimation of post-farm emissions. In this assessment, emissions related to the post-farm gate activities are reported as per kg of milk equivalent at the farm-gate, and not per kilogram of processed product.

Energy Consumption

Energy consumption is the most important source of GHG emissions from the post-farm gate supply chain. Table A3.1 below summarizes the regional CO_2 emission coefficients used in this assessment. The types of energy sources used in the different regions were obtained from the International Energy Agency (IEA, 2009). Regional variations in CO_2 emissions are explained by the differences in primary energy sources, used to generate electricity and heat. For example, the high CO_2 emissions per MJ from electricity and heat generation in Asia and China, are explained by the dominant use of coal as a source of energy (contributing 80% of total energy supply). In contrast, the low CO_2 emissions in Latin America are explained by the prevalent use of hydro power, which contributes to about 70% of the energy supplies within the region.

Table A3.1. Regional specific CO_2 emissions per MJ from electricity and heat generation, 2007

Region	gCO_2/MJ
Europe	99
North America	142
Pacific	139
Russia	90
Latin America	54
Asia (excluding China)	202
China	216
Africa	175

Source: IEA, 2009

The data on CO_2 emissions from electricity and heat generation given in Table A3.1 were combined with data on average energy use for processing of the different dairy products and production of packaging obtained from literature.

Emissions related to processing

Greenhouse gas emissions related to the processing of dairy products, were calculated based on reported data values obtained from various studies. Energy during the processing phase is used for a number of processes, e.g. running electric motors on processing equipment, for creating steam for heating processes, evaporating and drying, for cooling and refrigeration and for generating compressed air. Average energy use per kg of product for milk and yoghurt products, was based on studies from Norway and Sweden (Hogass, 2002; Berlin et al., 2006); for cheese, information was taken from Berlin et al. (2001) and Berlin (2008); for whey it was based on Berlin (2001; 2002); for milk powder it was based on data from Ramirez et al (2006); and for butter information on energy uses came from Masoni et al. (1998). Table A3.2 below presents average energy values for processing of dairy products used in this study, expressed per kg of product and per kg of raw milk.

Table A3.2. Average energy use in the processing of dairy products

Product	MJ/kg of product	MJ/kg of raw milk
Milk	0.56	0.53
Yoghurt	2.2	2.04
Cheese	7.7	0.77
Whey	0.019	0.02
Skim milk powder	10	0.93
Whole milk powder	10	1.21

According to the average energy use for processing, and the proportions of different products, a total energy use for the processing of a kg of raw milk is calculated.

Emissions from transportation and distribution

In defining the post-farm stages of the milk value-chain, a distinction is made between transportation from the *farm to dairy processor* and *distribution from the processor to the retail sector*.

The primary source of GHG emissions in both stages is from fuel combustion, however, distribution to the retail sector also includes the use of refrigerants such as hydro fluorocarbons (HFC), which are considered to be a powerful greenhouse gas (for example, the potency of HFC/HCFC refrigerants ranges from 400 – 12,000 times the potency of carbon dioxide).

Transport from farm to dairy

GHG emissions from transport between the farm and dairy processors mainly arise from fuel combustion. Consequently, emissions depend on the relative locations of the producer and the processor (i.e. distance travelled) as well as vehicle efficiency. Data on greenhouse gas emissions from milk transport from the farm to the dairy processor was obtained from 8 studies (Arla, 1999; Nicol, 2004; Stadig et al., 2007; Defra, 2007; Cashman, 2009; Hogaas, 2002; Hospido et al., 2003; Berlin et al., 2006) on six OECD countries (Australia, Norway, Spain, Sweden, UK and USA). Table A3.3 presents the average values for energy use and GHG emissions for transport from the farm to the processor, as well as the upper and lower values (variations) obtained from the literature reviewed.

Table A3.3. Estimated energy use and GHG emissions from transport from farm to dairy in OECD countries

	Average	**Variation**
Energy use, MJ/kg milk	0.22	0.09-0.36
GHG emissions, g CO_2/kg milk	16	8-40

Distribution from dairy to retail point

Total emissions from the distribution of dairy products from processors to retail locations were calculated for consumer milk, cheese, butter and milk powder, by combining data on transport mode, fuel consumption, total distance, emissions per distance, and emissions per unit of time for the cooling system. The transportation modes that were considered included both road and ocean transport. Major emissions during this stage relate to fuel combustion and refrigeration during transport, as well as leakage of refrigerates from the cooling systems.

Consumer milk, cheese and butter

Emissions related to the transportation of fresh milk are not significant compared to other dairy products, because the transportation distances in fresh milk systems are often not very long. Average values on energy use per kg of milk was obtained from a literature survey based on 6 countries (USA, Australia, Brazil, UK, Norway and Sweden) based on 8 studies by Berlin et al., 2006; LRF, 2002; Arla, 1999; Nicol, 2004; Defra, 2007; Cashman et al., 2009; Hogaas, 2002; and Mourad et al., 2008. For cheese and butter data values used were taken from Berlin et al., 2008; Burton et al., 2000; Nicol, 2004 and Masoni, 1998. Results from the reviewed literature are presented in Table A.3.4.

Table A3.4. Energy use and GHG emissions for distribution of milk, cheese and butter – from literature reviewed for this assessment

	Average	Variation
Consumer milk		
Energy use, MJ/kg milk	0.45	0.03-2.3
GHG emissions, g CO_2/kg milk	20	2.6-41
Cheese		
Energy use, MJ/kg cheese	3.7	0.058-0.87
GHG emissions, g CO_2/kg cheese	159	-
Butter		-
Energy use, MJ/kg milk	1.67	
GHG emissions, g CO_2/butter	No data in literature	-

Energy demand for different transportation distances for consumer milk, cheese and butter was calculated based on distance, average speed of transport, average GHG emissions emitted during the transport process (taken from EcoInvent 2.0 database), and greenhouse gas emission related to cooling and leakage of refrigerants (based on data from Thermoking). Table A3.5 provides CO_2 emissions calculated for the distribution of consumer milk, cheese and butter for different distances.

Table A3.5. CO_2 emissions from the distribution of consumer milk, cheese and butter for different distances

	g CO_2/kg milk
Consumer milk	
25 km	4.5
50 km	10
100 km	17
Cheese and butter	g CO_2/kg cheese and butter
100 km	20
500 km	28
1 000 km	43

Milk Powder

A literature review has been carried out to collect data for the transport of milk powder. As Milk powder is globally traded, the transport is always a combination of land and water transport. The standard CO_2 emissions for the different transport modes are given in Table A3.6.

Table A3.6. GHG emissions per unit of product transported by transport mode – from literature reviewed for this assessment

	CO_2 / tonne/ km	Distance (km)	g CO_2 / kg product
Lorry, Rural, general conditions	71.0	250	17.7
Lorry, Rural to Wholesale	88.7	500	44.4
Lorry, Rural to Retail	124.2	100	12.4
Container ship, Small (305 TEU) 17 knots	30.6	-	43.78
Container ship, Large (2000 TEU) 23 knots	20	-	29.07

Source: Swedish Institute of Food and Technology, Göteborg, Sweden

In addition to the CO_2 emissions, estimates have been made of:

- Globally traded quantities of milk powder on the basis of trade-flows (FAOSTAT, 2009)
- Distances between major ports (source and destination) and distances from ports to major cities

The following assumptions were made regarding transportation mode utilized and the distances:

- International transport was modelled with two types of container ships (350 TEU and 2000 TEU) depending on delivery distance.
- Distances from Industry to Port were considered to be short, based on western European conditions. Either 100 km with an empty return or 300 km if new container is loaded at port. Thus, a total distance of 250 km was used in model.
- Transportation from Port to Wholesale was considered to cover longer rural distances with a 25% increase in fuel required. As the general model uses a modern Norwegian lorry, and many of the importing countries are considered have less efficient vehicles, the transportation distance is set to 500 km, with one day of travel time required.
- Wholesale to retail transport is also modelled as rural road transport, with a 25% increase in fuel required. Cargo capacity utilization is set to 50% for distribution transports with multiple stops per cargo haul. Distance is set to 100 km covering a larger city area were largest part of the population lives.

Table A3.7 provides the average values that have been used for this study, based on the average transport distances. Table A3.8 presents GHG emissions, per kg of product, for some specific transport routes.

Table A3.7. Global simulations of the nautical distances and related road distances for skimmed and whole milk powder

	Nautical calculations (g CO_2/kg milk powder)	Road (g CO_2/kg milk powder)	TOTAL, (g CO_2/kg milk powder)
Skimmed milk powder	154	75	229
Whole milk powder	164	75	239

Table A3.8. CO_2-emissions from distribution of milk powder, based on simulations for different routes

Distance	Distribution, g CO_2/kg milk powder
Denmark-Kenya	460
New Zealand-Japan	270

Emissions from the production of packaging material

Cheese and butter

Data on the type of packaging and energy use for cheese and butter per kilogram of product were obtained from literature sources (Burton et al., 2000; Berlin et al., 2008; Berlin, 2002; Masoni et al., 1998) for cheese and butter. Package types assessed were aluminium foil and greaseproof paper for butter, and plastic for cheese. Table A3.7 presents data obtained from the literature survey on energy use and GHG emissions, for different packaging for cheese and butter. Average

GHG emissions per kg of milk, provided in Table A3.9, are combined with data on regional CO_2 emissions from electricity and energy generation from Table A3.1 above.

Table A3.9. Energy use and GHG emissions for packaging – from literature reviewed for this assessment

	Average	Variation
Cheese		
Energy use, MJ/kg milk	1.5	0.99-1.9
GHG emissions, g CO_2/kg milk	52	48-58
Butter		
Energy use, MJ/kg milk	2.1	-

Consumer Milk

Data on milk packaging types (material and size) for consumer milk was obtained from Tetra Pak. Despite the variation within the different regions, three major types of packaging are used (Table A3.10):

- Cartons: comprising of gable top (for chilled milk) and brick cartons (for ambient milk)[3]
- High density polyethylene (HDPE) bottles
- Plastic pillow pouch

Table A3.10. Share of regional milk packaging market for three major packaging types and total volume of milk consumed and packaged, 2008

	Total milk consumed	Total volume consumed, packaged	Carton rigid	HDPE	Plastic pillow pouch	Other packaging
	Million liters				%	
Central & South America	15 000	13 000	0.53	0.02	0.39	0.05
Former Soviet Union	10 000	5 000	0.36	0.01	0.54	0.09
China	7 000	7 000	0.39	0.05	0.37	0.19
USA, Canada and Mexico	29 000	29 000	0.24	0.68	0.07	0.01
Northeast Asia & Oceania	8 000	8 000	0.67	0.27	0.00	0.06
Sub-Saharan Africa	5 000	2 000	0.41	0.30	0.24	0.05
EU-27	34 000	32 000	0.65	0.23	0.02	0.10
Southern Asia, incl. Mediterranean Africa	78 000	19 000	0.22	0.03	0.72	0.03
TOTAL, WORLD	**186 000**	**114 000**				

Source: Tetra Pak, 2009

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[3] Ambient milk refers to heat processed milk that can be transported and stored at room temperature.

Life cycle stages included in the calculations of packaging include extraction of raw materials and production of packaging. However, waste handling of the packaging materials at the consumer phase is excluded. Emissions related to energy use during the production of packaging material and packaging was calculated from average regional GHG emissions from electricity and heat production (Table A3.1). In order to calculate the regional GHG emissions, the most frequently used packaging container was chosen to represent packaging in the region (Table A3.11).

Table A3.11. Average regional GHG emissions per main packaging type

Region	Packaging alternative	GHG emissions per packaging , g CO_2-eq per litre milk
Central & South America	Carton brick, 1 litre	56
Former Soviet Union	Plastic pillow pouch 1 litre	20
Greater China	Plastic pillow pouch, 0,25 litre	52
USA, Canada and Mexico	HDPE bottle, ½ gallon	91
Northeast Asia & Oceania	Carton gable top, 1 litre, chilled	38
Sub-Saharan Africa	Carton brick, 1 litre	63
EU-27	Carton brick, 1 litre	59
Southern Asia, incl. Mediterranean Africa	Plastic pillow pouch, 1 litre	23

Post-farm gate: Reference list

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Annex 4: Mitigation Options

Ideally, GHG mitigation strategies should consider all greenhouse gases, their specific formation processes, and the overall net effect of all GHG emissions, since efforts to mitigate GHG emissions at one point in the production chain may actually raise emissions at a later point.

Recent research has identified a wide range of mitigation options for reducing emissions from livestock sources. This section presents a summary of mitigation strategies for the three greenhouse gases considered in this assessment.

Methane

- **Dietary measures.** Quantity of methane produced is strongly influenced by the form, quality and composition of feed. Feeding strategies likely to lower methane emissions include:
    - *Altering and improving diet for higher animal productivity.* Feeding increased levels of starch, feeding supplementary dietary fat, and reducing the proportion of fibre in the diet are examples of potential methane reduction strategies. In the case of diet changes, one should be aware of possible trade-offs caused by land use change or by changes of the nitrogen content in the diet.
    - *Forage selection and management.* Increasing forage quality combined with the management of stocking rates and rotational grazing strategies have been demonstrated to reduce enteric methane emissions.
    - *Use of feed additives.* Additives can manipulate rumen microflora populations to induce a stable and modified rumen fermentation with lower emissions. Some of the additives are not permitted in the European Union, because they are considered medicine. Research on additives is still ongoing.

- **Herd management for increased animal productivity**. Management systems designed for high milk output per cow will tend to result in lower emissions per unit of milk produced. In contrast, more extensive systems require more animals to produce a given quantity of milk-- resulting in higher methane output per litre. The opportunities to reduce methane emissions by increased animal productivity are larger in the extensive systems compared to the intensive systems with already high milk production levels per cow.
- **Manure management and treatment.** Changes to manure handling practices including use of anaerobic digesters can improve energy efficiency as well as reduce methane output. Helpful manure-management techniques include frequent and complete removal

of manure from indoor storage, deep cooling of manure, and management of bedding and manure heaps to avoid anaerobic conditions.

Nitrous Oxide

The most important sources of nitrous oxide emissions on dairy farms are application of mineral and organic fertilizer as well as manure deposition and spreading by grazing stock.

Options to reduce nitrous oxide emissions from dairy systems include:

- *Dietary manipulation to increase efficiency.* Avoiding excess N in the diet and/or making dietary N more absorbable reduces N excretion.
- *Manure management techniques.* Methods such as anaerobic digestion indirectly reduce N_2O emissions when slurry is applied to land by decreasing the available N content. Increasing manure storage time and covering manure storage structures, also help.
- *Grazing management methods.* Reduced stocking and minimized grazing periods--which reduce compaction through grazing--increase soil aeration and are likely to result in lower emissions.
- *Manure application techniques to increase N use efficiency.* Optimizing methods and timing of applications using rapid incorporation; use of injection methods; use of chemical nitrification inhibitors, better N use from fertilizers and manure through synchronization of N release with plant growth are all options for lowering emissions.
- *Housing system and management*. Options for mitigating emissions include more frequent removal from housing floors, and changing housing systems. Animal housing and manure stores of straw-based systems result in higher N_2O emissions than anaerobic slurry-based systems.

Carbon dioxide

Carbon dioxide emissions are linked to energy and resource use. Major sources of carbon dioxide emissions from the dairy chain are related to land use and land-use change, energy use on the farm, and post-farm processing and distribution of milk and dairy products.

- *Increasing carbon storage*. Opportunities to increase carbon storage within dairy farming systems include:
  - agricultural intensification to reduce the land needed for production. This can decrease the rate of land-use change or halt this process at all;
  - restoring soil carbon by improving soil management techniques;
  - improved grassland management; and

  - Changing from highly intensive, short duration pastures to more permanent grasslands, as well as reduced tillage, can also increase carbon sequestration.

- *Increasing energy efficiency along the dairy food chain.* Energy efficiency can be improved in milking parlors and milk processing plants.

- *Digestion of manure to produce heat and electricity* will also contribute to lower fossil fuel energy use and CO_2 emissions.

- *Renewable energy* may have a large role to play on farms and in processing as well.

Individual mitigation measures must however be evaluated with regard to emission reduction potential, environmental trade-offs within and outside the livestock system, technical feasibility and specific costs.

It is important to underscore that the implementation of GHG mitigation measures requires not only technological development, but also economic incentives, and institutional frameworks that are adapted to the specific farm conditions and regions.

Annex 5: Regional and Country List

Central & South America

Anguilla
Antigua and Barbuda
Argentina
Aruba
Bahamas
Barbados
Belize
Bolivia
Brazil
British Virgin Islands
Cayman Islands
Chile
Colombia
Costa Rica
Cuba
Dominica
Dominican Republic
Ecuador
El Salvador
Falkland Islands (Malvinas)
French Guiana
Grenada
Guadeloupe
Guatemala
Guyana
Haiti
Honduras
Jamaica
Martinique
Mexico
Montserrat
Netherlands Antilles
Nicaragua
Panama
Paraguay
Peru
Puerto Rico
Saint Kitts and Nevis
Saint Lucia
Saint Vincent and the Grenadines
Suriname
Trinidad and Tobago
Turks and Caicos Islands
United States Virgin Islands
Uruguay
Venezuela

Sub-Saharan Africa

Angola
Benin
Botswana
Burkina Faso
Burundi
Cote d'Ivoire
Cameroon
Cape Verde
Central African Republic
Chad
Comoros
Congo
Democratic Republic of the Congo
Djibouti
Equatorial Guinea
Eritrea
Ethiopia
Gabon
Gambia
Ghana
Guinea
Guinea-Bissau
Kenya
Lesotho
Liberia
Madagascar
Malawi
Mali
Mauritania
Mauritius
Mayotte
Mozambique
Namibia
Niger
Nigeria
Rwanda
Reunion
Saint Helena
Sao Tome and Principe
Senegal
Seychelles
Sierra Leone
Somalia
South Africa
Swaziland
Togo
Uganda
United Republic of Tanzania
Zambia
Zimbabwe

West Asia & Northern Africa
Algeria
Armenia
Azerbaijan
Bahrain
Cyprus
Dhekelia and Akrotiri SBA
Egypt
Gaza Strip
Georgia
Hala'ib triangle
Ilemi triangle
Iraq
Israel
Jordan
Kazakhstan
Kuwait
Kyrgyzstan
Lebanon
Libyan Arab Jamahiriya
Ma'tan al-Sarra
Morocco
Oman
Qatar
Saudi Arabia
Sudan
Syrian Arab Republic
Tajikistan
Tunisia
Turkey
Turkmenistan
United Arab Emirates
Uzbekistan
West Bank
Western Sahara
Yemen

South Asia
Afghanistan
Bangladesh
Bhutan
British Indian Ocean Territory

Eastern Europe
Belarus
Bulgaria
Czech Republic
Hungary
Moldova, Republic of
Poland
Romania
Slovakia
Ukraine

Russian Federation
Russian Federation

East Asia
Aksai Chin
Arunashal Pradesh
Brunei Darussalam
Cambodia
China
China/India
Christmas Island
Dem People's Rep of Korea
Hong Kong
Indonesia
Jammu Kashmir
Japan
Kuril Islands
Lao People's Democratic Republic
Malaysia
Mongolia
Myanmar
Philippines
Republic of Korea
Singapore
Thailand
Timor-Leste
Viet Nam

Oceania
American Samoa
Australia
Cook Islands
Fiji
French Polynesia
Guam
Kiribati
Micronesia (Federated States of)
New Caledonia
New Zealand
Niue
Norfolk Island
Northern Mariana Islands
Palau
Papua New Guinea
Pitcairn
Saint Pierre et Miquelon
Samoa
Solomon Islands
Tokelau
Tonga
Vanuatu
Wallis and Futuna

Western Europe

Albania
Andorra
Austria
Belgium
Bosnia and Herzegovina
Croatia
Denmark
Estonia
Faroe Islands
Finland
France
Germany
Greece
Guernsey
Iceland
Ireland
Isle of Man
Italy
Jersey
Latvia
Liechtenstein
Lithuania
Luxembourg
Madeira Islands
Malta
Montenegro
Netherlands
Norway
Portugal
Republic of Serbia
San Marino
Slovenia
Spain
Svalbard and Jan Mayen Islands
Sweden
Switzerland
The former Yugoslav Republic of Macedonia
U.K. of Great Britain and Northern Ireland

North America

Bermuda
Canada
Greenland
United States of America