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A sustainable dairy sector

Global, regional and life cycle facts and figures on greenhouse-gas emissions

Report

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Summary

This report examines ‘facts and figures’ concerning climate impacts in the dairy sector, based on a literature review. Recent studies point to the relatively large share of meat and dairy products in the total environmental impact of our consumption. The context for dairy as a separate sector is provided by this report.

The focus is on carbon dioxide, methane and nitrous oxide emissions that together account for 98% of the total greenhouse-gas emissions. Globally, carbon dioxide emissions contribute most to the enhanced greenhouse effect, but in agriculture, methane and nitrous oxide are the most important greenhouse gases.

The conclusions in this summary are divided in four parts. First, the global on-farm dairy emissions are examined. Then, the global cradle-to-farm-gate emissions are estimated. The third part discusses the emissions per unit of milk. Finally, some recommendations are given.

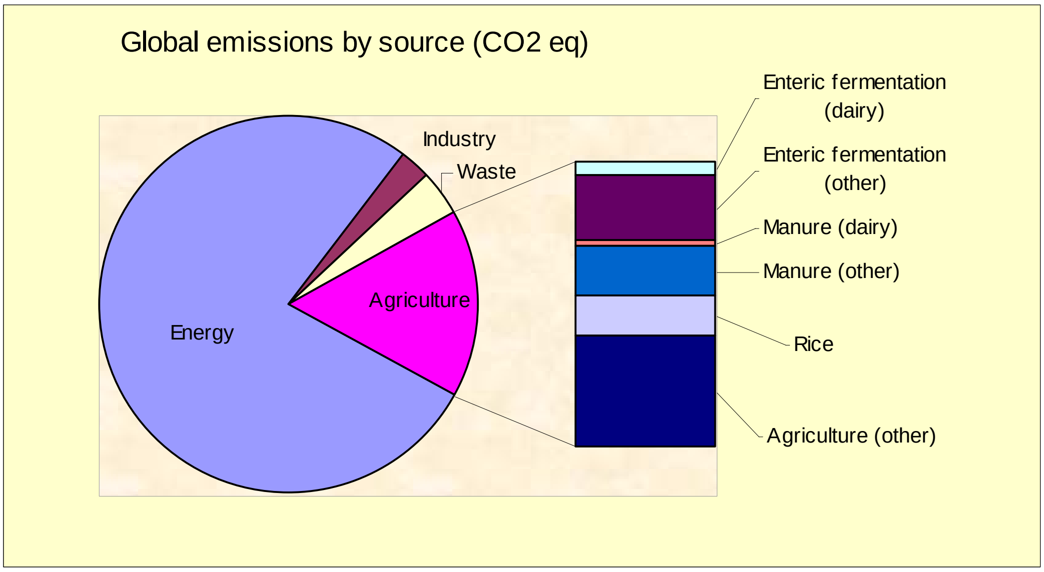
These major conclusions are summarized below.

On-farm emissions in a global context

Dairy livestock emissions contribute 1.2% to the total global greenhouse gas emissions

This study finds that 1.2% of global as well as Annex-1 emissions can be attributed to direct livestock emissions of dairy cattle. This compares to 2.2% for rice cultivation globally (year 2000) and about 1.3% for landfills (methane only). The figure does not include the greenhouse emissions from land use or management, such as savannah burning or drainage of pasture lands. A case study for the Netherlands shows that on-farm emissions would almost double when emissions from grassland are included, but such emissions are very region-specific.

Global greenhouse-gas emissions by source



On-farm methane emissions have decreased in Annex-I countries, but share of dairy sector remained stable

Methane emissions have decreased across the board for Annex-I countries. Between 1990 and 2005 emissions from enteric fermentation in dairy cattle lowered by 30% and emissions due to manure handling by 20%. As other sectors also lowered emissions, the share of dairy remained constant since 1990. Within EU-15, the share of livestock in methane emissions has even increased very slightly, as the shares of waste and natural gas production decreased more strongly. Globally, livestock emissions seem to level out after 1990, but are still significant. The emissions of dairy cattle have increased over the 20th century and probably contribute significantly to the total rise of methane livestock emissions, despite a much smaller relative growth of global production volumes.

Cradle-to-farm gate emissions

Cradle-to-farm gate emissions of milk contribute 3% to total global climate emissions

This study finds that 3% of global emissions can be attributed to the dairy life cycle up to the farm gate (still excluding post-farm and land use emissions). For Annex-I countries this share is 2-3%. These figures exclude the emissions of dairy processing and the consumer phase.

So while dairy livestock emissions contribute 1.2% to the global climate emissions, pre-farm associated with feed and other on-farm emissions contribute 1.8%.

Enteric fermentation is the main source of climate impact, but reducing these emissions leads to trade offs
The contribution of enteric fermentation is large and may be up to 50% of the total cradle-to-farm gate life cycle emissions when emissions of young animals are included.
This contribution may be reduced by lowering emissions from enteric fermentation or increasing milk yields, but this will lead to an increase in concentrates production, and therefore potentially higher overall CO_2 and N_2O emissions. It was found that countries with a high average enteric fermentation per unit milk have lower total effective emissions than countries with high milk yields per animal.

Per-unit emissions

Cradle-to-farm gate emissions are 0.8-1.4 kg CO_2-eq. per kg milk
Methane is the greenhouse gas that contributes most to the climate impact of milk, followed closely by nitrous oxide. Total emissions range from 0.8-1.4 kg CO_2 eq. per kg milk, varying between countries and farming systems. These results from 'bottom up' life cycle studies show that most assessments lead to consistent conclusions. It is hard to establish, however, what are the factors critical in determining the differences.

Post-farm emissions add 10-20% to cradle-to-farm gate emissions
Total life cycle emissions then effectively range from 0.9-1.8 kg CO_2 eq. per kg milk, still excluding household energy use such as cooling, but including product loss. The IMPRO study, that also includes household energy use, finds cradle-to-grave emissions of 2.4 kg CO_2 eq. per kg milk.

Recommendations

Consumer options may be effective in lowering climate impacts
Product losses as well as electricity consumption for cooling contribute significantly to the total life cycle impacts of milk. Consumer options such as energy-efficient refrigerators may lower the impacts by 1% according to the IMPRO study. Product loss could be as high as 10% for fresh milk. Halving that loss would lead to a 5% reduction in life cycle climate impact, without leading to trade-offs.

More consistent comparison of life cycle effects of farm-management practices necessary

Methodological and regional differences make it hard to compare results of different life cycle studies and determine the critical factors influencing the overall climate effect of dairy production. In order to make a solid comparison of different farm-management systems and properly establish the effects of trade-offs in the life cycle, ideally a series of consistent life cycle assessments with a large variation of parameters would need to be performed. This could be achieved by establishing general standards for performing milk life cycle assessments.

1 Background and introduction

1.1 Why this report?

The European Dairy Association (EDA) has recently established a new Sustainability Working Group (WG). This working group aims to develop a holistic approach with respect to sustainability issues for the sector. Improving environmental impacts is an important part of sustainable production and therefore it was decided to focus on 'facts and figures' concerning climate impacts in the dairy life cycle as a first step in the process. Both dairy producers and consumers need clear and objective information to raise awareness of these issues. A proactive position of the sector and active involvement in eco-efficient production are essential in a political climate that puts more and more emphasis on sustainable production and consumption.

Recent studies (e.g. EIPRO, 2006) for the European Commission point out the environmental impacts associated with (animal) food products amongst which dairy. It may be expected that these results will play a role in future product policy and eco-labelling. Other studies, such as 'Livestock's long shadow' (FAO, 2006) discuss the total impacts of animal husbandry in a global sense.

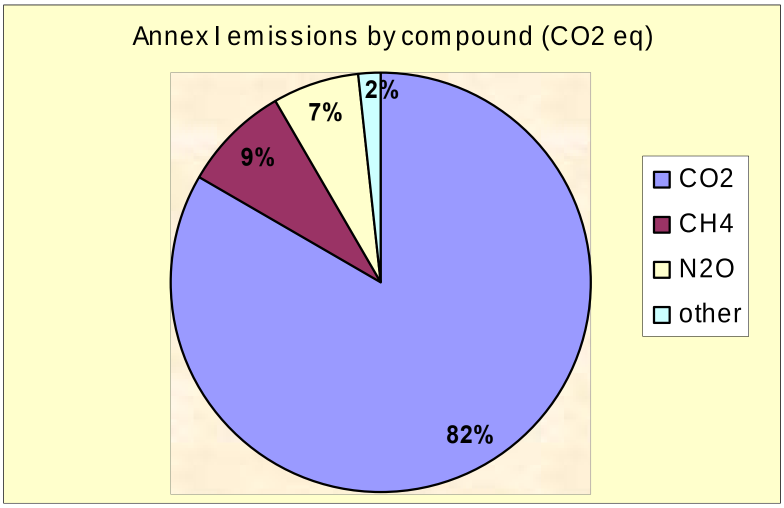
It is important to place such results in the proper context. What are the underlying assumptions that assertions are based on? What is the actual contribution of dairy compared to other animal husbandry sectors as well as compared to greenhouse-intensive sectors such as rice production, landfill of waste, transport, etc? How does the European dairy sector compare to dairy production in other regions? Are greenhouse-gas emissions of the dairy sector increasing?

1.2 Greenhouse gases

For the 'enhanced' greenhouse effect, the most important gases are CO_2, CH_4 and N_2O. Figure 1 below shows that emissions of these gases account for 98% of the total greenhouse-gas emissions emitted by Annex-I countries[1]. Other greenhouse gases are responsible for only 2% of the total emissions by Annex-I countries and are mostly attributable to a small number of specific industrial processes. The exclusion of these other greenhouse gases is therefore justified.

[1] Annex-1 countries are Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, UK, USA (see also Annex D).

Figure 1 Contributions of various greenhouse gases to total Annex-1 emissions



Source: UNFCCC, 2005.

The effect of the different greenhouse gases on global warming is expressed with the Global Warming Potential (GWP) of each gas. This is a measure for how effective the various greenhouse gases are in their impact on climate. The unit for this global warming potential is *CO_2 equivalents* because the effectiveness is expressed with respect to the effect of CO_2 itself.

Table 1 Global warming potential factors for the three main GHG (IPCC, 1996; time horizon 100 years)

Compound	*GWP factor in kg CO_2 equivalent per kg*
CO_2 (carbon dioxide)	1
CH_4 (methane)	21
N_2O (nitrous oxide)	310

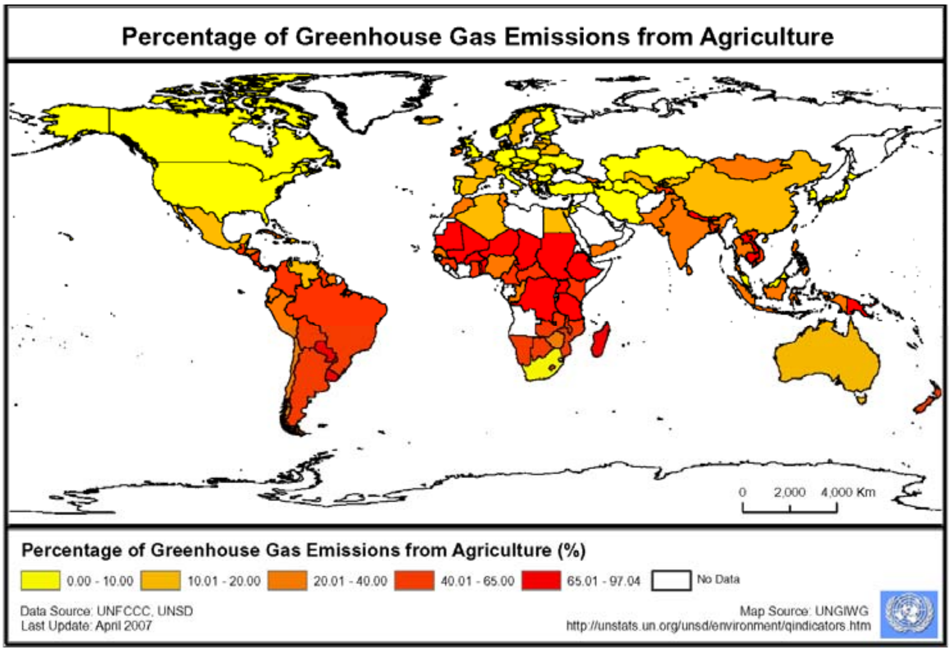
The GWP factors used in this report are taken from IPCC (1996). Although the scientific evidence in the later IPCC assessment reports (IPCC, 2001, 2007) suggests different GWP factors for methane and nitrous oxide, the original factors are still applied within the Kyoto protocol and in political context.

1.3 Climate emissions of agriculture and dairy

While globally, for all processes and activities in combination, carbon dioxide is responsible for 60% of the enhanced greenhouse effect and in Annex-1 countries for 82% (Figure 1), in agriculture methane and nitrous oxide are the most important greenhouse gases. This is also true for the dairy sector.

Figure 2 shows that the contribution of agricultural emissions to the total greenhouse emissions varies widely between countries. Agricultural activities are the largest contributors to climate effects in Africa, relative to other sources.

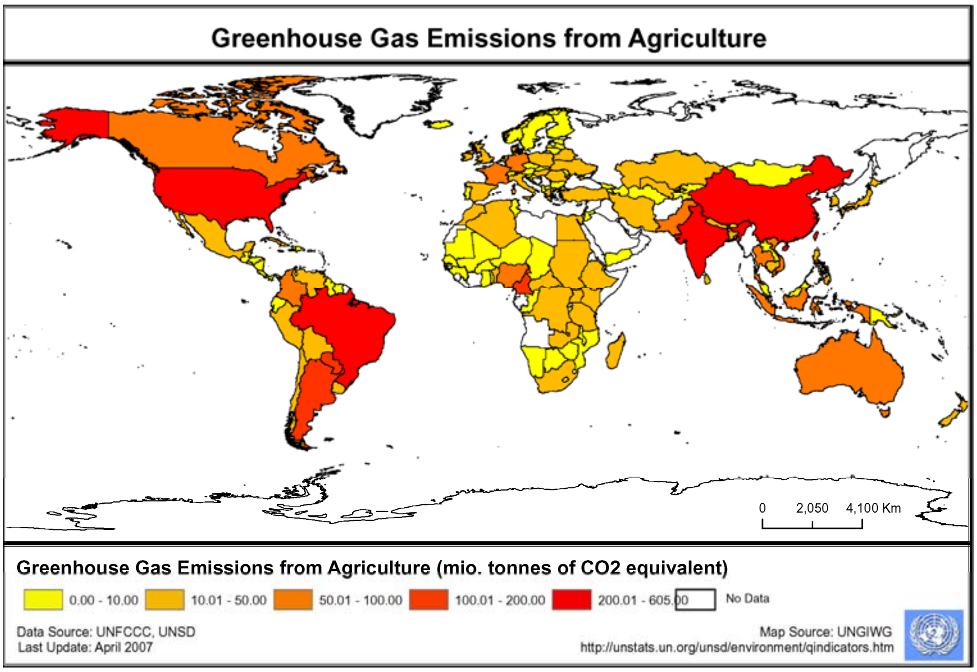
Figure 2 Relative contribution of agriculture to total GHG emissions per country



Source: UNSTATS.

In absolute terms, the largest contributors of agricultural greenhouse-gas emissions are China, India, USA and some South-American countries (Figure 3). Clearly, this is partly due to the fact that these countries have large populations.

Figure 3 Absolute contribution of agriculture by country



Source: UNSTATS.

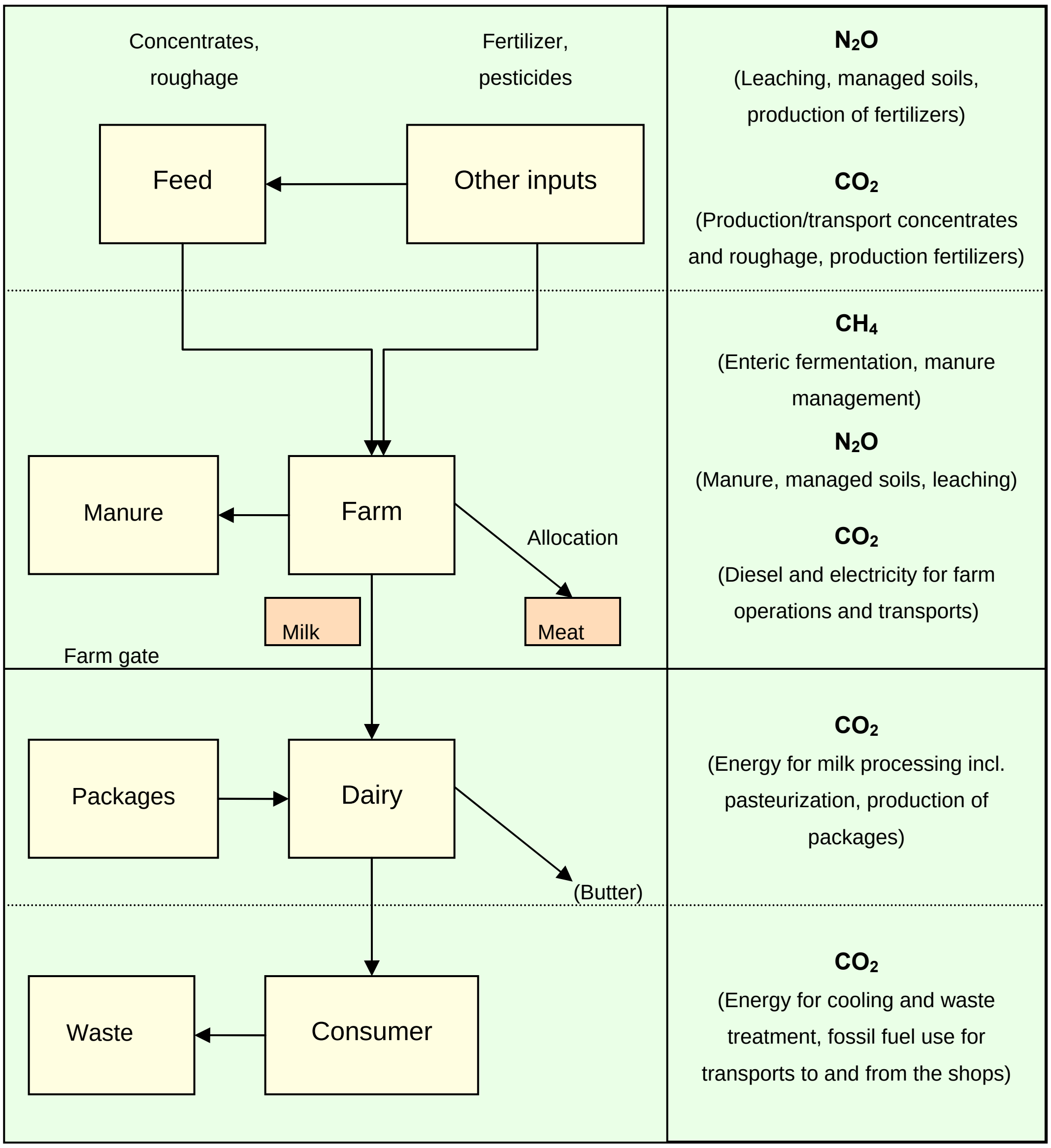
Although dairy comprises more than cattle milk alone, consistent and detailed data are available only for dairy cattle. Therefore, this report assesses cow dairy. According to the FAO production data, cow milk accounts for 84% of the total milk production globally (FAOSTAT). This means that the large majority of dairy production is covered in the climate figures presented. Dairy farming of goats, sheep, buffalo, et cetera, is comprised in the greenhouse emission data for total livestock.

All dairy production animals are ruminants. Methane is produced in a ruminant as a result of the microbial fermentation process in the rumen (enteric fermentation) and emitted by eructation. Production rate depends on the feed intake and digestibility. Methane is also produced from the anaerobic decomposition of the organic components in animal manure. Methane emissions from manure management depend on the way manure is stored and on the application technique. Nitrous oxide is emitted directly from manure management – liquid manure lowers nitrous oxide emissions – as well as manure deposition to soil.

Apart from these livestock emissions on-farm, nitrous oxide emission arise in the life cycle due to fertilizer application for fodder production. It is emitted indirectly from nitrogen lost through leaching, runoff or atmospheric deposition. Carbon dioxide emissions in the milk life cycle result from a variety of activities, ranging from the production and transport of fertilizers, cultivation and transport of concentrates to on-farm electricity and fossil fuel use. In national reporting frameworks, such as the UNFCCC framework discussed in Chapter 2, such emissions are not reported specifically for agriculture or even the dairy sector, but in the category ‘energy’ or ‘industry’. In full life cycle studies, these emissions are allocated to the production of dairy, however (Chapter 4).

Figure 4 shows a flowchart of the milk life cycle and the most important greenhouse-gas emissions at each stage.

Figure 4 Flowchart of the milk life cycle and associated greenhouse-gas emissions (for more details, see Chapter 4)



Furthermore, emissions from land use and land management practices such as burning can be related to animal husbandry. These are not typically included in life cycle assessments, but they are discussed to some extent in Chapter 2.

1.4 Overview of chapters

Chapter 2 gives quantitative data on the emissions of greenhouse gases and the contributions of different sectors (especially agriculture and the dairy sector), sources and compounds to the total. Trends in greenhouse-gas emissions are also given. Chapter 3 discusses methane emission factors from enteric fermentation and manure handling to show the variability in efficiency between countries and animal husbandry systems.

In Chapter 4, the life cycle emissions of milk are examined. Information from existing life cycle studies is used to determine the relative contributions of greenhouse gases and stages in the milk life cycle. Furthermore, the average greenhouse-gas emissions of different regions and farm management types are compared. Information from those chapters is combined in Chapter 5 to calculate total global emissions of the dairy chain and sector. Finally, in Chapter 6 the main conclusions are drawn.

2 Emissions : shares and trends

2.1 Introduction

This chapter gives quantitative data on the emission of greenhouse gases (GHG) and the contributions of different sectors, sources and compounds to the total. While carbon dioxide is the major source of climate effects over-all, in agriculture methane and nitrous oxide are the most important emissions and, vice-versa, agriculture is also the major source of methane and nitrous oxide. The contribution of the on-farm dairy emissions to total emissions is estimated to be 1.2%.

Emissions are either expressed in terms of weight (ton) or in terms of CO_2 equivalent weight (see Section 1.2). Focus is primarily on anthropogenic emissions. We make use of the most reliable data[2] for global and regional emissions:
- Global: EDGAR[3], for the year 2000 (EDGAR 32FT2000) and trends between 1890-1995 (EDGAR-HYDE 1.4). Differentiated by compound, emission source and 13 regions.
- Global: UNSTATS[4], data for each individual country for energy, industry, agriculture and waste, years vary. Uncertainties large, comparability low?
- Annex-I countries[5]: UNFCCC[6], for the years 1990-2005, by country, detailed emission source and country. Based on the National Inventory Reports under Kyoto protocol. These data include other GHG (see Section 1.2) for total emissions expressed in CO_2 equivalent weight.

Within the UNFCCC reporting framework, six main categories are distinguished that are also applied in most other data and studies:
- Energy; fuel use and production (cat.1).
- Industry; process emissions (cat.2).
- Solvent use (cat.3).
- Agriculture, including soil emissions, burning, livestock, etc. (cat.4).
- Land use, land use change and forestry (cat.5).
- Waste handling (cat.6).

The contributions of land use, land use change and forestry (LULUCF, cat.5) are not included in the general figures, as the net contribution in this category is negative for many countries and regions where carbon sink capacity is increasing. Also, reporting in category 5 is not obligatory and data are therefore likely to be incomplete. These emissions will be briefly discussed in Section 2.4, with special focus on natural sources of methane emissions.

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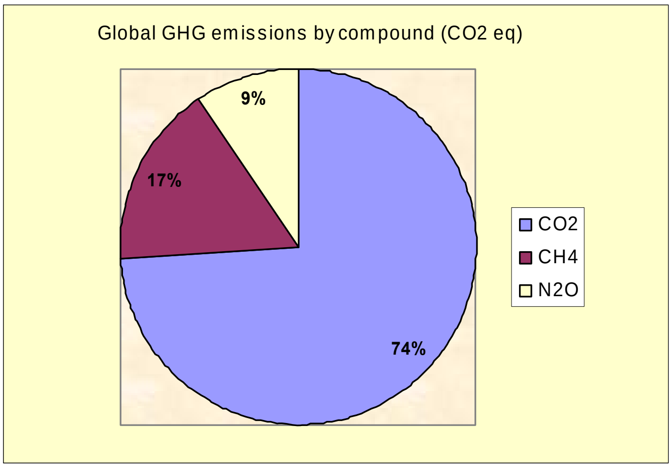
[2] For a discussion of uncertainties, see Annex A.
[3] http://www.mnp.nl/edgar/.
[4] http://unstats.un.org/unsd/default.htm.
[5] Listed in Annex D.
[6] http://unfccc.int/.

2.2 Total anthropogenic emissions

2.2.1 Shares by gas

By far the largest contribution to the total of greenhouse-gas emissions is that of carbon dioxide. Figure 5 only gives the global totals for the three main compounds, but as can be seen in Annex A.2, the combined contribution of all other gases is only of the order of 2% (Annex-I countries).

Figure 5 Contributions of CO_2, CH_4 and N_2O in CO_2 equivalent weight



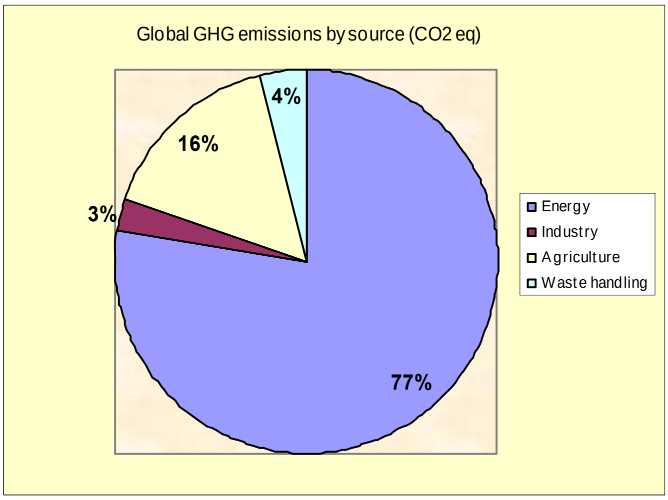
Source: EDGAR 32FT2000.

The share of methane and nitrous oxide is 17% and 9%, respectively. In Annex A.1, the same figure is given for GWP factors of the later IPCC assessment reports, showing that the contribution of methane may be somewhat higher than 17%. The contribution of N_2O is not significantly affected by the more recently determined scientific impact factors.

2.2.2 Shares by source

Of the six main categories of sources of GHG emissions, energy contributes by far the most to the total. On a global level, the second category is agriculture (Figure 6), while industry and waste together contribute only 7%.

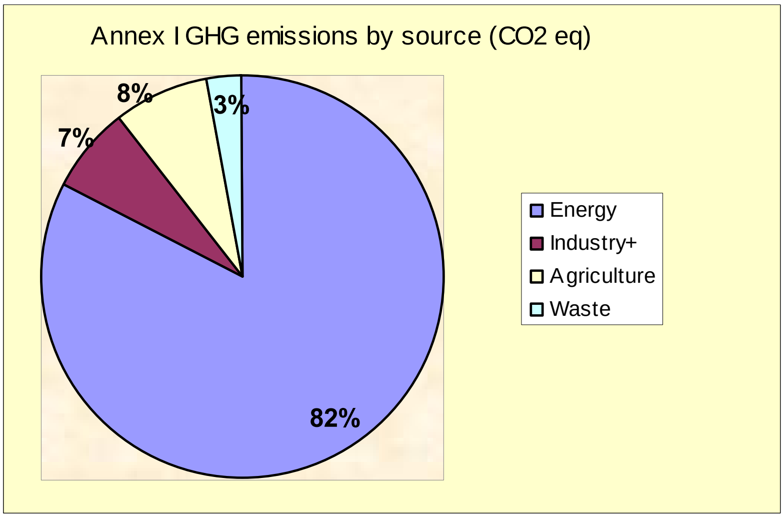
Figure 6 Shares in GHG emissions by top-level sector[7], year 2000



Source: EDGAR 32FT2000.

In Annex-I countries, the share of energy is even higher, but the share of agriculture is much lower than on a global level (Figure 7). The remaining categories of industry and waste account for 10% of the total for Annex-I countries.

Figure 7 Shares in GHG emissions by top-level sector[7], year 2005

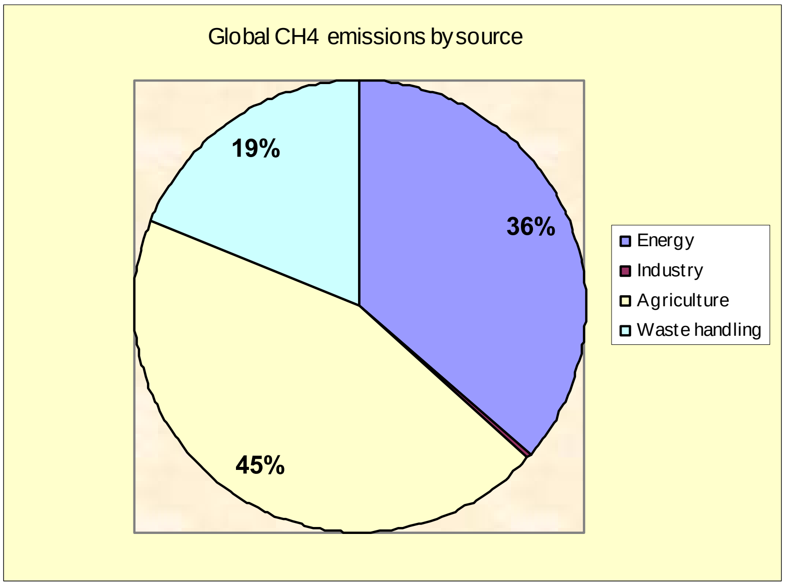


Source: UNFCCC.

Figure 8 and Figure 9 show the contributions to methane emissions separately. As already discussed before, agriculture is a major source of these emissions: 45% on a global level and 36% for Annex-I countries. Again, at the global level, the share of agriculture is higher than for Annex-I.

7 Solvents included in industry, LULUCF omitted.

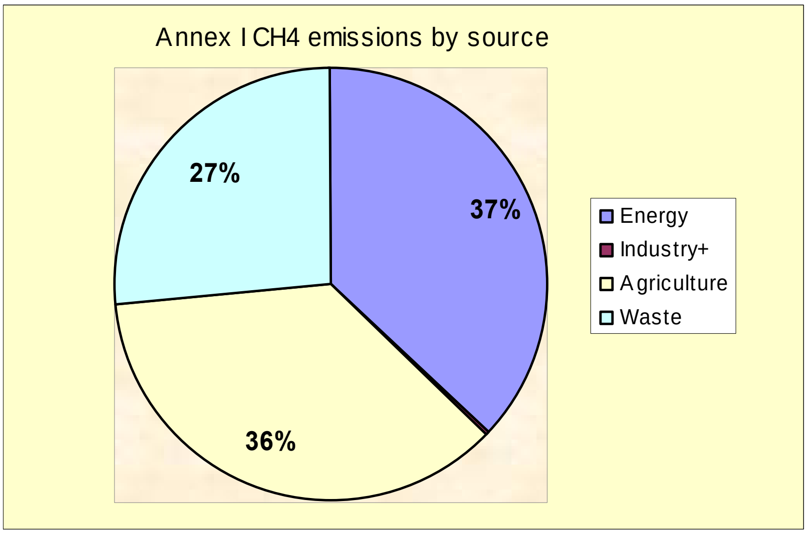
Figure 8 Shares in CH_4 emissions by top-level sector, year 2000



Source: EDGAR 32FT2000.

The share of waste handling (landfills et cetera), however, is considerably smaller at the global level.

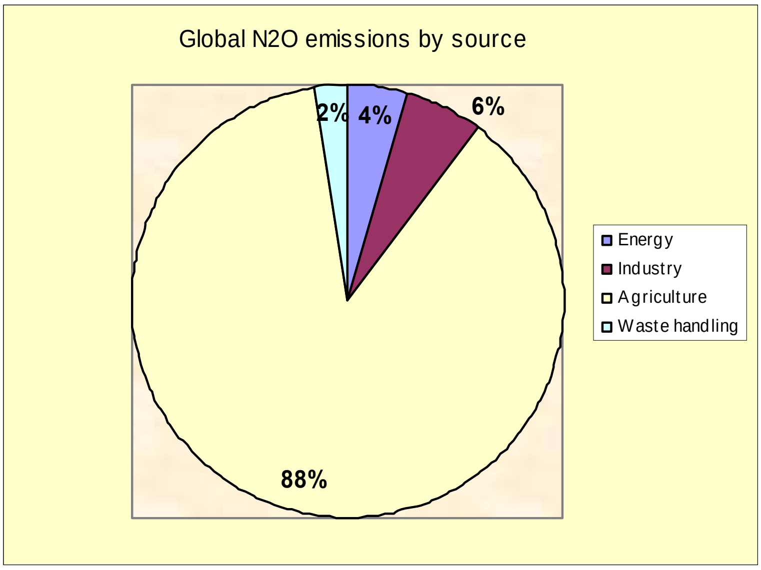
Figure 9 Shares in CH_4 emissions by top-level sector, year 2005



Source: UNFCCC.

For nitrous oxide, agricultural emissions dominate (Figure 10), with a second-largest contribution by industry of only 6%.

Figure 10 Shares in N_2O emissions by top-level sector, year 2000



Source: EDGAR 32FT2000.

Table 2 gives an overview of the contribution of agriculture to the various greenhouse-gas emissions on several levels of aggregation. For illustration, the shares are also given for New Zealand and Japan separately, as examples of countries with high and low contributions of agriculture, respectively.

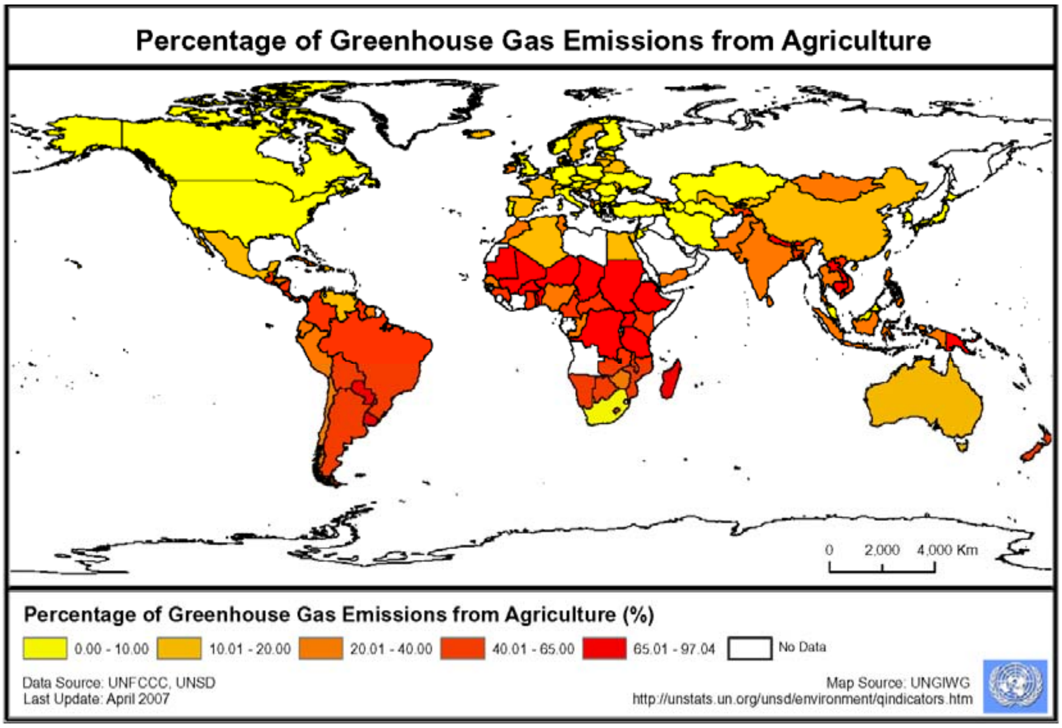
Table 2 Overview of contributions of agriculture to GHG emissions (excluding LULUCF)

	Total CO_2 eq.	Methane	Nitrous Oxide
Global	16%	45%	87%
Annex I	8%	36%	76%
EU-15	9%	54%	66%
Europe (other)	9%	31%	71%
New Zealand	49%	91%	96%
Japan	2%	64%	47%

2.3 Agriculture

The previous paragraph showed that in terms of contribution to the global greenhouse-gas emissions, the contribution of agriculture is 16%, but variations between countries are large (Figure 11). The agricultural sector is the main source of methane and nitrous oxide emissions. In this paragraph, the contributions of various sources within the agricultural sector are analysed in more detail.

Figure 11 Contribution of agriculture to total GHG emissions



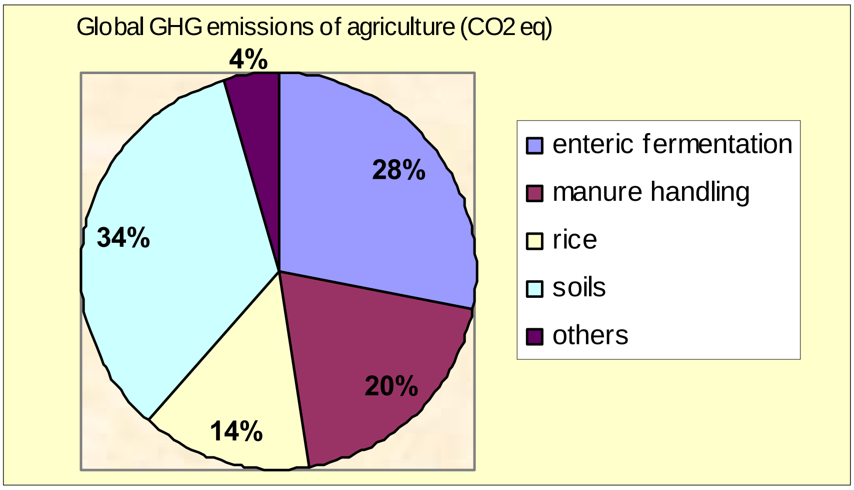
Source: UNSTATS.

In the presentation of the figures, the standard subcategories of the reporting framework of UNFCCC are used:

- Cat. 4A: enteric fermentation (CH_4).
- Cat. 4B: emissions of manure handling (CH_4, N_2O).
- Cat. 4C: emissions of rice cultivation (CH_4).
- Cat. 4D: agricultural soils, includes atmospheric deposition, etc. (N_2O).

The categories 4E (prescribed burning of savanna), 4F (field burning of agricultural residues) and 4G (other) are not reported separately here and the categories of the EDGAR database for global emissions were grouped to yield this same division in sources of emission.

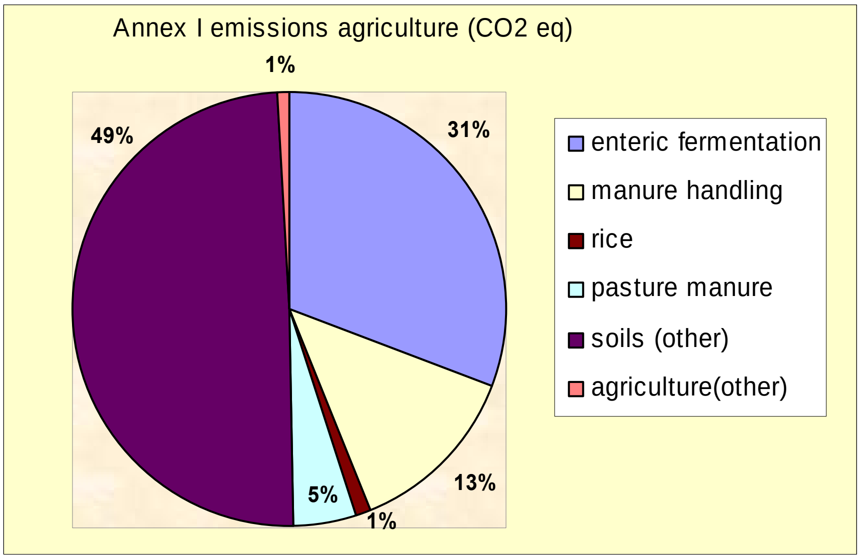
Figure 12 Shares in GHG emissions in agriculture, by source, year 2000



Source: EDGAR 32FT2000.

In the figure for Annex-1 countries (Figure 13), the category 'soils' (UNFCCC category 4D) is split into a contribution from Pasture, Range and Paddock Manure (cat. 4D2) and other soils. Along with enteric fermentation and manure handling, these pasture emissions may be attributed directly to livestock. Unfortunately, this split cannot easily be made for the global data.

Figure 13 Shares in GHG emissions in agriculture, by source, year 2005



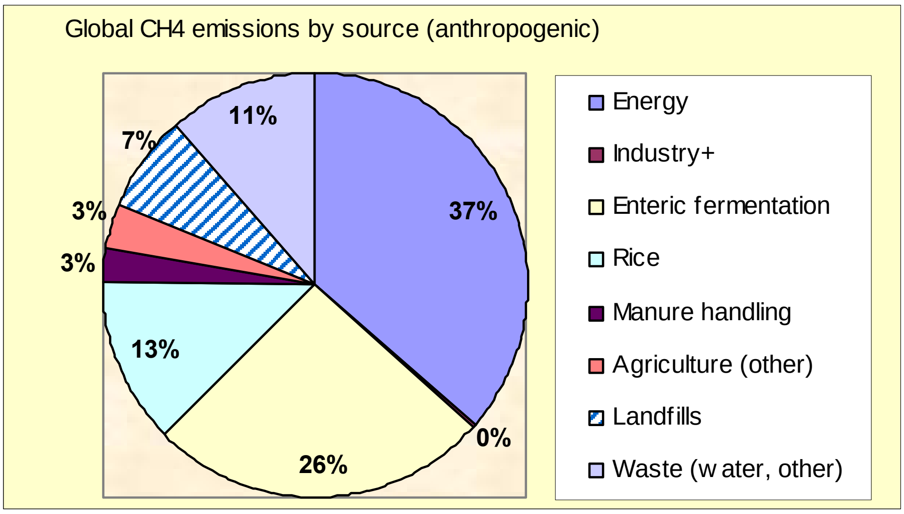
Source: UNFCCC.

Livestock contributes approximately half of the agricultural greenhouse-gas emissions. In the next few subparagraphs those livestock emissions are discussed in more detail.

2.3.1 Enteric fermentation and manure handling

Enteric fermentation is the source of approximately 30% of agricultural greenhouse-gas emissions, both globally and for Annex-I countries, as shown in Figure 12 and Figure 13. Given the total contribution of agriculture of 16% globally, this means a contribution of approximately 4.5% by enteric fermentation in terms of effective greenhouse gases. In terms of anthropogenic methane emissions, the share of enteric fermentation is 26% (Figure 14). Manure handling contributes about 3% to global methane emissions.

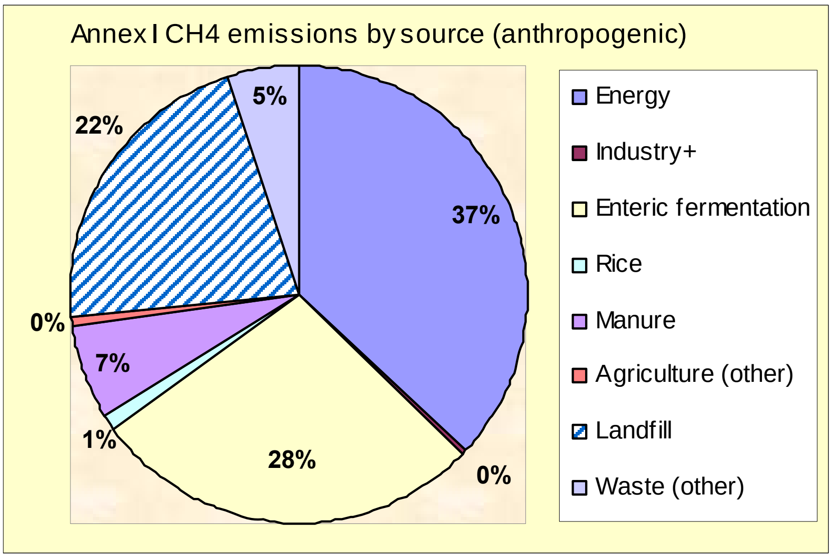
Figure 14 Contributions to total methane emissions, year 2000



Source: EDGAR 32FT2000.

For Annex-1 countries, the share of enteric fermentation and manure handling in methane emissions is somewhat higher with 28% and 7%, respectively (Figure 15).

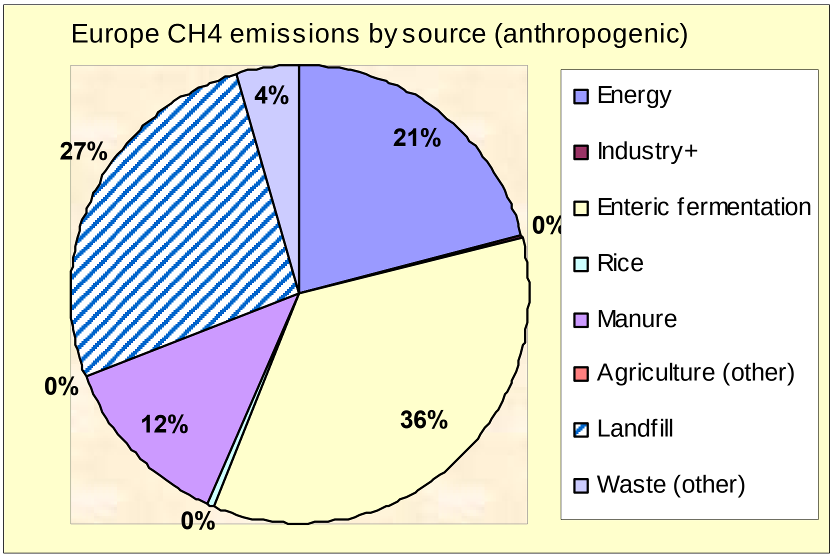
Figure 15 Contributions to total methane emissions, year 2005



Source: UNFCCC.

For European countries, the shares increase to 36% and 12% for enteric fermentation and manure handling, respectively (Figure 16).

Figure 16 Contributions to European methane emissions, year 2005



Source: UNFCCC.

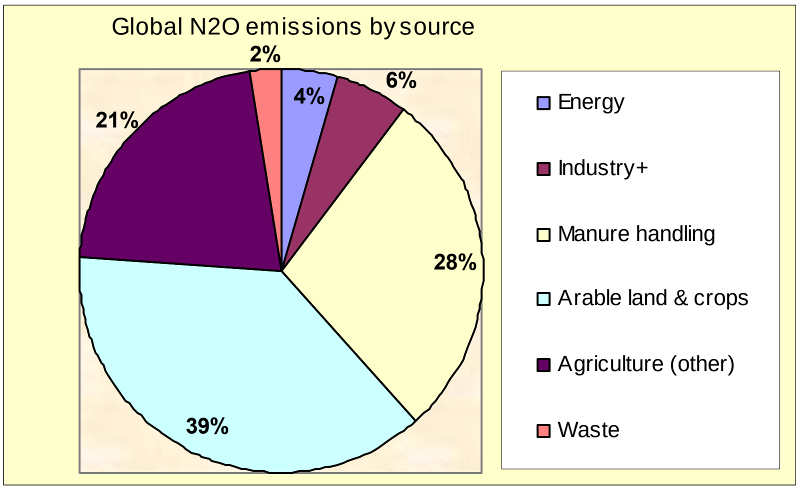
Dairy cattle
Of Annex-I countries, the share of enteric fermentation emissions reported for dairy cattle is 31.3% (year 2005). That means that 8.7% of anthropogenic methane emissions[8] stem from enteric fermentation by dairy cattle. For Europe, this percentage is 12.6%. Dairy cattle in this context means exclusively lactating or calving cows and excludes calves and young animals not yet productive. Globally, the share of dairy cattle in enteric fermentation emissions is 18% according to FAO (2006).

Methane emission factors for different types of production animals are discussed in Chapter 3.

Emissions arising from manure[9] concern both methane and nitrous oxide. Methane emissions (see Figure 14 to Figure 16) arise in anaerobic conditions. Thus, emissions are typically lower in less intensive animal-husbandry systems as will be discussed further in Chapter 3. Note that CO_2 emissions from burning dung would be reported under the category 'energy' within the UNFCCC system and are thus not part of the livestock emissions.

Nitrous oxide emission factors also depend on a number of parameters, such as the N-excretion rate (yielding a kg N per animal) and the type of manure management system (yielding a kg N_2O per kg N). According to the UNFCCC framework, these emissions are reported at the level of manure-handling system, not per animal type. Therefore we cannot directly attribute part of the manure-handling N_2O emissions to dairy cattle. The total of N_2O from manure handling contributes 28% to the global emissions (Figure 17). For Annex-I countries, this contribution is only 7% (UNFCCC, 2005).

Figure 17 Contributions to total nitrous oxide emissions, year 2000



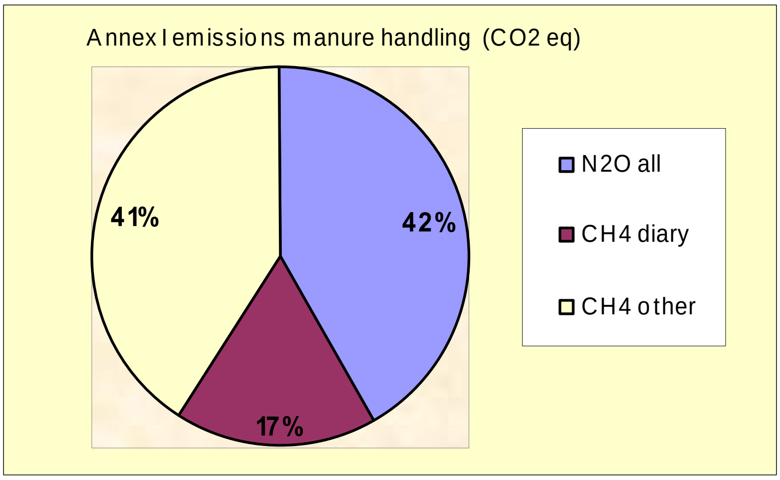
Source: EDGAR 32FT2000.

8 Still excluding LULUCF emissions, see Section 2.4.
9 Indicates combination of dung and urine.

For the total of this category (4B), we have to add the methane and the nitrous oxide emissions. As nitrous oxide is a very powerful greenhouse gas with a global warming potential of 310 (see Section 1.2), its contribution to the greenhouse-gas emissions of manure handling is significant: 42% versus 58% for methane.

Dairy cattle
The contribution of methane manure emissions of dairy cattle to this category is 17.3% (Annex I) to 10% (Europe). Globally, the contribution is 18% according to FAO (2006). Nitrous oxide emission factors for different types of production animals are discussed in Chapter 3.

Figure 18 Contributions to manure handling, category 4B, year 2005



Source: UNFCCC.

2.3.2 Pasture, range and paddock manure

The category 'manure handling' does not include emissions from manure that is produced by animals that are grazing in paddocks and pastures. Compared to enteric fermentation and manure handling, the emissions in this category are relatively small (Table 3). The contribution consists almost entirely of nitrous oxide emissions.

Table 3 Greenhouse-gas emissions of livestock categories for Annex-I countries

Source (UNFCCC subcat)	Mton CO_2 eq.	
Enteric fermentation (4A)	432.8	64%
Manure handling (4B)	182.6	27%
Pasture manure (4D2)	65.0	10%
		100%

Source: UNFCCC, 2005.

The reporting framework does not differentiate this category by animal type. For some individual countries, such as the Netherlands, these emissions may be almost entirely attributed to the dairy life cycle, as the use of pasture land for beef cattle or sheep is relatively small. On average, however, the allocation to dairy is probably much lower. According to FAO (2006), the allocation to dairy cattle of all N_2O emissions from manure is only 11% globally.

2.3.3 Dairy sector estimates

Summarizing the results of the previous sections, we arrive at the following overview. Of the different UNFCCC reporting categories, three sources of emissions can be attributed directly to animal husbandry and more in particular the dairy sector. For those three sources, we list the contribution of dairy for Annex-1 countries and for Europe as well as globally (Table 4). The percentages allocated to dairy are based on the UNFCCC reporting for methane emissions from enteric fermentation and manure handling. Emissions of nitrous oxide from manure handling cannot be directly allocated to animal type. Therefore, we estimate the share of dairy in pasture manure based on life cycle data for N_2O versus CH_4 (see Section 5.2, Vergé et al., 2007). The global shares are taken from FAO (2006).

Table 4 Share of dairy in contributions of sources to GHG emissions

	Mton CO_2 eq.	% for dairy	Mton CO_2 eq. dairy	Share of dairy in agriculture emissions	Share of dairy in total emissions
Annex I					
Enteric fermentation	432.8	31.3%	135.6	9.7%	0.8%
Manure handling (CH_4)	106.7	29.6%	31.6	2.3%	0.2%
Manure handling (N_2O)	76.0	*28%* [(a)]	21.3	1.5%	0.1%
Pasture manure (N_2O)	65.0	*28%* [(a)]	18.2	1.3%	0.1%
Total				**14.7%**	**1.2%**
Europe					
Enteric fermentation	148.1	35.8%	53.0	11%	1.3%
Manure handling (CH_4)	52.5	16.4%	8.6	1.8%	0.2%
Manure handling (N_2O)	33.1	*18%* [(a)]	6.0	1.2%	0.1%
Pasture manure (N_2O)	26.4	*18%* [(a)]	4.7	1.0%	0.1%
Total				**15.2%**	**1.7%**
World					
Enteric fermentation	1680.5	*18%* [(b)]	308	5.1%	0.8%
Manure handling (CH_4)	177.6	*18%* [(b)]	31	0.5%	0.1%
Manure total (N_2O)	1001.0	*11%* [(b)]	111	1.8%	0.3%
Total				**7.5%**	**1.2%**

(a) Assumption based on life cycle data, see Section 5.2.
(b) Taken from FAO (2006).

With a milk production of 338 Mton for Annex-1 countries and 157 Mton for Europe (FAOSTAT) these figures lead to a specific emission of 0.61 and 0.46 kg CO_2 eq. per kg of milk, respectively. For the world, a production of 491 Mton (for the year 2000, FAOSTAT) leads to an emission of 0.92 kg CO_2 eq. per kg of milk.

For comparison, Livestock's Long Shadow (FAO, 2006) finds a contribution of 521 million ton CO_2 eq. for dairy cattle, from enteric fermentation and manure handling, for 2004. This yields a climate effect of 0.99 kg CO_2 eq. per kg milk (production 528 Mton milk).

This concerns only the dairy-cow-related, on-farm emissions and does not include other life cycle emissions related to the production of concentrates or the post-farm emissions that are discussed in Chapter 4.

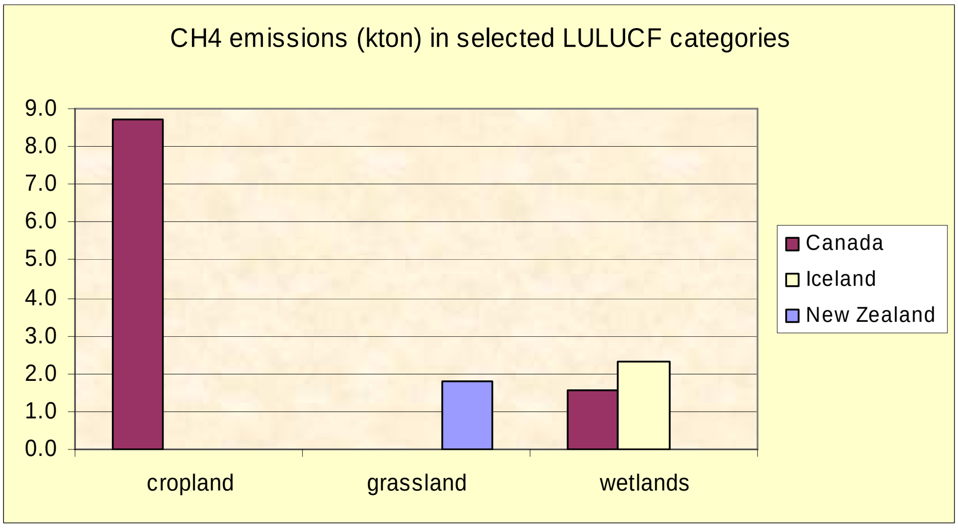
2.4 LULUCF emissions

In the figures and discussions in this Chapter so far, the emissions from land use, land use change and forestry (LULUCF, cat. 5) have been left out. Reporting in this category is not mandatory and therefore data are incomplete. Moreover, net emissions may be negative as biomass and soil carbon stocks are growing in many countries ('carbon sinks'). Indeed, the total net (reported) emissions for all of the Annex-1 countries in this category amount to -1.3 Gton CO_2 equivalent (UNFCCC).

2.4.1 Natural sources of methane annex 1

The LULUCF category covers both anthropogenic and natural sources of emissions, such as fires, wetland methane formation and other sources not directly related to the carbon balance. The UNFCCC data are very patchy, however. Figure 19 shows some of these emissions for a small number of Annex-I countries. Methane emissions from forests (category 5A) are left out, as they dominate this category for most countries, e.g. Canada and the USA, due to forest fires. Iceland, on the other hand, reports a significant emission only from wetlands (category 5D) and New Zealand from grasslands (category 5C).

Figure 19 Methane emissions from land use, land use change and forestry for selected categories and countries



Source: UNFCCC, 2005.

In total, an emission of 1.1 kton CH_4 is reported by Annex-1 countries in the category LULUCF, which is negligible with respect to the totals for energy, industry, agriculture or waste. This is not necessarily the case at the global scale, however, as we discuss in the subparagraph below.

2.4.2 Natural sources of methane globally

At a global level, estimates show that methane emissions from wetlands may constitute some 25-40% of the total methane emissions or up to 260 Mton (Walter et al., 2001a). In Table 5, we show some existing estimates. For comparison of variability between sources, we include the estimates for some anthropogenic sources from the current study.

Table 5 Natural and anthropogenic sources of methane

	Top-down	Bottom-up	This study	IPCC
	Hein et al., 1997	*Houweling et al., 1999*	*EDGAR, year 2000*	*Watson et al., 2000*
Animals	90	98	88.5	
Rice	69	80	39.2	
Wetlands	232	145		55-150
Landfills	40	48	23.1	
Biomass burning	41	40		
Fossil sources	103	89		
Other sources		58		
Total anthropogenic			321	
Total	575	558		

For error estimates of top-down and bottom-up assessment, please refer to Walter et al., 2001b.

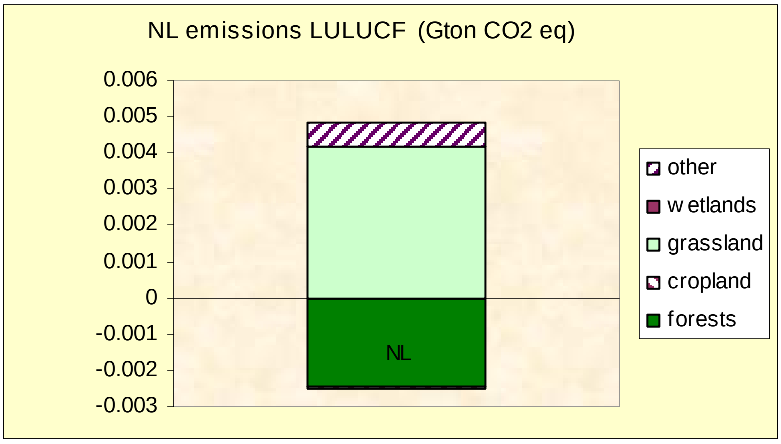
While anthropogenic emissions may have decreased since the earlier estimates, the emission from wetlands is very variable with climate conditions and therefore between years. Walter et al. (2001b) estimate that a $1^{o}C$ change in temperature may lead to 20% change in wetland emission (higher temperature is higher emission). Also, a 20% change in precipitation alters the emissions by about 8% (higher precipitation is higher emission). The former relation leads to a positive feedback in the climate system, with wetland methane emissions rising as the temperature is rising.

2.4.3 Case study: grassland in the Netherlands

In Section 2.3.3, greenhouse-gas emissions of land use, land-use change and forestry (LULUCF) have been left out of the discussion, as these categories may in fact be net sinks. Nevertheless, emissions from grassland may be partly attributed to the dairy life cycle. The same is true for emissions from cropland, that are indirectly related to the dairy sector through the use of concentrates. As LULUCF emissions are very variable between countries and not consistently reported within the UNFCCC framework, we assess the situation in the Netherlands as a case study.

Figure 20 shows that emissions from grassland dominate the LULUCF category for the Netherlands. The net emission is about twice as large as the net sink capacity of the forests and the main source of the emissions is drainage of peat soils (Maas, 2008), an obviously common activity in the Netherlands.

Figure 20 Reported LULUCF emissions for the Netherlands in 2005



Source: UNFCCC.

The emissions can be considered inherent to water-management systems that have been in place for centuries. Nevertheless, they arise largely in areas that are used for dairy production, so might be allocated to dairy, although this is not often done (in LCA studies, these emissions are not typically taken into account, see Chapter 4). If we were to allocate the emissions to dairy entirely, they would almost double the total of enteric fermentation, methane from manure handling and pasture and paddock manure (Table 6).

Table 6 Share of dairy in contributions of sources to GHG emissions

	Mton CO_2 eq. dairy	Share of dairy in agriculture emissions	Share of dairy in total emissions (excl. lulucf)
Netherlands			
Enteric fermentation [(a)]	3.9	21%	1.8%
Manure handling (methane) [(a)]	1.1	6%	0.5%
Manure handling N_2O (18%)	0.1	1%	0.1%
Pasture manure (100%)	0.7	4%	0.3%
Total		**32%**	**2.7%**
Grassland (5C, 100%)	4.2		

(a) Derived from emissions factors and number of cattle, see also Annex A.

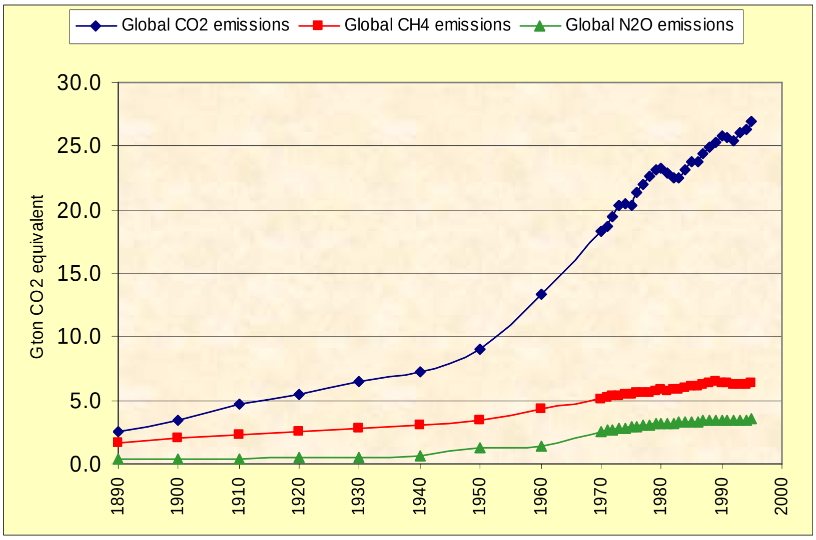
With a production of 10.5 Mton of milk (FAOSTAT), the 'livestock' emission factor for the first three categories only would amount to 0.55 kg CO_2 eq. per kg milk. Including the grassland emissions, we arrive at 0.95 kg CO_2 eq. per kg milk.

For other countries, such as France and UK, the reported net emissions for grasslands are negative. This is primarily due to amounts of land ‘converted to grassland’; the net emission for land ‘remaining grassland’ is slightly on the positive. Despite the fact that grass as a biomaterial extracts carbon dioxide from the atmosphere in the photosynthesis process, this carbon storage is not long term. In most Annex-1 countries, the net emission per hectare, if reported, is zero or slightly higher.

2.5 Trends

Fairly accurate global emission trends are available for a period spanning more than 100 years from 1890 to 1995. It is interesting to note that it is especially the contribution of CO_2 itself that has increased by an order of magnitude (Figure 21). At the end of the 19th century, the contribution of methane was almost equivalent to that of CO_2, but the emission of methane has less than quadrupled since.

Figure 21 Total global GHG emissions[10] between 1890 and 1995



Source: EDGAR-HYDE 1.4.

[10] Including LULUCF emissions from fires.

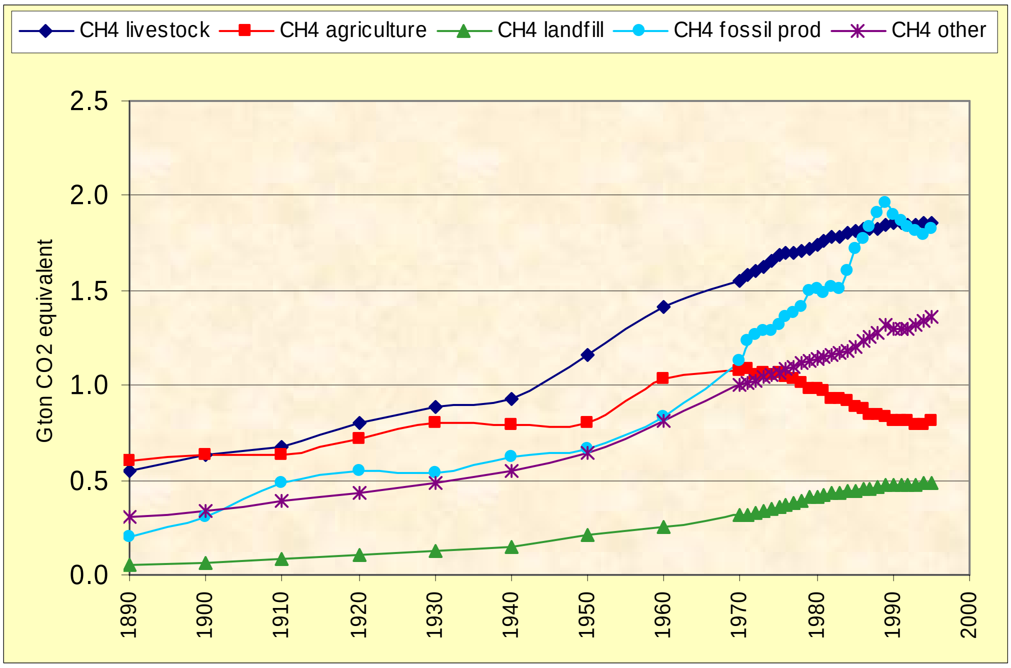
Atmospheric concentrations
As the life time of greenhouse gases is finite, their atmospheric concentrations do not rise as fast as emissions accumulate. Since pre-industrial times, atmospheric concentrations had changed in 2005 by the following amounts (IPCC, 2007):

Carbon dioxide: 280 to 379 parts per million (+35%), growth rate increasing.
Methane: 715 tot 1.774 parts per billion (+148%), growth rate declining.
Nitrous oxide: 270 to 319 parts per billion (+18%), growth rate constant.

So, despite a more than tenfold increase of CO_2 and N_2O emissions, concentrations have only increased by 35% and 18%, respectively. The methane concentration changed by a factor of 2.5, while emissions increased by a factor of 3.7, which is of a similar order of magnitude. Increased uptake of CO_2 by biosphere and oceans is one of the mechanisms that slows the growth of the atmospheric concentration for CO_2 (negative feedback), while methane concentrations may grow more quickly due to increased emissions from e.g. wetlands (positive feedback). Also, microbial agents for methane uptake from the atmosphere are easily disturbed, by several land-use practices including deforestation, and may be less efficient than possible (Jacinthe and Lal, 2005). For nitrous oxide, uptake mechanisms are even more complex.

The increase of methane emissions is mostly due to livestock and fossil fuel production, although it is clear that the emissions from landfill have also increased significantly (Figure 22).

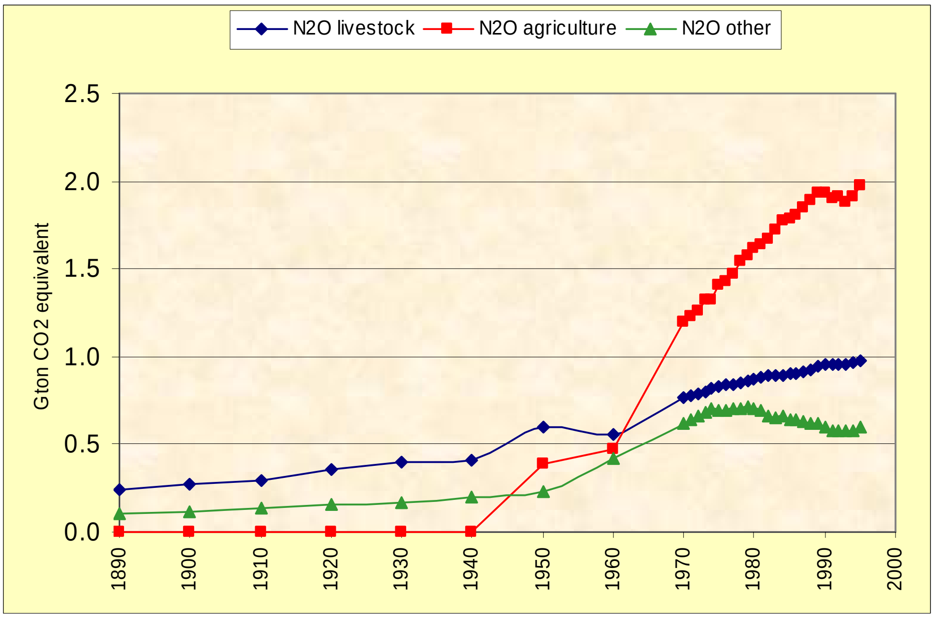
Figure 22 Total global CH_4 emissions for livestock, agriculture (other), landfill and fossil fuel production, between 1890 and 1995



Source: EDGAR-HYDE 1.4.

The increase in N_2O emissions is primarily due to crop fertilization (Figure 23).

Figure 23 Total global N_2O emissions for livestock and agriculture (other) between 1890 and 1995



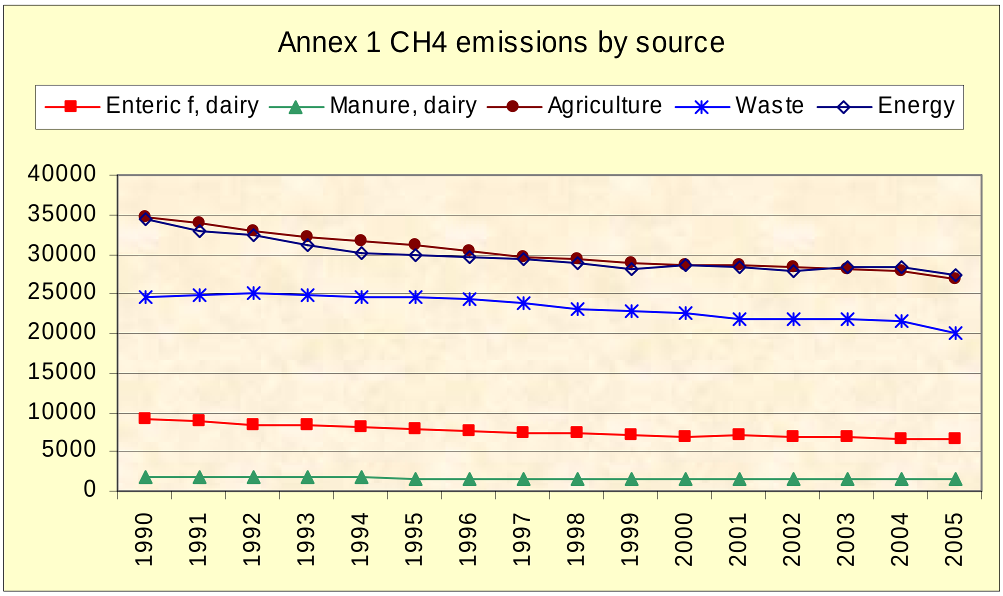
Source: EDGAR-HYDE 1.4.

It is of course interesting to relate those trends for livestock emissions to trends in production of animal products. Since approximately 1960, it is especially meat production that has increased globally. For instance, pig numbers have increased by almost one billion between 1960 and 2005, while dairy cattle number only rose by 67 million (FAOSTAT). Nevertheless, as emission factors are much higher for dairy cattle (see Chapter 3), those 67 million extra cows will have contributed a relatively high amount to the rise in methane emissions. For the increased nitrous oxide emissions, the contribution of meat production is probably higher.

2.5.1 Recent trends

For Annex-1 countries, the annual reporting framework provides detailed data covering the period between 1990 and 2005. Figure 24 shows that methane emissions have decreased across the board for Annex-1 countries. Emissions due to enteric fermentation in dairy cattle have lowered by 30% and emissions due to manure handling for dairy cattle by 20%.

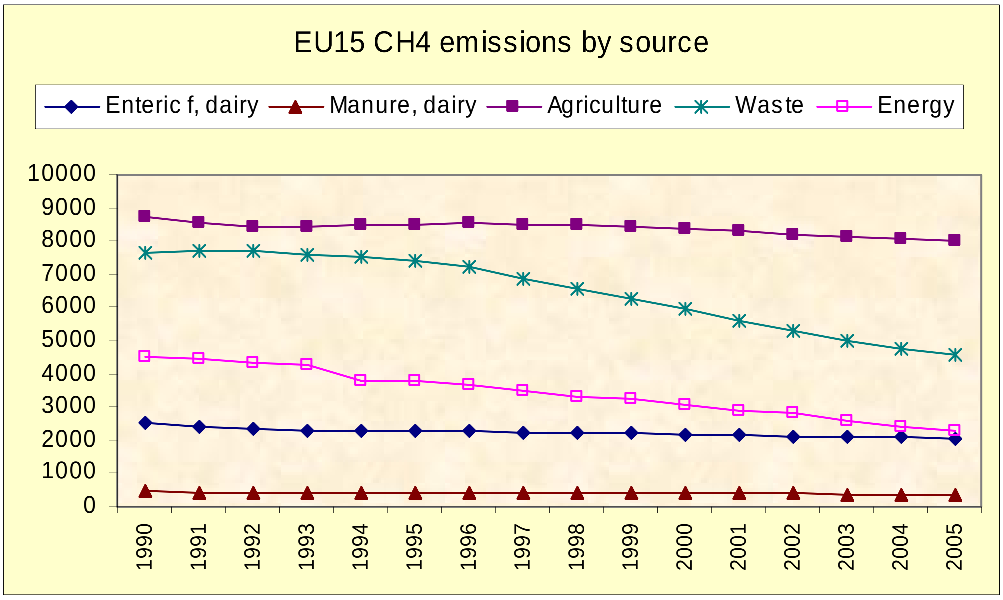
Figure 24 Trends in Annex-1 methane emissions between 1990 and 2005



Source: UNFCCC.

For the EU-15, the decrease is stronger for methane emissions from waste handling and energy production (primarily natural gas).

Figure 25 Trends in EU-15 methane emissions between 1990 and 2005



Source: UNFCCC.

2.6 Concluding remarks

Livestock-related emissions from dairy animal husbandry account for approximately 1.2% of total greenhouse-gas emissions[11] in Annex-I countries as well as globally. The share of dairy in anthropogenic methane emissions alone is considerably larger, approximately 11% for Annex-1 countries. At the global level, 18% of methane emissions from enteric fermentation may be attributed to dairy (FAO, 2006), making its contribution less than half that of rice production.

Land use and land-use change emissions may play an important role in the overall emissions of dairy and other livestock sectors. These contributions depend very much on local circumstances, however, and are therefore not easily taken into account at the global level.

Global livestock emissions have increased significantly in the 20th century. For methane emissions, probably approximately half of the increase is due to increased dairy production (cattle as well as others). Trends in emissions show that dairy emissions within Annex-1 countries have decreased significantly since 1990. In the EU-15, however, emission reductions lag behind those for energy (natural gas production) and waste (landfills). At the global level, livestock methane and nitrous oxide emissions seem to level out between 1990 and 1995.

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[11] Excluding land use, land use change and forestry.

3 Methane emission factors

3.1 Introduction

In this Chapter, we assess in more detail the two important categories of greenhouse-gas emissions from livestock: enteric fermentation and manure handling. While Chapter 2 looked at total emissions per year, here we relate these emissions to number of animals and annual production of milk, thus arriving at a measure of climate efficiency for a certain unit of productivity.

Emission factors (EF) per animal are reported within the UNFCCC framework for Annex-1 countries. The annual production of milk for each country is taken from the statistical databases of the FAO[12]. Based on these data, variations between countries of a factor of 1.5 to 2 are found in the emission factors for enteric fermentation. There is no apparent relationship between the EF per animal and the EF per kg milk, but there is a tendency for countries with a high EF per animal to have a low EF per kg milk.

For manure handling (methane), the EF per kg milk differs by more than a factor of 15 between Annex-1 countries and the EF per animal by a factor of 20. These emission factors depend very strongly on manure management system.

3.2 Enteric fermentation

All animals emit methane as a result of digestive processes, but for ruminants, enteric fermentation yields very large amounts of methane. In Table 7, emission factors per animal are shown for a variety of species. Clearly, dairy cattle rank highest in terms of EF per animal.

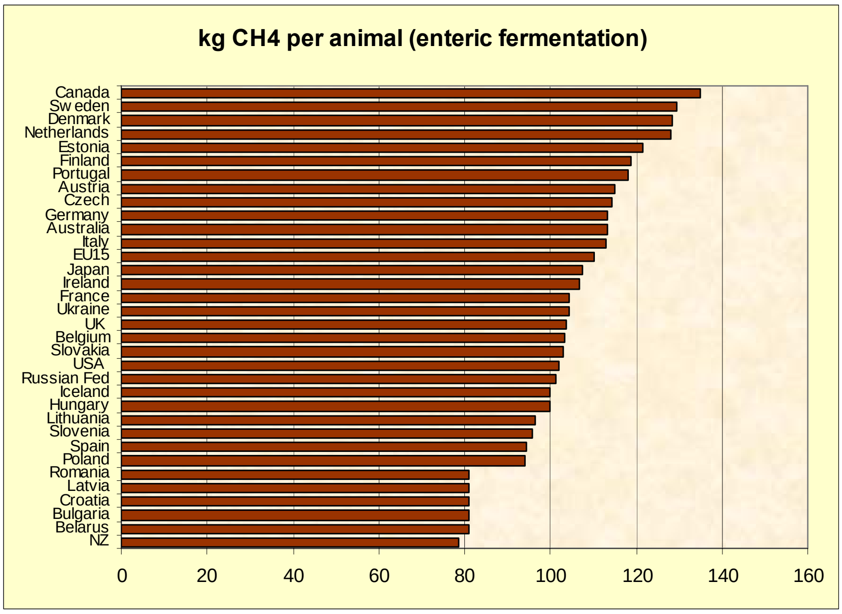
Table 7 Livestock contributing to methane emissions via enteric fermentation, emission factors in kg per head per year

	Developed countries	Developing countries	Source
Dairy cattle	79-135		NIR[13] Annex-I countries
Other cattle	39-82		Idem
Buffalo	55	55	Tier 1, IPCC 2006
Sheep	8	5	Idem
Goats	5	5	Idem
Camels	46	46	Idem
Horses	18	18	Idem
Mules and asses	10	10	Idem
Deer	20	20	Idem
Alpaca	8	8	Idem
Swine	1.5	1	Idem

12 Food and Agriculture Organization, UN, http://faostat.fao.org/.
13 National Inventory Reports, UNFCCC.

The EF for enteric fermentation depends on diet and Figure 26 shows a clear variation with high factors for relatively intensive systems (Canada, Scandinavia, Netherlands[14]) and low factors for extensive systems (New Zealand, Eastern Europe).

Figure 26 Emission factor per animal for Annex-I countries, 2005

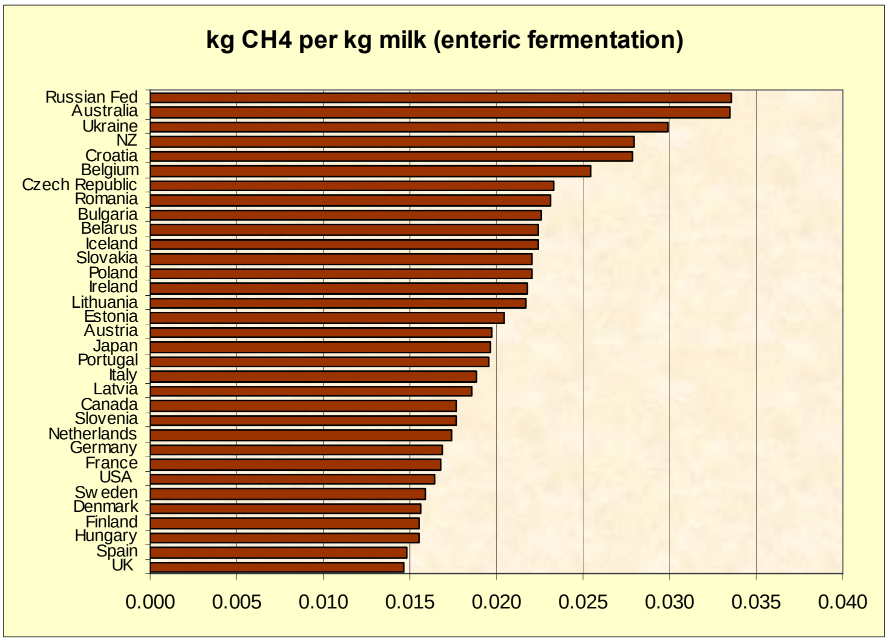


Source: UNFCCC.

However, as milk yield per animal also depends crucially on diet, the EF per kg milk shows a different picture (Figure 27).

[14] Note that emission factors for the Netherlands had to be derived in a slightly different way, see Annex A.3.

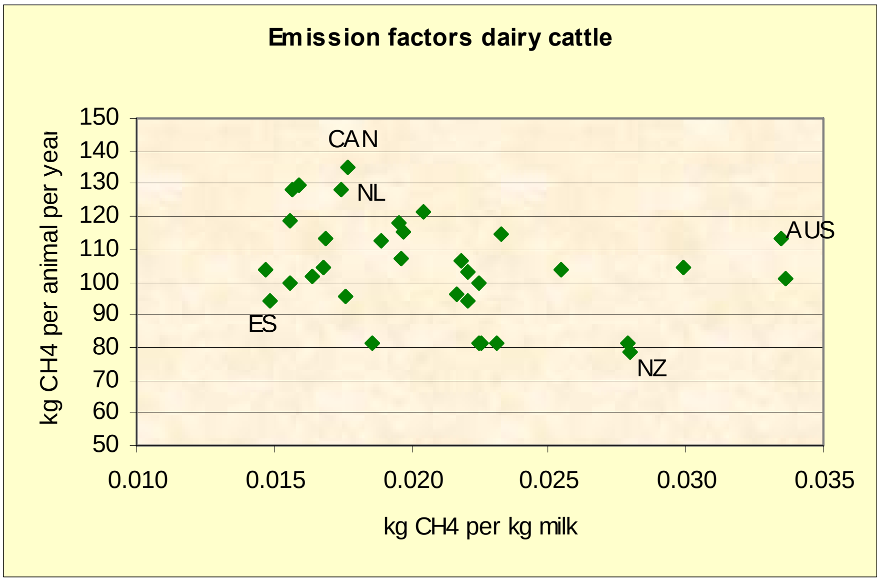
Figure 27 Emission factor per kg milk for Annex-I countries, 2005



Source: UNFCCC, FAOSTAT.

If the two EF are shown simultaneously, as in Figure 29, there is indeed no apparent correlation in efficiency per animal and efficiency per kg milk, although there is a trend for countries with a high EF per animal to have a low EF per kg milk or in other words a higher yield in milk per animal. For EF per animal below approximately 120 kg CH_4, the spread in yield is apparently very large.

Figure 28 Correlation between emission factors per animal and per kg milk



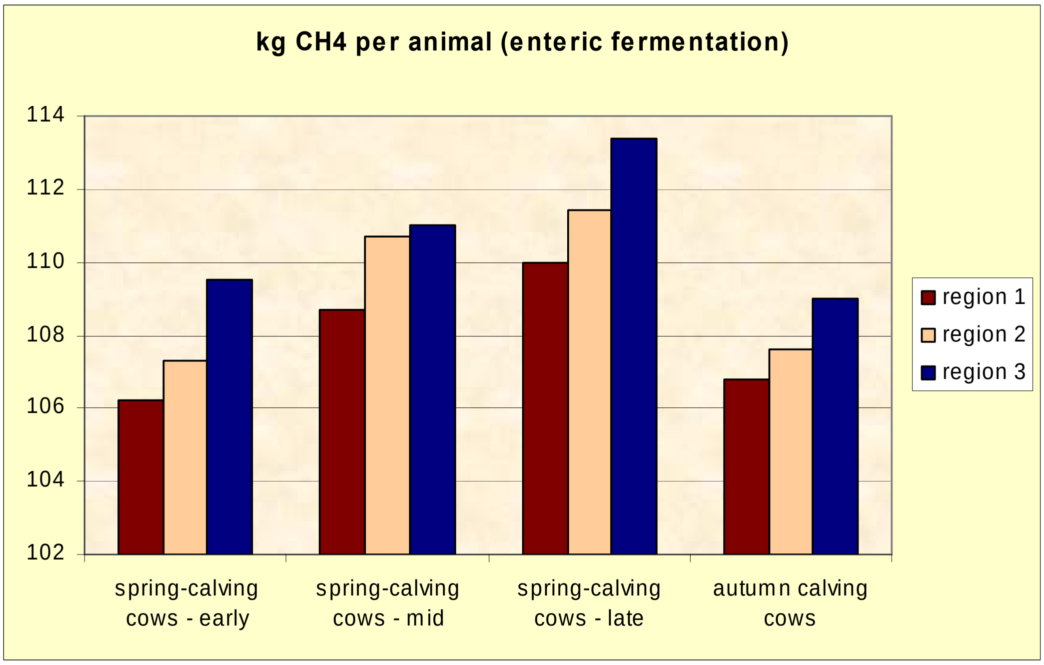
When considering enteric fermentation only, it would therefore appear that a high EF per animal is preferable in terms of climate-efficiency of milk production. Nevertheless, we will see in Chapter 4 that the diets in the more intensive systems require more energy for fodder production and therefore give rise to extra greenhouse-gas emissions earlier in the life cycle.

3.2.1 Case study: Ireland

The previous section has shown that the methane emissions per cow as a result of enteric fermentation differ widely per country. In New Zealand, 78 kg CH_4 per animal is emitted while in Canada the methane emission per animal amounts to 135 kg. This section will show that even within a country - Ireland -, there is a variation in methane emission per animal.

O'Mara (2006) reports the emissions factors for methane from enteric fermentation and manure management in Ireland. Three regions in Ireland are distinguished that differ in lengths of winter housing and feeding practices. As can be seen from Figure 29, the methane emissions per animal (enteric fermentation) differ per region: in region 3 they are approximately 2-3 kg higher than in region 1.

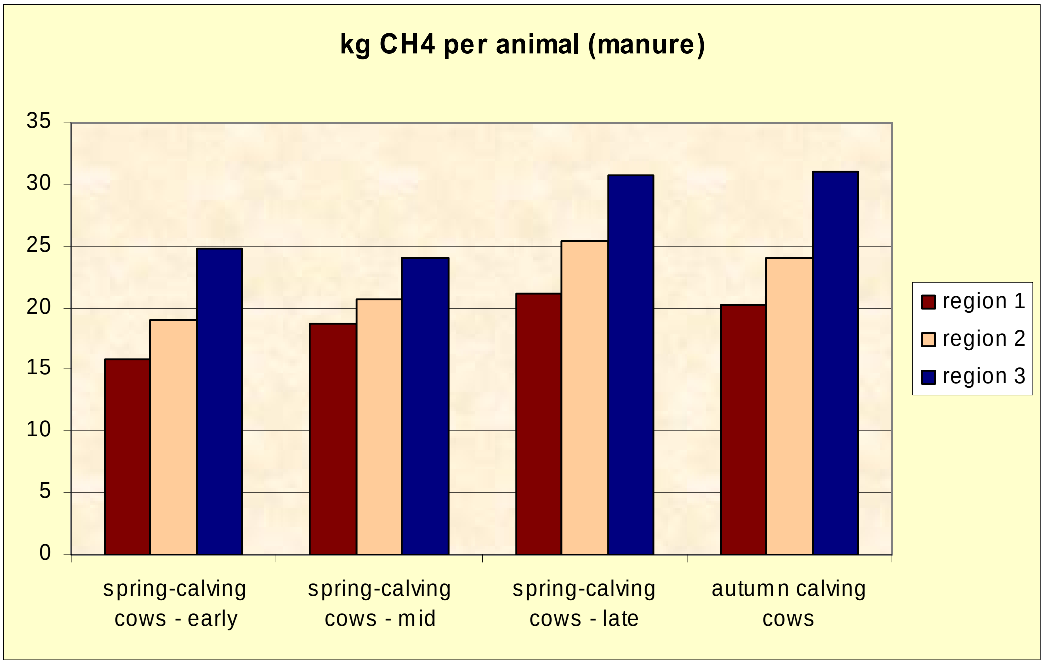
Figure 29 Emission factor per animal for three regions in Ireland



Source: O'Mara, 2006.

Figure 30 shows that methane emissions per animal for manure management are approximately 9 kg higher in region 3 than in region 1.

Figure 30 Emission factor per animal for three regions in Ireland



Source: O'Mara, 2006.

3.3 Manure handling

As discussed earlier, emissions from manure handling concern both methane and nitrous oxides. Emission factors for dairy cattle are only reported explicitly for methane. In Figure 31 and Figure 32 it is shown that emission factors depend very strongly on local circumstances. Per head, dairy cows have the largest emission factors. In developing countries, emission factors are typically much lower, as methane emissions arise in anaerobic conditions more prominent in intensive agricultural systems.

Specific reported EF per country are shown in Figure 33 (per animal) and Figure 34 (per kg milk). Contrary to the case of enteric fermentation, the ranking of countries in this emission category hardly changes when milk production efficiency is considered.

Figure 31 Methane emission factors for manure handling

Table 10.14
MANURE MANAGEMENT METHANE EMISSION FACTORS BY TEMPERATURE FOR CATTLE, SWINE, AND BUFFALO[a]

Regional characteristics	Livestock species	CH_4 emission factors by average annual temperature (°C)[b]																		
		Cool					Temperature											Warm		
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28
North America: Liquid-based systems are commonly used for dairy cows an swine manure. Other cattle manure is usually managed as a solid and deposited on pastures or ranges	Dairy Cows	48	50	53	55	58	63	65	68	71	74	78	81	85	89	93	98	105	110	112
	Other Cattle	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Market Swine	10	11	11	12	12	13	13	14	15	15	16	17	18	18	19	20	22	23	23
	Breeding Swine	19	20	21	22	23	24	26	27	28	29	31	32	34	35	37	39	41	44	45
Western Europe: Liquid/slurry and pit storage systems are commonly used for cattle and swine manure. Limited cropland is available for spreading manure.	Dairy Cows	21	23	25	27	29	34	37	40	43	47	51	55	59	64	70	75	83	90	92
	Other Cattle	6	7	7	8	8	10	11	12	13	14	15	16	17	18	20	21	24	25	26
	Market Swine	6	6	7	7	8	9	9	10	11	11	12	13	14	15	16	18	19	21	21
	Breeding Swine	9	10	10	11	12	13	14	15	16	17	19	20	22	23	25	27	29	32	33
	Buffalo	4	4	5	5	5	6	7	7	8	9	9	10	11	12	13	14	15	16	17
Eastern Europe: Solid based systems are used for the majority of manure. About one-third of livestock manure is managed in liquid-based systems.	Dairy Cows	11	12	13	14	15	20	21	22	23	25	27	28	30	33	35	37	42	45	46
	Other Cattle	6	6	7	7	8	9	10	11	11	12	13	14	15	16	18	19	21	23	23
	Market Swine	3	3	3	3	3	4	4	4	4	5	5	5	6	6	6	7	10	10	10
	Breeding Swine	4	5	5	5	5	6	7	7	7	8	8	9	9	10	11	12	16	17	17
	Buffalo	5	5	5	6	6	7	8	8	9	10	11	11	12	13	15	16	17	19	19
Oceania: Most cattle manure is managed as a solid on pastures and ranges, except dairy cows where there is some usage of lagoons. About half of the swine manure is managed in anaerobic lagoons.	Dairy Cows	23	24	25	26	26	27	28	28	28	29	29	29	29	29	30	30	31	31	31
	Other Cattle	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Market Swine	11	11	12	12	12	13	13	13	13	13	13	13	13	13	13	13	13	13	13
	Breeding Swine	20	20	21	21	22	22	23	23	23	23	23	24	24	24	24	24	24	24	24
Latin America: Almost all livestock manure is managed as a solid on pastures and ranges. Buffalo manure is deposited on pastures and ranges.	Dairy Cattle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
	Other Cattle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Swine	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
	Buffalo	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2

Source, IPCC, 2006

Figure 32 Methane emission factors for manure handling (continued)

Table 10.14

MANURE MANAGEMENT METHANE EMISSION FACTORS BY TEMPERATURE FOR CATTLE, SWINE, AND BUFFALO[a]

Regional characteristics	Livestock species	CH_4 emission factors by average annual temperature (°C)[b]																		
		Cool					Temperature											Warm		
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28
Africa: Most livestock manure is managed as a solid on pastures and ranges. A smaller, but significant fraction is burned as fuel.	Dairy Cows	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Other Cattle	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Swine	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Middle East: Over two-thirds of cattle manure is deposited on pastures and ranges. About one-third of swine manure is managed in liquid-based systems. Buffalo manure is burned for fuel or managed as a solid.	Dairy Cows	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3
	Other Cattle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Swine	1	1	1	2	2	2	2	2	3	3	3	3	4	4	4	5	5	5	6
	Buffalo	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Asia: About half of cattle manure is used for fuel with the remainder managed in dry systems. Almost 40% of swine manure is managed as a liquid. Buffalo manure is managed in drylots and deposited in pastures and ranges.	Dairy Cows	9	10	10	11	12	13	14	15	16	17	18	20	21	23	24	26	28	31	31
	Other Cattle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Swine	2	2	2	2	2	3	3	3	3	4	4	4	5	5	5	6	6	7	7
	Buffalo	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Indian Subcontinent: About half of cattle and buffalo manure is used for fuel with the remainder managed in dry systems. About one-third of swine manure is managed as a liquid.	Dairy Cows	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6	6
	Other Cattle	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Swine	2	2	3	3	3	3	3	3	4	4	4	4	4	5	5	5	6	6	6
	Buffalo	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Source: See Annex 10A.2. Tables 10A-4 to 10A-8 for derivation of these emission factors.

The uncertainty in these emission factors is ±30%.

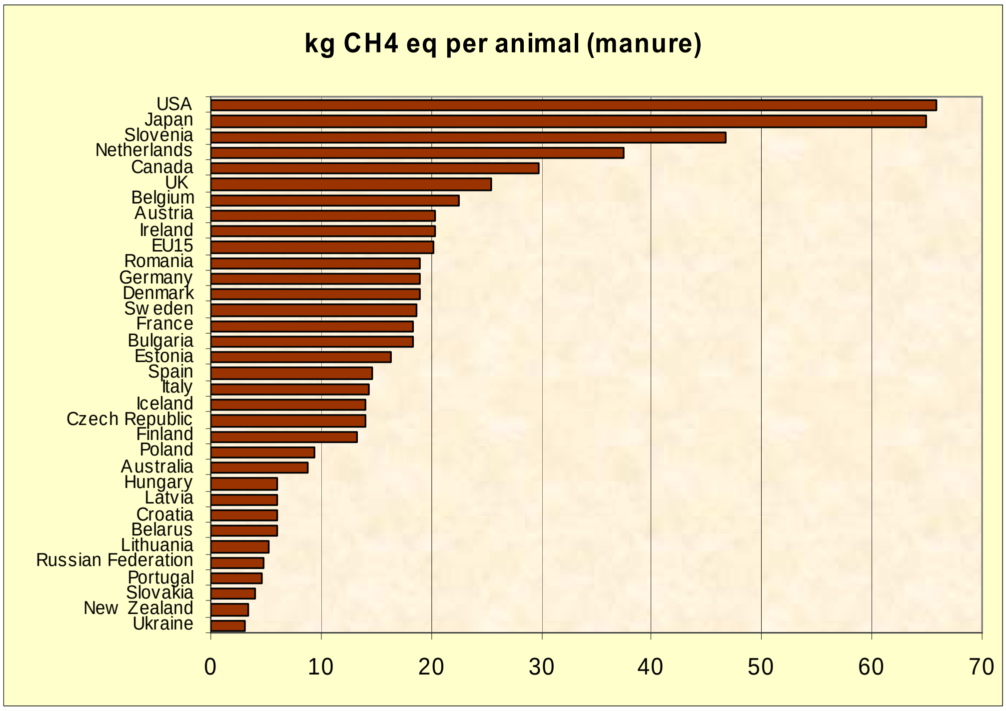
[a] When selecting a default emission factor, be sure to consult the supporting tables in Annex 10A.2 for the distribution of manure management systems and animal waste characteristics used to estimate emissions. Select an emission factor for a region that most closely matches your own in these characteristics.

[b] All temperatures are not necessarily represented within every region. For example there are no significant warm areas in Eastern or Western Europe. Similarly, there are no significant cool areas in Africa and the Middle East.

Note: Significant buffalo populations do not exist in North America, Oceania, or Africa.

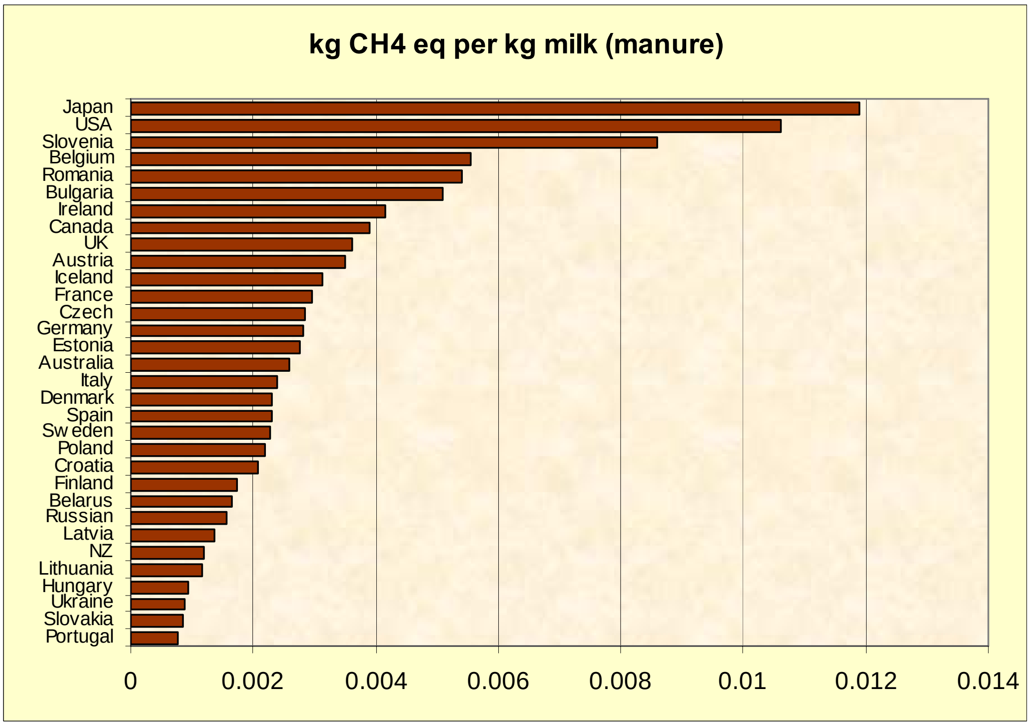
Source: IPCC,2006

Figure 33 Emission factor per animal per year for Annex-I countries, 2005



Source: UNFCCC.

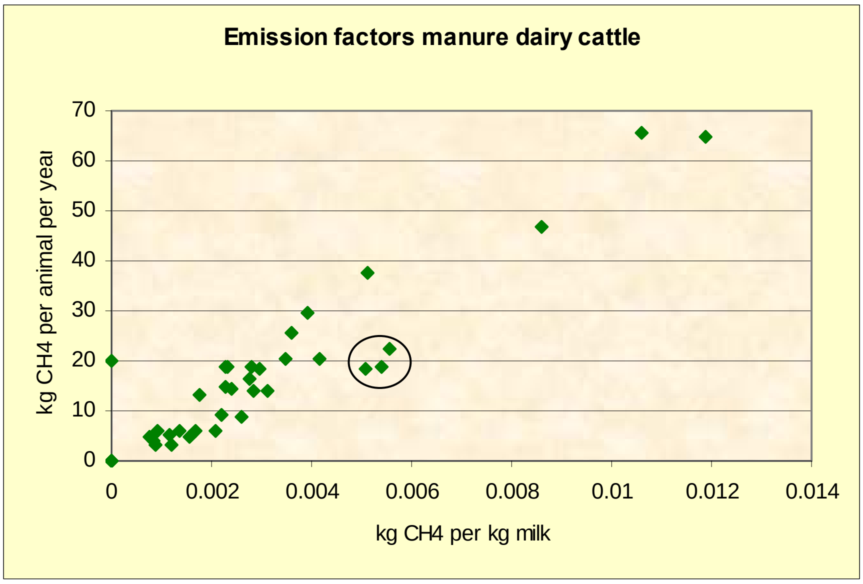
Figure 34 Emission factor per kg milk for Annex-I countries, 2005



Source: UNFCCC, FAOSTAT.

As can be seen in Figure 35, the spread in the correlation is small, but not absent. Data for Belgium, Bulgaria and Romania show a relatively high EF per kg milk for a low EF per animal, indicating a comparatively low milk yield.

Figure 35 Correlation between emission factors per animal and per kg milk. Encircled points are for Romania, Belgium and Bulgaria



3.4 Concluding remarks

Emission factors for enteric fermentation vary with milk production and with diet. Reduction of those emissions should therefore always be considered within the framework of the entire life cycle. Emission factors for methane emissions from manure depend primarily on the animal husbandry system. This gives more scope for reduction without influencing emissions at other stages of the life cycle, but the influence of manure management on the emissions of N_2O should of course be taken into account as well.

4 Emissions: life cycle

This chapter explores the life cycle emissions of a kg milk. Information is derived from existing Life Cycle Assessment (LCA) studies.

In the first section a flowchart of the milk life cycle is given. Most LCA studies for milk are up to the farm-gate, which means that the dairy processing and consumer stage are left out. Therefore, estimates of post farm emissions are given in the seventh section.
The second section looks at the relative contribution of greenhouse gases. Methane emissions have on average the largest share in the total greenhouse-gas emissions in the milk life cycle. The next section looks at the relative shares of stages in the milk life cycle. Enteric fermentation and feed production are the stages with the highest greenhouse-gas emissions. Section 4 shows that there's no significant difference between organic and conventional milk production.
In Section 5 and 6 the emissions of different countries in the world and Europe are compared. It seems that not only the country, but also the management system determines the amount of greenhouse-gas emissions in the milk life cycle.
Section 8 lists some of the operational issues that could explain part of the difference in LCA results. Different allocation methods and the chosen functional unit explain part of the variation in results.

Table 8 lists the life cycle studies used in this chapter (see also Appendix C).

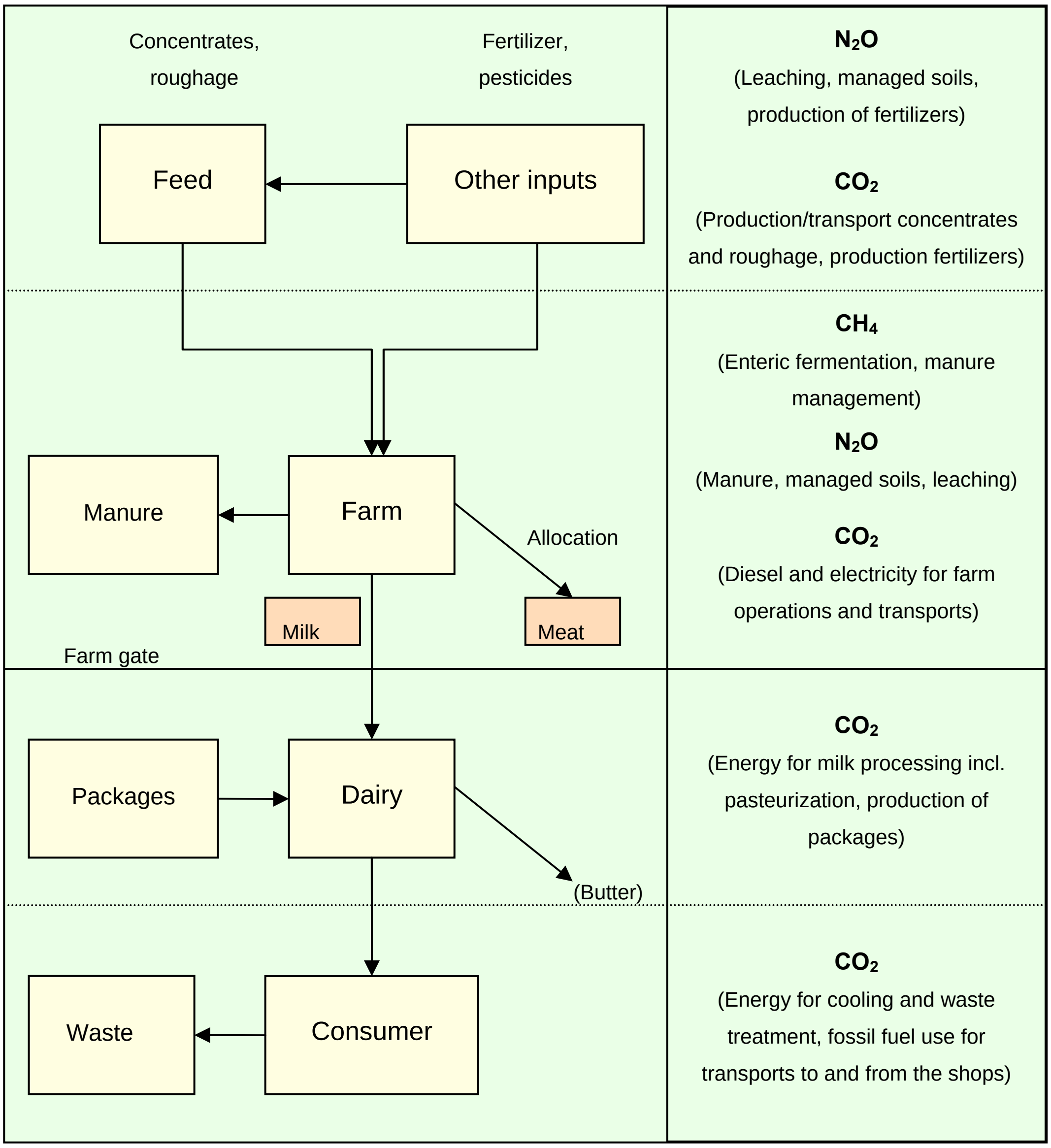
Table 8 The milk LCA studies used in this chapter

Country	Study	Reference
The Netherlands	NZO/KWA (2006)	
	Thomassen (2008)	(1)
	Iepema & Pijnenburg (2001)	(2)
Sweden	Cederberg & Mattson (2000)	(3)
	Cederberg & Flysjo (2004)	(4)
	Svenskjmolk	
Germany	Haas et al. (2001)	(5)
UK	Williams et al. (2006)	(6)
France	IDF (2007)	(7)
Ireland	Casey & Holden (2005)	(8)
EU	Weiske et al. (2006)	
EU/IMPRO	Weidema et al. (2008)	
US	Phetteplace et al. (2001)	(9)
Canada	Vergé et al. (2007)	(10)
New Zealand	Basset-Mens et al. (2005)	(11)
	Ledgard et al. (2004)	(12)
Australia	Howden & Reyenga (1999)	(13)

4.1 Milk life cycle

The life cycle of a product includes the extraction of resources, the production of materials, other inputs and the product, and the removal of the product (by reuse, recycling or final disposal). The life cycle of milk includes the production and transport of feed and fertilizers, manure handling, farm operations, dairy processing, the production of packages, cooling at the shop and consumer, consumer transport to/from the shop and finally, waste handling.
Life Cycle Assessments can be used to assess the environmental burdens of a product at all stages in their life cycle. For this report we only focus on the climate effect of milk (see Figure 36). While an LCA aims to be 'from cradle-to-grave', most of the LCA studies used in this chapter are from 'cradle to farm gate', which means that the greenhouse-gas emissions at the dairy and consumer stage are omitted. Section 7 will therefore estimate the post-farm emissions.

Figure 36 Flowchart of the milk life cycle and the associated greenhouse-gas emissions



Short-cycle carbon
The carbon dioxide fixed by photosynthesis in grasslands is exhaled again by the cattle and thus has no effect on the atmospheric concentrations. This 'short-cycle' carbon is not included in the life cycle studies, except for the fraction of carbon that is emitted as methane instead of carbon dioxide, e.g. from enteric fermentation.

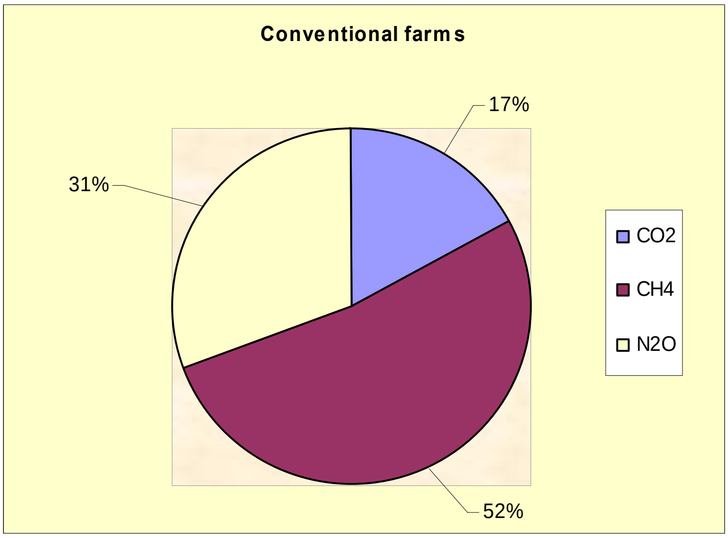
4.2 Contribution of the greenhouse gases

In the milk life cycle, methane contributes most to the climate effect, followed closely by nitrous oxide.

Two studies that contradict the finding that methane is the biggest contributor are the studies by Thomassen (2008) and Weiske et al. (2005), who find that nitrous oxide is the most important greenhouse gas in the milk life cycle.

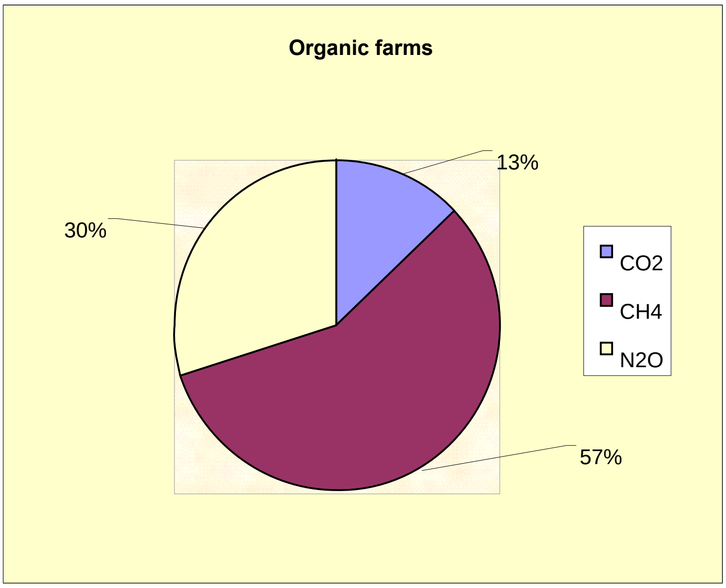
In the conventional milk life cycle, methane is on average responsible for more than half of the total greenhouse-gas emissions (52%), to be followed by nitrous oxide (31%) and carbon dioxide (17%). See also Figure 37.

Figure 37 Share of greenhouse-gas emissions (on average for conventional farms)



In the organic milk life cycle, the contributions of nitrous oxide (30%) and carbon dioxide (13%) are smaller. Organic production usually needs less fossil fuel per ton of milk than conventional production, because no artificial fertilizer is used and the cow's diet contains relatively little concentrates. On the other hand, methane is an even more important greenhouse gas in the organic milk life cycle (57%). This is due to the lower milk production level per cow and the higher use of roughage (De Boer, 2003).

Figure 38 Share of greenhouse-gas emissions (on average for organic farms)



4.3 Contribution of the stages in the milk life cycle

Enteric fermentation accounts for almost half of the greenhouse-gas emissions in the milk life cycle up to the farm. Feed production accounts for on average a third of the climate effect of milk.

Enteric fermentation is the stage with the biggest climate effect. Enteric fermentation of cows accounts for on average 30% of the total greenhouse gases, while fermentation of other dairy cattle (calves, heifers, bulls) add another 15-20%.

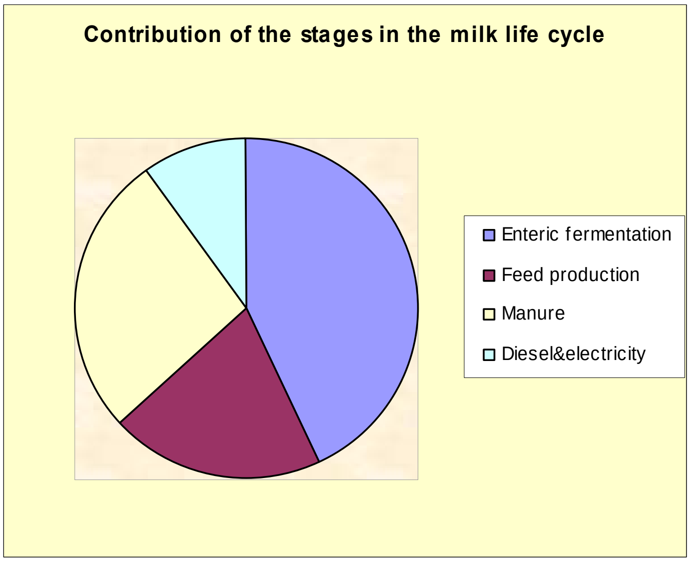
Feed production is almost as important as enteric fermentation. Fertilizer production, spreading and concentrate feed contribute 20 up to 44% to the total climate effect of milk.

Manure handling results in both methane and nitrous oxide emissions. Its contribution ranges from 11% (Casey & Holden, 2005) up to 26% (Vergé et al., 2007).

Carbon dioxide emissions are, among other things, associated with on farm fuel and energy use. On farm fuel and energy use are responsible for a relatively small part (5-9%) of the total climate effect.

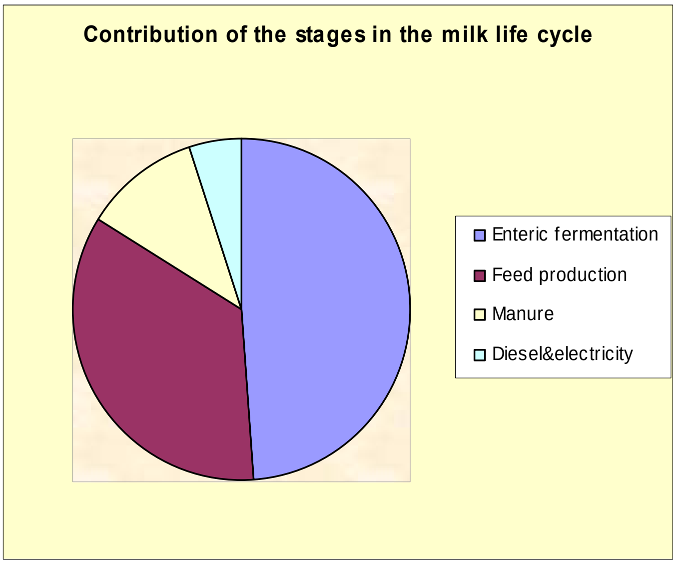
In the figures below the contribution in the climate effect of the stages in the milk life cycle are shown based on LCAs performed by Vergé et al. (2007) and Casey & Holden (2005).

Figure 39 Contribution in GHG emissions of the stages in the milk life cycle (1)



Source: Vergé et al., 2007.

Figure 40 Contribution in GHG emissions of the stages in the milk life cycle (2)



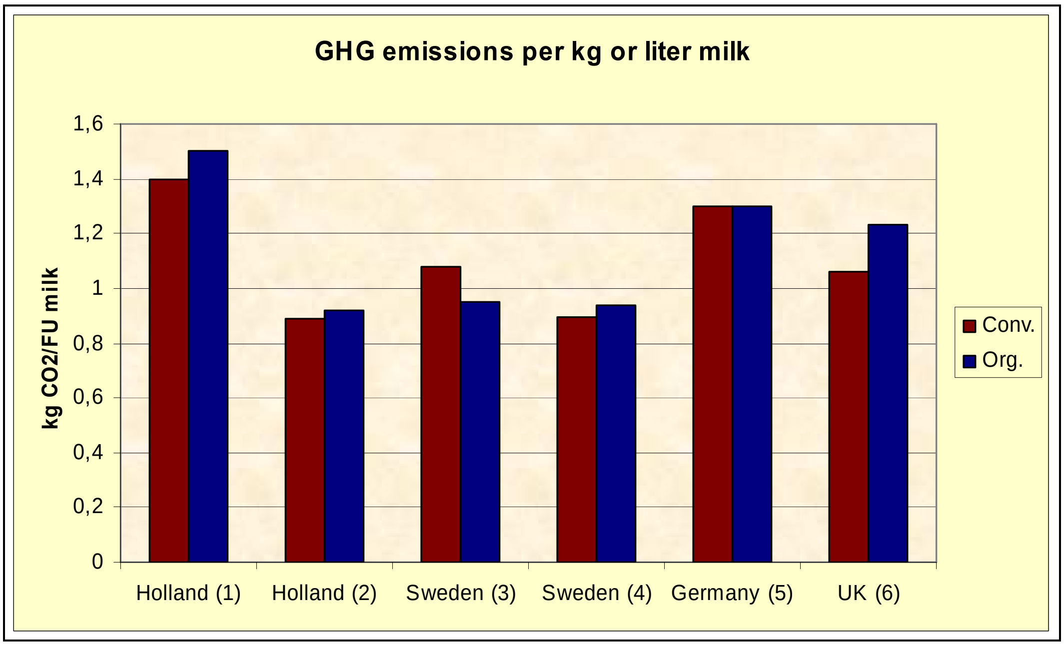
Source: Casey & Holden, 2005.

4.4 Organic versus conventional dairy farms

The climate effect of organic and conventional milk is quite similar; most studies find that milk from organic farms have slightly higher greenhouse-gas emissions.

From the six studies shown in Figure 41, only the Sweden study by Cederberg & Mattson (2000) finds that the climate effect of organic milk is lower than the climate effect of conventional milk[15]. The difference is quite small: the greenhouse-gas emissions in the organic milk life cycle are on average 6% higher than emissions in the conventional milk life cycle.

Figure 41 Greenhouse-gas emissions for conventional and organic milk



4.5 Spread in efficiencies worldwide

LCA studies show that milk from New Zealand has the lowest and Dutch milk has the highest climate effect. The difference in climate effect does not have to be the result of geographical differences, but could also be due to farm management.

It is shown in Figure 42 that the climate effect of a kg milk ranges from 0.8 (New Zealand) to 1.4 (Holland) kg CO_2 eq.

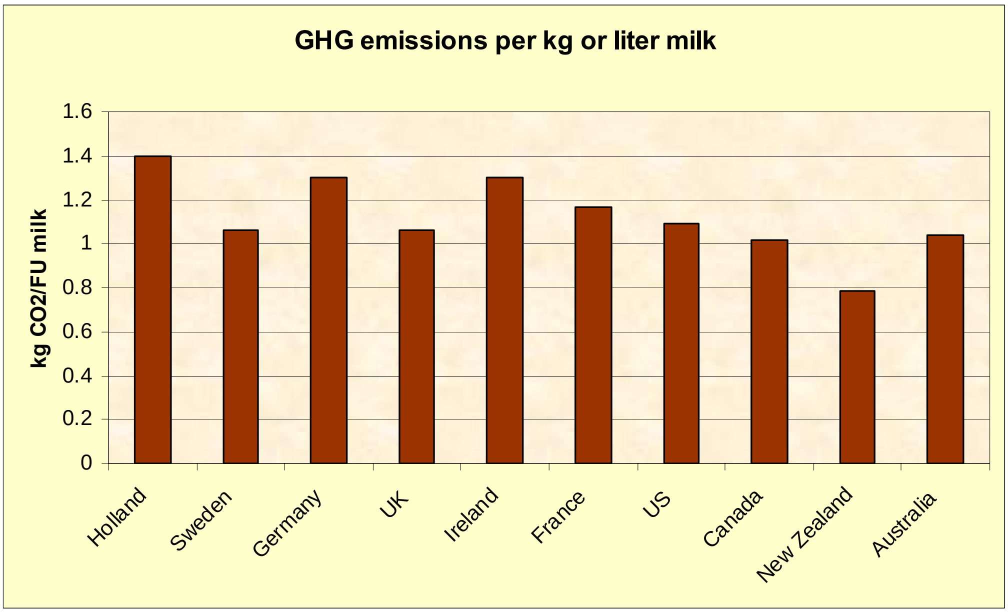
The climate effect is the lowest for milk from New Zealand. This is the result of:
- Low methane emissions from manure handling (manure is directly applied to the pastures).
- Low nitrous oxide emissions from low fertilizer use and no manure storage.
- Low carbon dioxide emissions from low fertilizer and concentrates use.

So even though methane emissions from enteric fermentation are high (the cows' main feed - clover, grass - are difficult to digest), the total climate effect is low.

15 Hirschfeld et al. (2008) also find that organic milk production has a lower global warming impact than conventional milk production. However, their figure for the total greenhouse-gas emissions of a kg milk are substantially lower than the estimates from other LCA studies. Therefore the results of Hirschfeld et al. (2008) are not included in this chapter.

The Dutch milk life cycle has the most greenhouse-gas emissions. This is probably the result of high fertilizer use resulting in high nitrous oxide and carbon dioxide emissions. Methane emissions from enteric fermentation are low.

Figure 42 Greenhouse-gas emissions per functional unit (FU) milk (conventional)



4.6 Spread in efficiencies within the EU

In the EU there is a trend towards intensification on a smaller number of larger, more specialized farms. The differences in the average annual milk yield are large and range from 4.5 ton per cow in Portugal to 8.3 ton per cow in Denmark (EC, 2007).

4.6.1 Study by Weiske et al.

The study by Weiske et al. (2005) models farms in five bio-geographical regions in Europe. On average for all European dairy regions, the greenhouse-gas emissions on conventional model farms are 1.4 kg CO_2 eq. per kg milk.

The five bio-geographical regions are (EC, 2000):

1 The Atlantic region.
2 The Continental region.
3 The Pre-Alpine region.
4 The Boreal region.
5 The Mediterranean region.

The study further distinguished between farm type (conventional or organic), livestock density, crop rotation (mixed, grass or maize) and milk yield.

Overall, the highest emissions are found in the Mediterranean region (1.70 kg CO_2 eq. per kg milk). The Mediterranean commercial systems are characterized by relatively large herd sizes, a feeding system with large amounts of concentrates and milk yields of about 6,000 kg per cow (EC, 2000).
The lowest emissions (1.25 kg CO_2 eq. per kg milk) are found in the Atlantic region on farms with intensive maize silage systems. These farms are characterized by mineral fertilizer application at the rate of 120-150 kg N/ha, 1,300-1,800 kg concentrates fed per cow and milk yields between 7,000 and 8,000 kg per cow (EC, 2000).
See also Table 9.

Table 9 Greenhouse-gas emissions from conventional dairy model farms

	Livestock density (LU/ha)	**Crop rotation**	**Manure**	**Kg CO_2 eq./ kg milk**	**(CO_2/CH_4/N_2O)**
Atlantic 1	2.7	Mixed	Slurry	1.33	11/41/48
Atlantic 3	2.7	Grass	Slurry	1.55	12/34/54
Atlantic 4	2.7	Maize	Slurry	1.25	10/41/49
Continental 1	2.2	Mixed	Slurry	1.33	10/40/50
Pre-Alpine 1	2.1	Mixed	FYM[1]	1.48	12/37/51
Boreal 1	1.1	Mixed	Slurry	1.28	13/36/51
Mediterranean 1	2.5	Mixed	Slurry	1.70	9 /43/48

[1] Farmyard manure.
Source: Weiske et al., 2005.

4.6.2 LCA studies

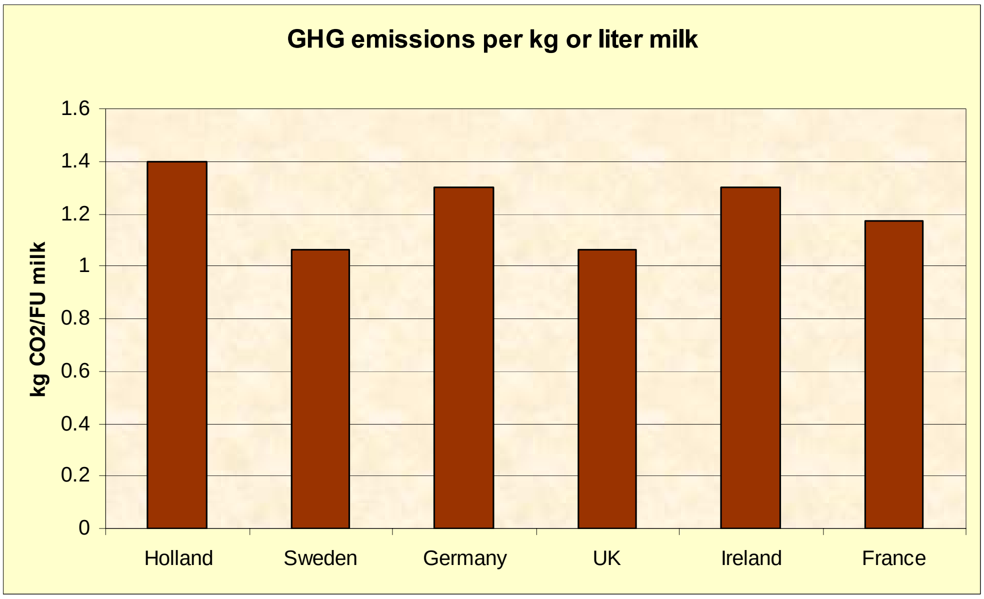
European life cycle studies show that the climate effect of milk ranges between 1.04 (Sweden) and 1.4 (Holland) kg CO_2 eq.

The consulted LCA studies show that the highest emissions in the milk life cycle are found in the Netherlands even though the Netherlands has one of the highest milk yields per cow.
Thomassen (2008) estimates that on average 1.4 kg CO_2 eq. are emitted per kg milk, whereby nitrous oxide emissions from fertilizer application are relatively high. Holland is located in the Atlantic region and a Dutch dairy farm can be characterized by a farm with intensive grassland. The study by Weiske et al. (2005) has shown that the average global warming impact for such a farm is 1.55 kg CO_2 eq. per kg milk.

Emissions in the Swedish milk life cycle are the lowest: the global warming impact of a kg milk is 1.04-1.08 kg CO_2 eq. Sweden is located in the Boreal region and Weiske et al. (2005) estimates that a farm in this region has a global warming impact of 1.28 kg CO_2 eq. per kg milk.

All in all, the European life cycle studies and the study by Weiske et al. (2005) both show that the range in the climate effect of milk is 35-40%.

Figure 43 Greenhouse-gas emissions in the milk life cycle in different European countries



4.6.3 IMPRO study

In 2003 the Communication on Integrated Product Policy promised that the European Commission would seek to identify products with the greatest environmental improvement potential. The first phase of this work led to the EIPRO (Environmental Impact of Products) study which identified three areas of consumption - food and drink, private transportation and housing - that together are responsible for most of the environmental impacts. In the second phase, IMPRO (Environmental Improvement Potentials of Products) projects were launched for these three groups of products. This subsection deals with the IMPRO report on meat and dairy (for the category ‘food and drink’).

The IMPRO study is unique in that it looks at the total life cycle of meat and dairy products and uses a hybrid approach of ‘top-down’ input-output matrices and ‘bottom-up’ life cycle assessments to calculate the environmental impacts. For input-output tables it is assumed that all products in an industry have the same environmental impact per Euro. For inhomogeneous industries like agriculture this may not be a reasonable assumption. The livestock processes were therefore divided in a range of production systems and modelled based on biological input-output relations. Dairy, for example, was represented by five systems.

The IMPRO study finds that the climate effect of a kg milk is 2.4 kg CO_2 eq.

This global warming impact of milk is almost twice as much as the impact from life cycle studies. Explanations for the difference:

- The IMPRO study looks at the total milk life cycle (i.e. including dairy processing, consumer transport, electricity use from storage in households, packaging production), while most LCA studies are only up to the farm gate. Especially electricity consumption is important in the total milk life cycle (see below).
- The LCA studies investigate just milk, while the IMPRO study takes all dairy products (cheese, yoghurt) into account.
- Methodological differences: IMPRO uses a hybrid approach of input/output models and life cycle assessments.

Important processes that contribute to the climate effect are dairy farming, electricity production (notably the storage of dairy products in households) and grain crops.

Packaging plays only a small role in the milk life cycle.

As improvement options for households, the study examines:

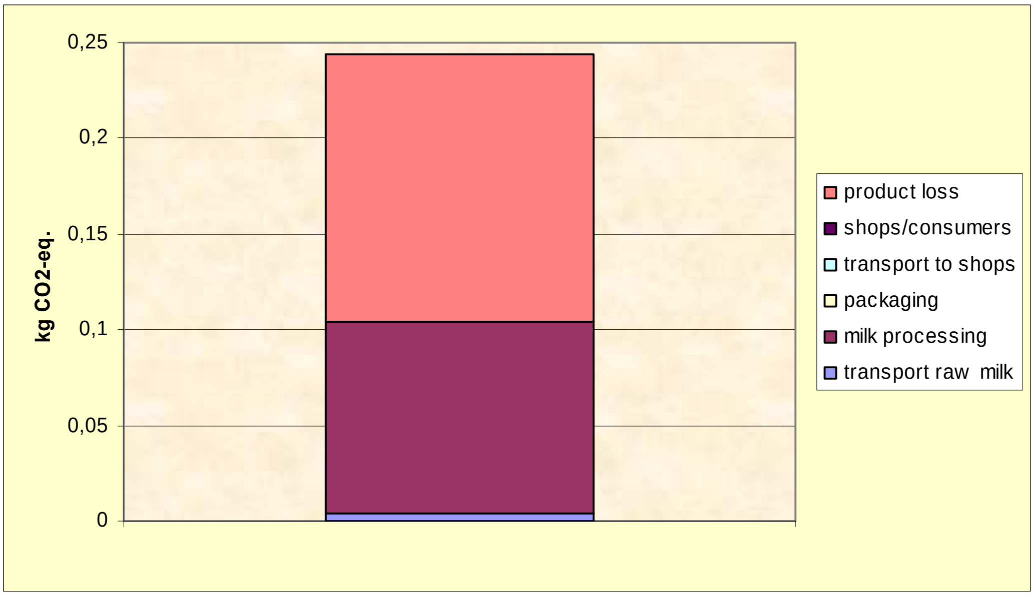
- A scheme for early replacement of old refridgerators by highly energy efficient new ones. When consumers hand in their old refridgerator, they are offered A+/A++ appliances at about the same price as an average appliance. As a result, the climate effect of meat and dairy products is reduced by 1%.
- Application of planning tools for consumers that could lead to a 12.5% reduction of waste. The GHG emissions of meat and dairy products are estimated to decline by 1.75%.

4.7 Post farm emissions

Most LCA studies focus on the emissions up to the farm gate, but the milk life cycle also includes post farm emissions, that are examined in this section.

According to NZO/KWA (2006), post farm emissions amount to approximately 20% of the emissions up to the farm gate. When it is assumed that the amount of product loss varies between 5 and 20%, product losses are responsible for 57% of the post farm emissions. Almost 41% of the post farm emissions is due to milk processing (including cheese and milk powder production). See also Figure 44.

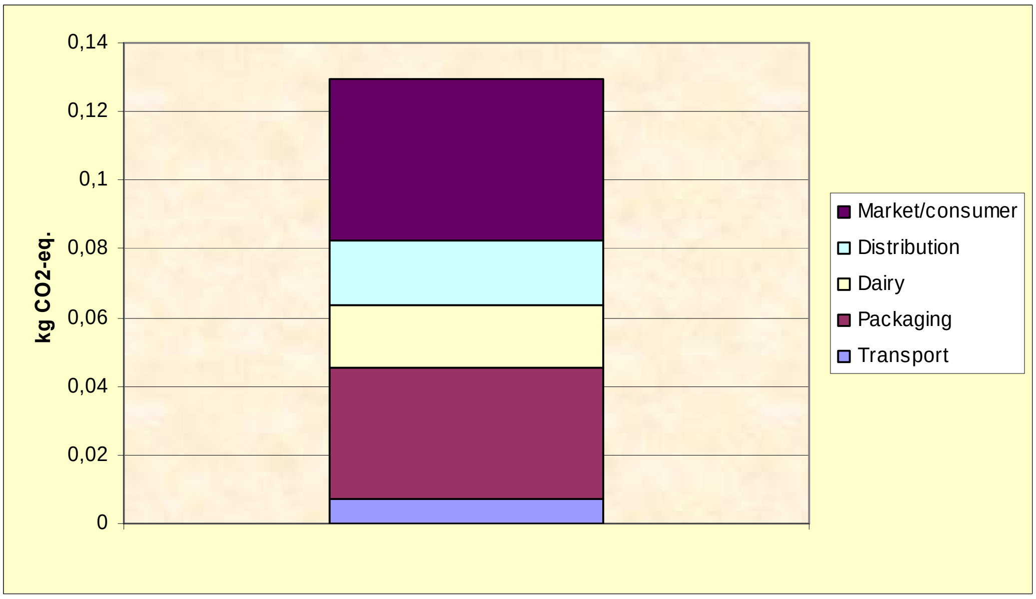
Figure 44 Greenhouse-gas emissions after the farm (per kg milk)



Source: NZO/KWA, 2006.

Svenskmjolk finds that post farm emissions are approximately 10% of the emissions up to the farm gate. The most important post farm stages are market/consumer (36%, mostly fossil fuel use due to the consumer driving to the shop) and packaging (29%). See also Figure 45.

Figure 45 Greenhouse-gas emissions after the farm (per kg milk)



Source: Svenskmjolk.

The two studies reveal that 10-20% needs to be added to the emissions up to the farm gate. These estimates for post farm emissions are underestimates since storage of milk in the household are left out of the analyses, while the IMPRO study has shown that household storage has a substantial climate impact (see Section 4.6.3).

Milk life cycle emissions (including post-farm emissions but excluding household storage) would then total 1.2-1.8 kg CO_2 eq. per kg milk (using European LCA studies).

4.8 Operational issues as an explanation of the differences

The various LCA studies for milk find that the greenhouse-gas emissions for a kg milk are between 0.9-1.4 kg CO_2 eq. The variation in results is partly explained by different farm management practices, but part of it stems from methodological issues. Differences in the allocation methods, the functional unit and the type of farm examined explain part of the variation (see also Appendix B).

In dairy farms, not only milk is produced, but also meat (from bull cows and culled cows). Thus, part of the emissions associated with the dairy farm has to be allocated to meat. Different allocations are possible: mass allocation, economic allocation, system expansion or no allocation. Studies show that different allocation rules could account for 3-15% of the variation in results (see Appendix B).

The LCA studies also differ in the sort of farm they look at. The studies that examine experimental farms may obtain different results than the studies that look at commercial farms. Some studies do not look at specific farms, but model an average farm.
The effect of different farm types on the global warming potential is difficult to quantify.

The functional unit is a reference flow to which all other flows in the LCA are related (Berlin, 2002). This means that different functional units could yield different results.
Different functional units could account for 0-3% of the variation in greenhouse-gas emissions (see Appendix B).

4.9 Conclusions

The milk life cycle includes the extraction of resources like feed and fertilizers, the farm operations and manure handling, the processing of milk in the dairy farm, the production and transport of milk packages, the transport of the consumer to the shops and the cooling and waste treatment of milk.

LCA studies find that greenhouse-gas emissions are 0.8-1.4 kg CO_2 eq. per kg milk for the milk life cycle up to the farm. Including post farm emissions would lead to a climate effect of 0.9-1.8 kg CO_2 eq. per kg milk. This stands in stark contrast to the estimate by the IMPRO study (2.4 kg CO_2 eq. per kg milk). The IMPRO study also includes electricity production from household storage, which appears to be a significant process in the milk life cycle.

From the consulted milk life cycle studies, New Zealand reports the lowest global warming potential and Holland the highest global warming potential even though Holland has one of the highest milk yields per cow.

Not only the region of milk production, but also farm management is important for the GWP of milk. The lowest greenhouse-gas emissions are found on the intensive maize silage systems in the Atlantic region. The highest emissions are found on Mediterranean commercial systems.

From the LCA studies, no other conclusions can be drawn on the CO_2 efficiency of European farms. There are differences between countries but these could stem from methodological issues that could account for up to 18% of the variation in results. The studies show that within Europe, Sweden has the lowest and Holland the highest greenhouse-gas emissions per kg milk.

In the milk life cycle up to the farm, methane contributes most to the climate effect, followed closely by nitrous oxide. There is no significant difference between the GHG emissions for the production of organic and conventional milk. The organic milk life cycle is - on average - associated with higher methane emissions, but lower nitrous oxide and CO_2 emissions per kg milk.

The most important stage in the milk life cycle up to the farm is enteric fermentation, followed by feed production. For the total milk life cycle, electricity use due to household storage is also significant.
The IMPRO study has calculated that changing the energy efficiency of refrigerators in households could reduce the climate effect of milk by 1%. Reducing food losses is another improvement option. Assuming a product loss of 20%, it is found that if meat and dairy product loss is reduced to 17.5%, the climate effect of milk decreases by 1.75%.

5 Discussion and interpretation

5.1 Livestock emissions of the dairy sector

In terms of direct emissions of dairy livestock, enteric fermentation and manure handling are the two sources of emission. The contribution of dairy cattle to total emissions in Annex-I countries in these two categories is approximately 30% to methane emissions and an estimated 28% for nitrous oxide from manure handling including pasture manure (Section 2.3.3). In comparison, at a global level, the FAO's report *Livestock's Long Shadow* (FAO, 2006) finds contributions of dairy to total livestock emissions of 18% for enteric fermentation as well as methane from manure handling and a much lower 11% for nitrous oxide emissions from manure handling.

The contribution of enteric fermentation and manure handling for dairy cattle to total greenhouse-gas emissions is 1.2%, both for Annex-1 countries and globally. For Europe, the contribution is slightly higher with 1.7%. The efficiency of Europe's production is much higher, however, with 0.46 kg CO_2 eq. per kg milk from livestock emissions. For Annex-1 countries, this figure is 0.61 kg CO_2 eq. per kg milk and globally, it is approximately 0.95 kg CO_2 eq. per kg milk (see Section 2.3.3).

It is interesting to compare those 'efficiencies' for on-farm livestock emissions to the life cycle totals found in Chapter 4. Enteric fermentation of dairy cattle and manure handling contribute some 50% of total cradle-to-farm-gate emissions of milk production, so total life cycle figures should be twice as large as the on-farm figures established in Chapters 2 and 3. This is roughly the case, as can be seen in Figure 42. Interestingly, a higher on-farm efficiency does not necessarily result in a high life cycle efficiency, as illustrated by New Zealand. For this country, life cycle emissions are low (Figure 42), but enteric fermentation is very high, as demonstrated in Chapter 3 (Figure 27). The use of concentrates plays a role in this.

5.2 Total emissions of the diary chain

Of national and global data on greenhouse-gas emissions, typically only methane emissions from enteric fermentation and manure management may be directly attributed to dairy production. Clearly, however, some of the emissions of other categories, such as energy (transport), crop production, land use as well as the N_2O emissions discussed in Section 2.3.2 and Section 2.3.3 should also be attributed to the dairy chain.

Based on the life cycle studies discussed in Chapter 4, we derive the relative contribution of life cycle steps with respect to the contribution of methane from enteric fermentation of the lactating cows. The share of global greenhouse-gas emissions associated with enteric fermentation of dairy cattle is 0.8% and the same percentage is true for Annex-I countries (see Section 2.3.3).

This 0.8% equals 28% of the cradle-to-farmgate emissions of dairy production, as can be seen in Table 10. This means the dairy life cycle totals **3%** of the global GHG emissions. For Annex-1 countries, the dairy life cycle also totals **3%** of the Annex-I emissions.

Table 10 Emissions in the milk life cycle

Stage	**Share of total GHG emissions in milk life cycle[1]**	**Share of total global GHG emissions**	**Share of total GHG emissions for Annex 1**
Enteric fermentation:	43%	1.2%0.4%	1.2%/0.7%
- dairy cows	*28%*	***0.8%**/0.2%*	**0.8%**/0.5%
- heifers, bulls and calves	*15%*	*0.4%/0.1%*	0.4%/0.3%
Manure:	27%	0.8%/0.2%	0.8%/0.5%
- N_2O	*15%*	*0.4%/0.1%*	0.4%/0.3%
- CH_4	*12%*	*0.3%/**0.1%***	0.3%/**0.2%**
Synthetic fertilizer	10%	0.3%/0.1%	0.3%/0.2%
Energy use (field work, machinery, electricity, transport)	10%	0.3%/0.1%	0.3%/0.2%
Nitrous oxide from crop residue, leaching and volatization	10%	0.3%/0.1%	0.3%/0.2%
Total	**100%**	**3%/1%**	**3% / 2%**

[1] Source: Vergé et al., 2007.

For control, the same calculation may be made using the share of greenhouse-gas emissions associated with manure handling of dairy cattle (methane). In this calculation, the dairy life cycle totals 1% of the global GHG emissions. For Annex 1, the dairy cradle-to-farm gate life cycle totals 2% of the Annex-I countries GHG emissions. This is slightly lower than the 3% we derived from the share of enteric fermentation.

Overall, this figures are in good agreement with figures in FAO (2006), that established a total climate contribution of 18% for animal production over the entire life cycle. If we assume a share of 16% for dairy (based on direct livestock emissions) this yields an estimate of 3% for the global contribution of the dairy life cycle. Contrary to most life cycle studies, this figure includes some emissions from deforestation. Not all 'land use, land-use change and forestry' (LULUCF) emissions are taken into account, which locally may be quite important contributions[16], as shown in the case study for the Netherlands (Section 2.4.3).

[16] Note, however, that LULUCF emissions are not included in the figures for total greenhouse-gas emissions either, which would of course have to be the case to establish shares of the dairy sector including LULUCF emissions.

The EIPRO study (Williams et al., 2006) and IMPRO study (Weidema et al. 2008) find that milk and dairy products (including post-farm contributions) account for around 5% to 5.7% of the global warming impact of consumption across the EU-27. Of this, 2.4% is for fluid milk, 2.1% for cheese and 0.6% for dry condensed and other dairy products (EIPRO). These results are similar to our estimates above, given that post-farm emissions are included.

5.3 Life cycle contributions

The life cycle studies show that reducing the climate impact of milk by adjusting feed to lower methane emissions from enteric fermentation is not straightforward. Increasing the amount of concentrates for example, results in higher N_2O and CO_2 emissions from the production and transport of these concentrates. New Zealand has one of the highest emission factors for enteric fermentation (see Figure 27) but one of the lowest global warming impact for milk. As it happens, the low GHG emissions from manure handling and the low nitrous oxide emissions from low fertilizer application result in a low total global warming impact. The Netherlands on the other hand, where the emission factor for enteric fermentation is relatively low, has one of the highest total global warming impact for milk.

Increasing the milk yield per cow could lower the enteric fermentation emissions (per kg milk) as well. However, if the feed is adjusted to increase the milk yield per cow, one should also be careful that the N_2O and CO_2 emissions do not increase.

The climate impact of milk could be reduced by reducing milk losses in households. Estimates for milk losses vary widely: from 4% (Berlin et al., 2008) up to 20% (Weidema et al., 2008). Reducing milk losses can be achieved by changing consumer behaviour, for example through planning tools. A reduction of 12.5% milk loss would lower GHG emissions by 1.75% (Weidema et al., 2008). Electricity consumption in households is another important contributor of the global warming impact of milk. A scheme that would encourage consumers to change to A+ or A++ refrigerators could lead to a 1% reduction in climate effect (Weidema et al., 2008).

From the LCA studies, no conclusions can be drawn on the CO_2 efficiency of European farms. There are differences between countries but these could stem from methodological issues that could account for up to 18% of the variation in results. The studies show that within Europe, Sweden has the lowest and Holland the highest greenhouse-gas emissions per kg milk.

5.4 Comparison with other protein rich products

For the IMPRO project (Weidema et al., 2008), the environmental impacts of our meat and dairy consumption have been calculated. Meat and dairy products are responsible for 14% of the total climate effect of EU-27 consumption, of which dairy products contribute 41% (see Table 11). This is mainly due to the relative large consumption of dairy products: the global warming impact per kg product is smaller for dairy than for meat products.

Table 11 Comparison of dairy and meat products

	Dairy products	Beef (products)	Pork (products)	Poultry (products)
Consumption per capita (kg)	237	14	32	19
Relative contribution to global warming (%)	41	28	26	5
Global warming impact (kg CO_2-eq. per kg)	2.4	28.7	11.2	3.6

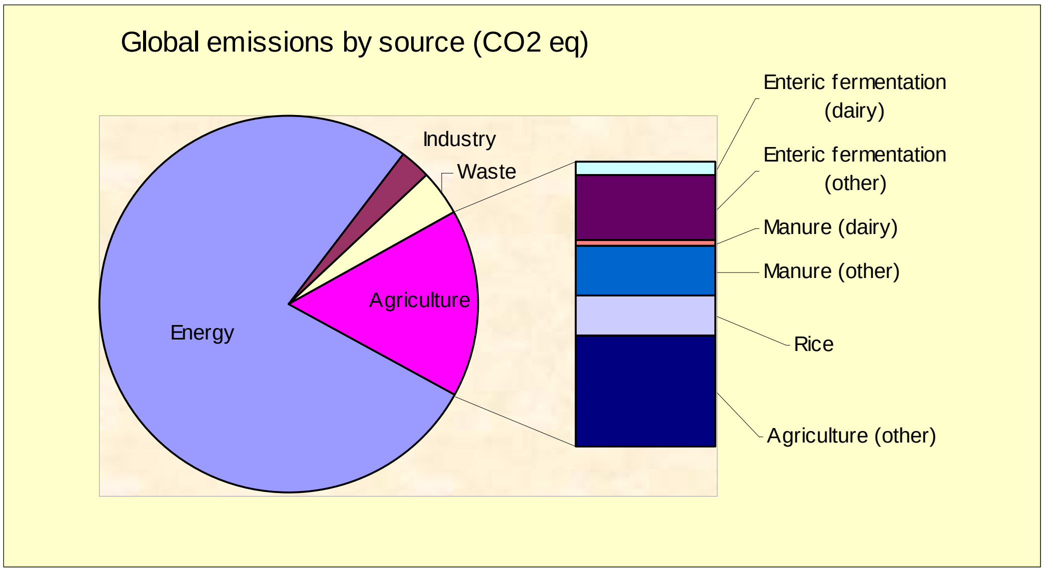
Source: Weidema et al. (2008).

6 Conclusions

On-farm emissions

Dairy livestock emissions contribute 1.2% to the total global greenhouse gas emissions
This study finds that 1.2% of global as well as Annex-1 emissions can be attributed to direct livestock emissions of dairy cattle. This compares to 2.2% for rice cultivation globally (year 2000) and about 1.3% for landfills (methane only). The figure does not include the greenhouse emissions from land use or management, such as savannah burning or drainage of pasture lands. A case study for the Netherlands shows that on-farm emissions would almost double when emissions from grassland are included, but such emissions are very region-specific.

Figure 46 Global greenhouse-gas emissions by source



On-farm methane emissions have decreased in Annex-I countries, but share of dairy sector remained stable

Methane emissions have decreased across the board for Annex-I countries. Between 1990 and 2005 emissions from enteric fermentation in dairy cattle lowered by 30% and emissions due to manure handling by 20%. As other sectors also lowered emissions, the share of dairy remained constant since 1990. Within EU-15, the share of livestock in methane emissions has even increased very slightly, as the shares of waste and natural gas production decreased more strongly. Globally, livestock emissions seem to level out after 1990, but are still significant. The emissions of dairy cattle have increased over the 20th century and probably contribute significantly to the total rise of methane livestock emissions, despite a much smaller relative growth of global production volumes.

Sectoral emissions

Cradle-to-farm gate emissions of milk contribute 3% to total global climate emissions

This study finds that 3% of global emissions can be attributed to the dairy life cycle up to the farm gate (still excluding post-farm and land use emissions). For Annex-I countries this share is 2-3%. These figures exclude the emissions of dairy processing and the consumer phase.

So while dairy livestock emissions contribute 1.2% to the global climate emissions, pre-farm associated with feed and other on-farm emissions contribute 1.8%.

Enteric fermentation is the main source of climate impact, but reducing these emissions leads to trade offs

The contribution of enteric fermentation is large and may be up to 50% of the total cradle-to-farm gate life cycle emissions when emissions of young animals are included.

This contribution may be reduced by lowering emissions from enteric fermentation or increasing milk yields, but this will lead to an increase in concentrates production, and therefore potentially higher overall CO_2 and N_2O emissions. It was found that countries with a high average enteric fermentation per unit milk have lower total effective emissions than countries with high milk yields per animal.

Per-unit emissions

Cradle-to-farm gate emissions are 0.8-1.4 kg CO_2 eq. per kg milk
Methane is the greenhouse gas that contributes most to the climate impact of milk, followed closely by nitrous oxide. Total emissions range from 0.8-1.4 kg CO_2 eq. per kg milk, varying between countries and farming systems. These results from 'bottom up' life cycle studies show that most assessments lead to consistent conclusions. It is hard to establish, however, what are the factors critical in determining the differences.

Post-farm emissions add 10-20% to cradle-to-farm gate emissions
Total life cycle emissions then effectively range from 0.9-1.8 kg CO_2 eq. per kg milk, still excluding household energy use such as cooling, but including product loss. The IMPRO study, that also includes household energy use, finds cradle-to-grave emissions of 2.4 kg CO_2 eq. per kg milk.

Recommendations

Consumer options may be effective in lowering climate impacts
Product losses as well as electricity consumption for cooling contribute significantly to the total life cycle impacts of milk. Consumer options such as energy-efficient refrigerators may lower the impacts by 1% according to the IMPRO study. Product loss could be as high as 10% for fresh milk. Halving that loss would lead to a 5% reduction in life cycle climate impact, without leading to trade-offs.

More consistent comparison of life-cycle effects of farm-management practices necessary
Methodological and regional differences make it hard to compare results of different life cycle studies and determine the critical factors influencing the overall climate effect of dairy production. In order to make a solid comparison of different farm-management systems and properly establish the effects of trade-offs in the life cycle, ideally a series of consistent life cycle assessments with a large variation of parameters would need to be performed. This could be achieved by establishing general standards for performing milk life cycle assessments.

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A sustainable dairy sector

Global, regional and life cycle facts and figures on greenhouse-gas emissions

Annexes

Report

Delft, October 2008

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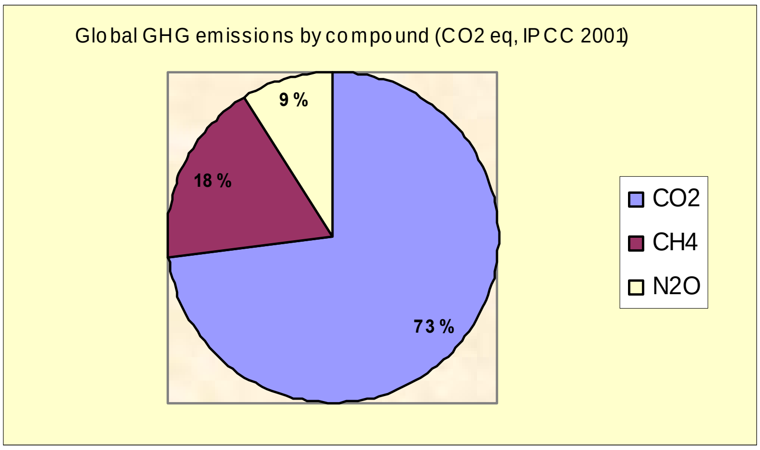
A Sensitivity and uncertainty assessment

A.1 GWP factor

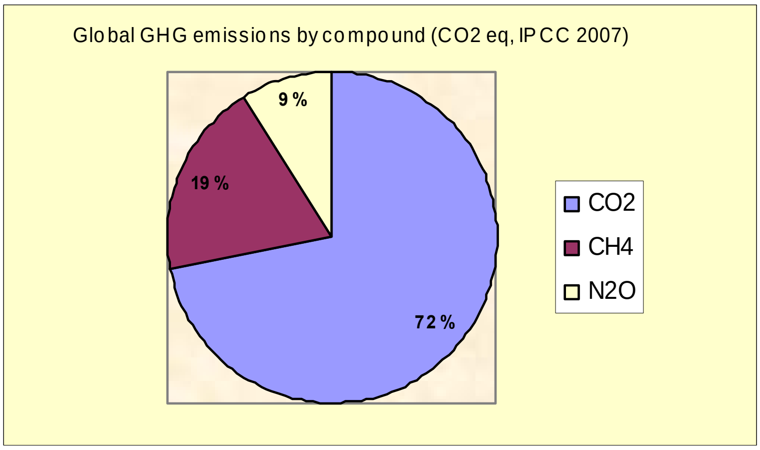
The figures below illustrate the effect of using the GWP factors from the third and fourth assessment report, respectively.

Figure 47 Shares of the three main gases for GWP factors from the third assessment report



Source: IPCC, 2001.

Figure 48 Shares of the three main gases for GWP factors from the fourth assessment report

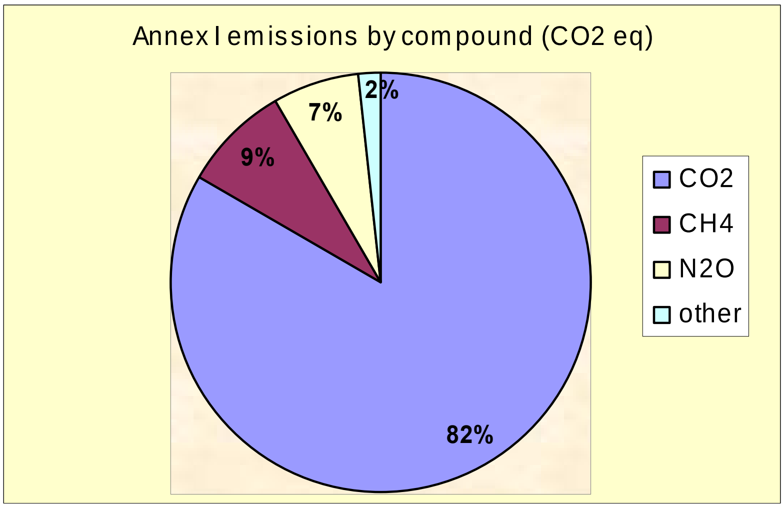


Source: IPCC, 2007.

A.2 Other GHG

The contribution of greenhouse gases other than CO_2, CH_4 and N_2O is 2% in total.

Figure 49 Annex-1 emissions including other greenhouse gases



A.3 Uncertainties in EDGAR and UNFCCC data

Uncertainty estimates for EDGAR data are given as follows:
- Most CH_4 data 50% (industry 10%).
- Most N_2O data 100%.
- CO_2 mostly 10% (biomass burning 100%).

This means that uncertainties in the livestock emission figures may be fairly large. The UNFCCC framework does create a large degree of consistency, but this does not preclude uncertainties either. To provide further insight in variations between data sources, we compare figures for the USA in 2000, that can be derived both from the EDGAR data and from UNFCCC.

Table 12 Comparison of values for the USA, year 2000

	EDGAR	UNFCCC	Difference	
Rice cultivation (4C)	0.31	0.36	16%	Tg CH_4
Enteric fermentation (4A)	5.5	5.4	2.3%	Tg CH_4
Manure management (4B)	45	48	6%	Tg CO_2 eq.

The two data sources are not independent and probably largely based on the same underlying data, so the differences should not be interpreted as indications of the true uncertainties.

Not all categories are covered for all countries in the reporting for UNFCCC. For some small European countries (Monaco, etc.) data are missing altogether, as well as data for Turkey for 2005. The basic UNFCCC data did not include specific data for the Netherlands for dairy cattle. Figures for EU-15 for dairy cattle do include those for the Netherlands, however. Emission factors for enteric fermentation and manure handling (methane) were taken directly from the National Inventory Report for the Netherlands (Maas, 2008), as well as necessary figures for the number of dairy cows (1.433 million). Together with a milk production of 10.5 Mton (FAOSTAT) this yields an average milk production of 7,349 kg per cow per year.

B Operational issues in life cycle assessments

B.1 Allocation

In dairy farms, not only milk is produced, but also meat (from bull cows and culled cows). Thus, part of the emissions associated with the dairy farm has to be allocated to meat. Different allocations are possible: mass allocation, economic allocation, system expansion or no allocation. With mass allocation, emissions are attributed to milk respectively meat based on their weight. With economic allocation, the share in proceeds of milk and meat is used to allocate the emissions. System expansion, as applied by Thomassen et al. (2008), uses marginal data. For example, for feed, the environmental burden of the feed ingredient that is used when milk production increases is taken. No allocation means that all the emissions are attributed to milk.
Table 13 shows how the greenhouse-gas emissions per kg milk differ when different allocation rules are applied. The study of Thomassen et al. (2008) finds that with mass allocation, 96% of the environmental burden is attributed to milk, while with economic allocation, this percentage is 92%[17]. The greenhouse-gas emissions are lowest for system expansion. System expansion includes subtracting avoided burdens of alternative products (for example, avoided beef production), which lowers the burden of milk. Casey & Holden (2005) find a greater difference between mass and economic allocation. Mass allocation attributes 97% of the environmental burden to milk, while economic allocation attributes 85% of the burden to milk.

Table 13 Differences in results (kg CO_2 eq./kg milk) from different allocations

Study	Mass allocation	Economic allocation	System expansion	No allocation
Thomassen et al. (2008)	1.56	1.61	0.901	-
Casey & Holden (2005)	1.45	1.3	-	1.5

The Casey & Holden (2005) study shows that the difference between no allocation and economic allocation can be up to 15%. The difference between mass and economic allocation is 3% in the study by Thomassen (2008) and 10% in the study by Casey & Holden (2005).

[17] The effect on climate change is higher for economic allocation than for mass allocation, even though the environmental burden attributed to milk is lower in the former case. Allocation is not only applied to milk/meat but also to other processes like feed production.

B.2 Functional unit

A functional unit is a 'specification of the material or immaterial function of a product or product system used as a basis for the selection of one or more products which could provide that function' (Heijungs, 1992). The functional unit is a reference flow to which all other flows in the LCA are related (Berlin, 2002). This means that different functional units could yield different results.

The functional unit used in the LCA studies for milk are either 1 kg milk, 1 kg FPCM (Fat and Protein Corrected Milk), 1 kg ECM (Energy Corrected Milk) or 1 liter milk.

Definitions given for these functional units include:

FPCM (kg) = $(0.337 + 0.116 \times \%F + 0.006 \times \%P) \times M$, with $\%F$ the percentage fat, $\%P$ the percentage protein and M kg milk (Thomassen, 2008).
ECM (kg) = $0.25 \times M + 12.2 \times F + 7.7 \times P$, with M kg milk, F kg fat and P kg protein (Casey & Holden, 2005b).
Milk (l) = $\frac{M}{1.03}$, with M kg milk (Casey & Holden, 2005b).
In this report, it is assumed that: 1 kg milk = 1 kg FPCM = 1 kg ECM = 1 liter milk.

The difference between1 kg FPCM and 1 kg ECM is approximately 0%-1%[18]. The difference between 1 kg milk and 1 liter milk is approximately 3%.

B.3 Farm type

The LCA studies also differ in the sort of farm they look at. The studies that look at experimental farms may obtain different results than the studies that look at commercial farms within a country. Some studies do not look at specific farms, but model an average farm.
The effect of different farm types on the global warming potential is difficult to quantify.

[18] Several fat and protein percentages were used to assess the difference between ECM and FPCM.

C Characteristics of the LCA studies

Table 14 Parameters of the LCA studies

Country	System	# farms	Sort farm	Yield (kg per Cow)	FU	Allocation	Kg CO_2 eq./FU	Source
The Netherlands	Conv.	10	Commercial	7,991	Kg FPCM	91/9	1.4	(1)
	Org.	11	Commercial	6,138	Kg FPCM	90/10	1.5	(1)
The Netherlands	Conv.	1	Experimental	-	Kg FPCM	86/14	0.888	(2)
	Env. Friendly	1	Experimental	-	Kg FPCM	86/14	0.689	(2)
	Org.	1	Experimental	-	Kg FPCM	86/14	0.922	(2)
Sweden	Conv.	1	-	7,813	Kg ECM	85/15	1.08	(3)
	Org.	1	-	7,127	Kg ECM	85/15	0.95	(3)
Sweden	Conv. high	9	Commercial	9,240	Kg ECM	90/10	0.896	(4)
	Conv. med.	8	Commercial	8,340	Kg ECM	90/10	1.037	(4)
	Org.	6	Commercial	7,690	Kg ECM	90/10	0.938	(4)
Germany	Int.	6	Commercial	6,758	Kg milk	?	1.3	(5)
	Ext.	6	Commercial	6,390	Kg milk	?	1	(5)
	Org.	6	Commercial	5,275	Kg milk	?	1.3	(5)
UK	Conv.	All	Model	5,000	L milk	Econ.	1.06	(6)
	Org.	All	Model	6,500	L milk	Econ.	1.23	(6)
France	10-30% maize	24	-	6,444	L milk	?	1.17	(7)
Ireland	Conv.	All	Model	4,822	Kg ECM	85/15	1.3	(8)
US	Conv.	2	-	4,894	Kg milk	No	1.09	(9)
Canada	Conv.	All	Model	9,400	Kg milk	?	1.02	(10)
New-Zealand	Conv.	All	Model	4,120	Kg ECM	85/15	0.718	(11)
New-Zealand	Conv.	All	Average	3,571	L milk	?	0.859	(12)
Australia	Conv.	-	-	-	L milk	?	1.0385	(13)

D Geographical definitions

ANNEX 1
Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, United States of America

EU-15: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom.

Europe (other) : Bulgaria, Croatia, Czech Republic, Estonia,Hungary,Iceland, Latvia, Liechtenstein, Lithuania, Monaco, Norway, Poland, Romania, Slovakia, Slovenia, Switzerland

Europe = EU-15 + Europe (other)

EU-27: Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom.