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GHG survey of German agriculture -specific view on dairy production systems

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Abstract

This paper comprises a summary and categorization of different greenhouse gases occurring in different sectors in Germany and from agricultural and dairy production systems in particular. Further specific characterisation of different greenhouse gases, including nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) is given regarding their primary sources and especially the major processes stemming from the farming sector which are responsible for and influence their occurrence. In 2007 Germany emitted nearly 1 billion t CO_2-equivalents, of which 5.6% stemmed from agricultural processes.

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1 Greenhouse Gases in Germany

As a consequence of national efforts to reduce GHG emissions from different sectors in Germany, the overall emission levels of anthropogenic gases declined markedly over recent decades. According to the results of the UMWELTBUNDESAMT (UBA, 2009) and DÄMMGEN (2009) Germany´s GHG emissions in 2007 added up to 942 047 000 t CO_2-equ. in total. The following graphic presents the development of overall GHG emissions in CO_2-equ. from all sectors of the German economy. As illustrated in the figure below, total emissions diminished by 20.8% from 1990 to 2007. CO_2 accounts for about 86% of total emissions each year on average. This GHG is followed by CH_4, with an average yearly fraction of 6.6% and N_2O with about 5.7% of total emissions (expressed in CO_2-equ). The emissions of the remaining GHGs (like HFCs, PFCs, SFs)[1] are negligible, amounting to 1.4% of total emissions on average. Because of these exiguous amounts, stemming mainly from industry emissions, HFCs, PFCs and SFs are not considered further here.

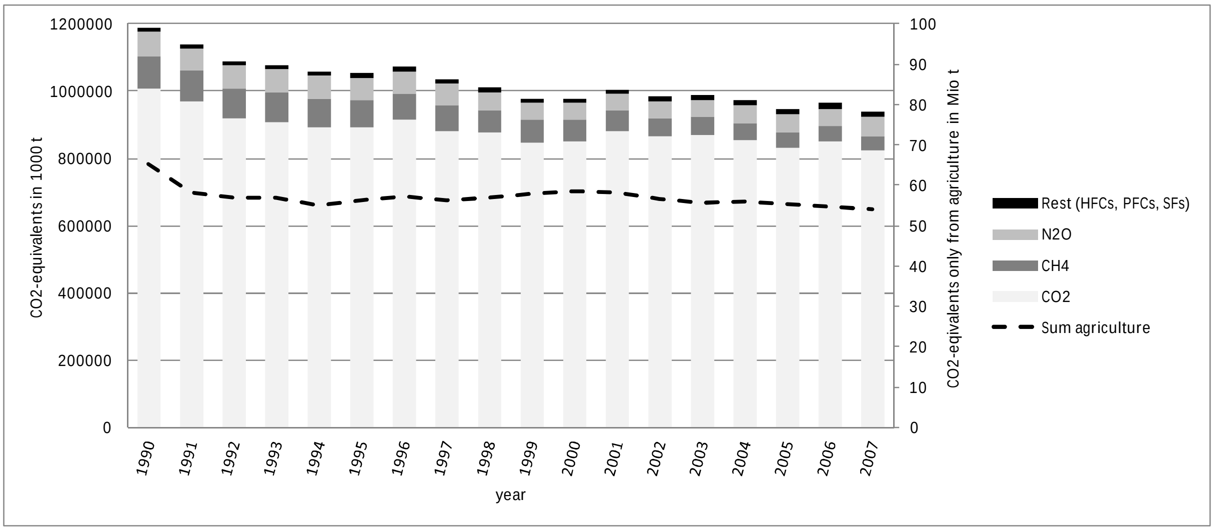

Figure 1: Total GHG emissions in Germany from 1990–2007 in 1000t CO_2-equivalents

(own illustration following UBA, 2009)

Specific values for the year 2007 are highlighted in Table 1, showing amounts of the single basic gases emitted in CO_2-equivalents. Nearly 9/10 of total emissions were as direct CO_2 gas followed by 5.9% from N_2O and 4.5% CH_4 (expressed in CO_2-equ.). Consequently, concern-

[1] These are the three greenhouse gases (major industrial) - hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfurhexafluoride (SFs).

ing the relative fraction of each GHG type, no evident change took place comparing their relative values in 2007 with their average fractions over time. But changes in the emission levels of single gases occurred from 1990 until 2007. CO_2 decreased by 18.2%, CH_4 decreased by 56.5% and N_2O declined by 20.8% (UBA, 2009). Weighting these deteriorations by the average fractions of each gas, it sums up to an overall decline in GHGs of 20.8%, as already stated at the beginning of this chapter.

Table 1: Specific values of GHG emissions by Germany in 2007 (basic gas calculation of Rest not possible because of different GWP-potentials of the gases)

(own calculation and illustration following DÄMMGEN, 2009 and UBA, 2009)

gas [t]	percentage from whole emissions [%]	emission amount of basic gas [t]	emission amount [t CO2-equ]
CO2	87.7%	826424000	826424000
CH4	4.5%	2026286	42552000
N2O	5.9%	180252	55878000
Rest (HFCs, PFCs, SFs)	1.8%	-	17193000
Sum			942047000

Overall, GHG emissions from Germany added up to 942 Mio. t CO_2-equ. in 2007 as denoted by the table above. These can be allocated to single sectors of the economy congruent to their emission proportions (Figure 2).

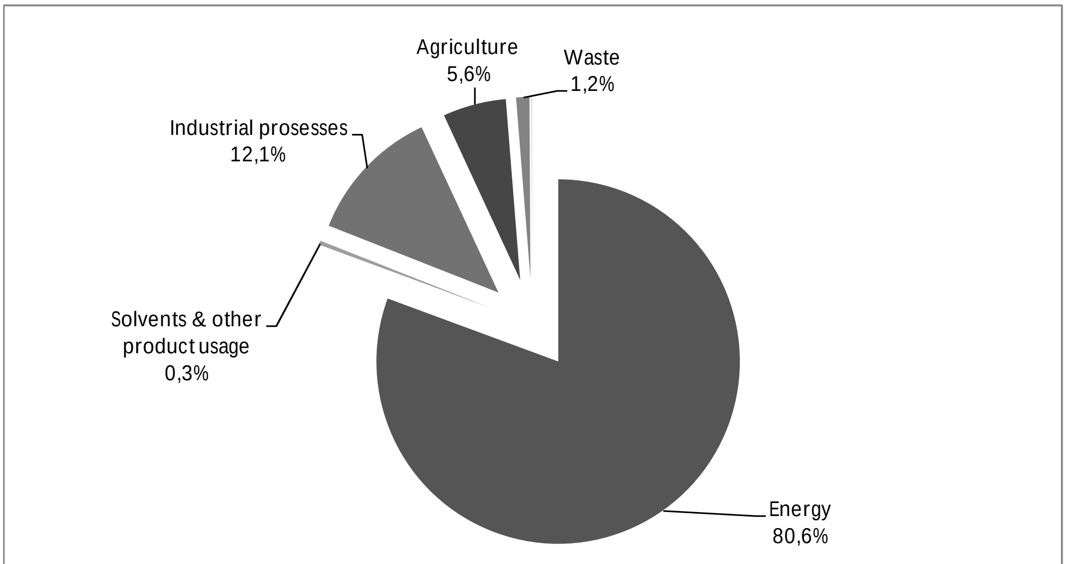

Figure 2: Contributions of emitting groups to total German emissions in2007

(own calculation and illustration following UBA, 2009)

As illustrated above, the majority of Germany´s GHG emissions in 2007 was determined by energy consumption (80.6%). 12% was produced by industrial processes and the agricultural sector emitted 5.6% of the total GHG in Germany, followed by waste management (1.2%) and solvents and use of other products (0.3%). So, agriculture produced about 54 Mio. t CO_2-equ, with 40.3% stemming from CH_4, 5% from CO_2 and 54.6% caused by direct and indirect nitrous oxide emissions (Table 2).

Table 2: GHGs of German agriculture in 2007 fragmented by gas type and compared with overall German GHGs.

(own calculation following DÄMMGEN, 2009 and UBA, 2009)

gas	emission amount [t]	fraction of overall emissions of gas type from all industry sectors[%]	fraction on overall emissions from agriculture [%]	emission amount [t CO2 equ]
CO2	2703000	0.3%	5.0%	2703000
CH4	1040118	51.3%	40.3%	21842484
N2O direct	77292	42.9%	44.2%	23960461
N2O indirect	18200	10.1%	10.4%	5642000
		Sum:	100.0%	54147945

Overall GHG emissions from agriculture in Germany declined by 17% from 1990 until 2007 as shown by the illustration below. According to Table 2, agricultural production is only responsible for 0.3% of German CO_2 emissions. But viewed from agriculture’s fraction of methane and nitrous oxide emissions, agriculture turns out to be a meaningful emitter, accountable for 53% of nitrous oxide (direct + indirect) and 51.3% of German methane emissions in 2007. Even though the proportions of total CH_4 and N_2O in the overall German emissions are relatively low (CH_4: 6.6%; N_2O: 5.7%) it is important to take a closer look at the involved sources in the agricultural sector, because by emitting more than the half the total N_2O as well as CH_4 in Germany, focusing on the main emitting sources can lead to further abatement potentials.

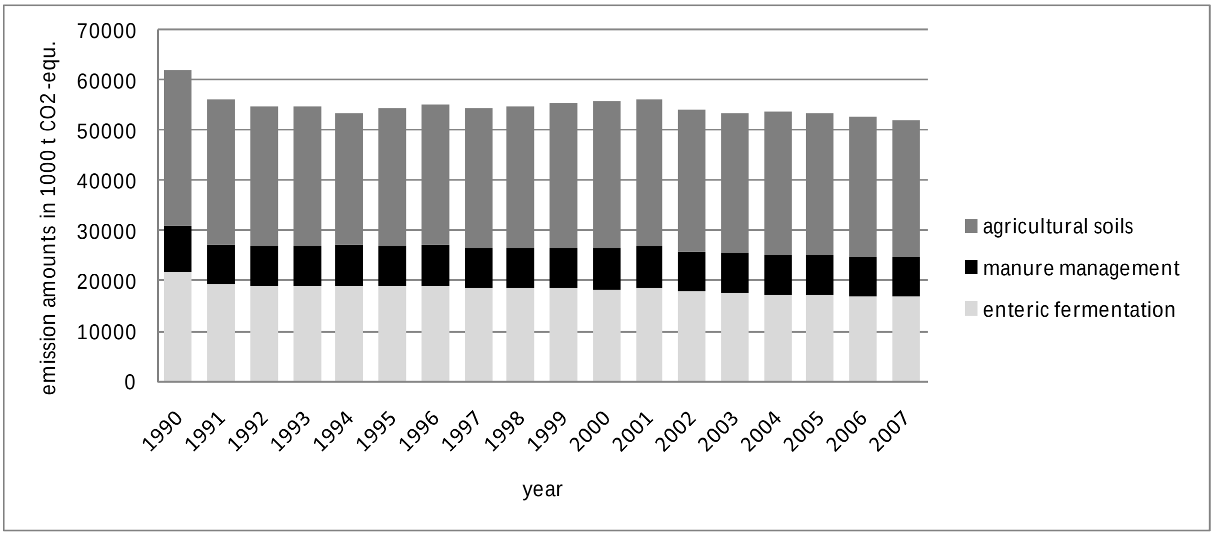

Figure 3: Production of GHG emissions in 1000 t CO_2-equ. from German agriculture by source

(own calculations and illustration following DÄMMGEN, 2009 and UBA, 2009)

With nearly constant emissions from manure management (organic as well as mineral), the 17% decrease in total emissions from agriculture from 1990 to 2007 can mainly be traced back to reductions in GHGs caused by ruminant fermentation processes (partly due to smaller animal numbers, e.g. from dairy as a main CH_4 emitter, a sector which decreased by 35% in terms of animal numbers during that time period (DÄMMGEN, 2009:p.263)) and varying emissions from agricultural soils (depending on cultivation and climatic impacts).

Apparently, the largest share of each year's agricultural emissions (in CO_2-equ.) stems from agricultural soils (about 54% on average from 1990 to 2007) which were responsible for the highest percentages of whole agricultural N_2O and CO_2 emissions (shown in the fifth column of Table 3). Concerning methane emissions, enteric fermentation can be identified as the main culprit. More than ¾ of agricultural methane emissions are caused by ruminant fermentation processes, followed by anaerobic processes in manure during different storage techniques. But as seen in the table below, deposition of CH_4 in the soil is also possible, quantifiable as 30200 t CH_4 in 2007, which, however, reduces overall agricultural emissions only marginally.

Table 3: GHGs from German agriculture separated according to production source

(own calculations and illustration following DÄMMGEN, 2009)

Source/Sink	gas	emission amount [t/a]	emission amount in CO2-equ. [t CO2-equ]	percentage of gas type caused by source
enteric fermentation	CH4	809285	16994985	76%
manure management	CH4	261033	5481699	24%
	N2O	7752	2403061	8%
agricultural soils	CH4	-30200	-634200	-3%
	N2O	87740	27199400	92%
	CO2	2703000	2703000	100%
		Sum:	54147945	

Since agriculture is responsible for more than the half the overall German methane and nitrous oxide emissions (Table 2), it is important to take a look at the specific sources of these high levels in agriculture. Enteric fermentation processes emitted 809285 t of CH_4 in 2007, of which 91.7% stemmed from ruminant fermentation of cattle in general. 46.5% can be ascribed to dairy cows alone. Adding fractions of heifers and calves, dairy farm systems (cows, heifers and calves) are responsible for nearly 70% of German methane emissions from digestive activities. Other animal production systems emit only minor amounts of CH_4 due to smaller numbers of animals (like sheep) or the animals being monogastrics. (DÄMMGEN, 2009)

Nearly 50% of methane emissions from manure management were caused by cattle husbandry, directly followed by pigs with 47.3%. Other animal categories were only responsible for percentages of about 1%. Also, with regard to manure management as a source, dairy farm systems represented a high fraction of total methane emission, with the amounts from dairy cows, heifers and calves adding up to 40.1% of total manure caused methane.

In the case of nitrous oxide production from manure management activities, the polluter weighting is nearly the same. Cattle farms in total emitted about ¾ of N_2O emissions from animal excreta. Again here, dairy farm systems are primarily liable (64.9%), followed by pigs (19%) and only minor fractions of poultry and other animals.

In the following table, total agricultural emissions of methane, nitrous oxide and carbon dioxide are allocated to the different animal production categories and soils, summing up the previously stated amounts of emissions from enteric fermentation, manure management and agricultural soils.

Table 4: GHGs allocated by emitting groups

(own calculation and illustration following DÄMMGEN, 2009)

	CO2	CH4	N2O
total amount [t/a]	2703000	1040118	95492
dairy cows		43.9%	3.0%
cows+heifers+calves		63.8%	5.3%
cattle total		83.7%	6.1%
pigs		15.0%	1.5%
poultry		0.4%	0.2%
sheep		2.0%	0.0%
other		1.8%	0.3%
soil activities	100.0%	-2.9%	91.9%

It can be seen that, for CH_4 as well as N_2O, cattle husbandry systems are responsible for the majority of emissions from animal production. Dairy production systems (including cows, heifers and calves) are responsible for the majority of CH_4 (63.8%) and N_2O (5.3%) by themselves. As shown in Figure 2, agriculture accounted for about 5.6% of overall 2007 German GHGs (in CO_2-equ.), whereas cattle are responsible for 81% of overall livestock emissions (see the left side of Figure 4). Animal husbandry in dairy production systems accounted for nearly 1/3 of Germany´s emissions from agricultural production as a whole and about 75% (right diagram of Figure 4) of German cattle livestock induced emissions (in CO_2-equivalents) (calculations according to data from DÄMMGEN, 2009).

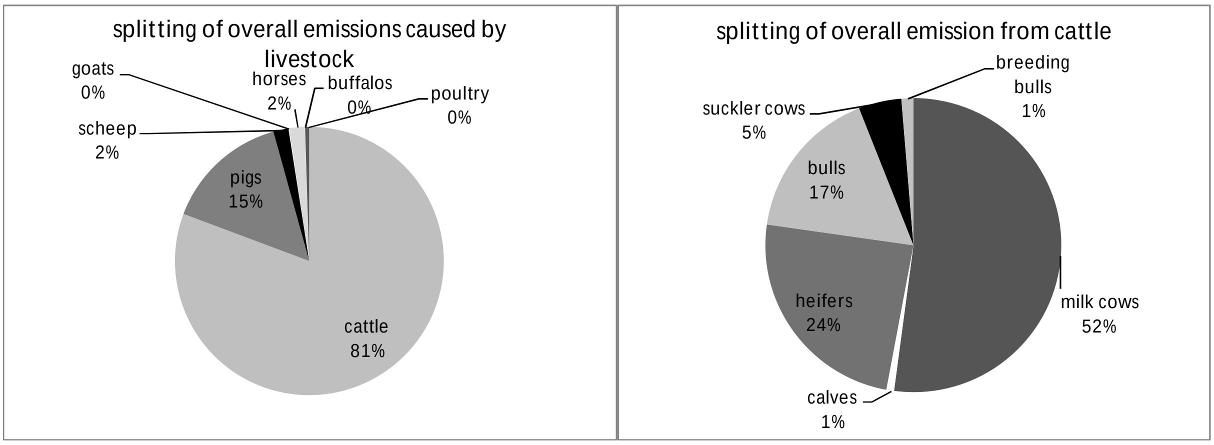

Figure 4: fractions of overall emissions from German livestock in CO_2-equivalents assignable to different sources

(own calculations and illustration following DÄMMGEN, 2009 and UBA, 2009)

It can be concluded from the aforementioned summary of emissions from German agriculture and their apportionments to different single responsible sources that dairy production systems as a whole and dairy cows in particular can be identified as the main emitters of agricultural GHG emissions. As highlighted on the left side diagram of Figure 4, cattle livestock systems are responsible for 81% of overall GHG emissions from German livestock production. This level produced by cattle husbandry is basically caused by dairy production systems (77%), summing up the percentages due to heifers, calves and milk cows from the right hand side of the diagram. The picture even intensifies by taking soil cultivation into account, which has to be done in light of the 'whole farm' approach, as it builds the basis for fodder production and application of organic fertilizers. Hence, dairy production systems will play a decisive role concerning GHG abatement efforts in Germany. It is important to do further research on emission abatement strategies, abatement potentials and their economic incentives and effects at the dairy farm level.

2 Greenhouse gases in dairy production

In the following sections the most important greenhouse gases (CH_4, N_2O, CO_2) resulting from production processes on dairy farms are defined. The main sources at the farm level important for the occurrence of gaseous emissions are allocated.

2.1 Methane

The major sources of agricultural CH_4 emissions (a colorless, odourless gas) are the enteric fermentation of ruminants and their excrements through anaerobic processes (ERG, 2008:p.3; HARTUNG, 2002:p.193). Emissions from enteric fermentation are primarily caused by eructation, stemming mainly from the rumen (87%) and to a small extent from the large intestines (13%) (MURRAY et al., 1976:p.9). It occurs during the process of converting feed material in the animal´s fore stomach[2] by the inclusion of different types of microbial species (bacteria, protozoa and fungi) (SHIH et al., 2006:p.4; UBA, 2010:p.365). The intermediate products of these microbial species are converted to CH_4 by methanogenic bacteria[3]. (MOSS et al., 2000:pp.236-237) Concerning differences in livestock type, age, size, fodder intake and fodder digestibility, CH_4 emissions between individual animals and different livestock types vary significantly (CHADWICK and JARVIS, 2004:p.69; FLACHOWSKY and BRADE, 2007:pp.436-

[2] A detailed description of ruminal processes is given in BATES (2001:pp.36-37) and MOSS et al. (2000).

[3] Detailed characterization of methanogens in BOADI et al. (2004:p.321).

438; WILKERSON et al., 1995:p.2403). Furthermore, the lactation periods and proficiency levels of animals have a meaningful impact (JUNGBLUTH et al., 2001:p.135).

But as mentioned before, CH_4 is also emitted from the excrements of the animals. Following e.g. HUSTED (1994) and HARTUNG (2002:p.195), stable floor conditions and manure storage techniques (outdoors or in sub-floor pits) are important CH_4 sources on farms, with different emission rates dependent on the specific type of manure handling (slurry, solid, deep litter and manure removal frequencies from stables). As methane is produced by anaerobic digestion[4] of organic components in the manure, CH_4 emissions are high when liquid storage techniques are used (SHIH et al., 2006:p.4) compared to storage techniques with higher aeration rates (e.g. straw based systems). (CHIANESE et al., 2009b; JANZEN et al., 2006) Animal type and number, temperature, manure amount and management system can thus be named as the primal factors that affect methane emissions. Regarding this, SMITH et al.[5] (2008:p.797) summarised the biophysical reduction potentials of dairy cows. For Western Europe, a reduction potential of 18% is inherent in improved feeding strategies. According to these authors, dietary additives can lead to an 8% reduction and structural management strategies in combination with breeding activities can lead to a 4% decline in methane production. Hence, biophysical activities and implementations in dairy production systems play significant roles regarding methane production at the farm level.

Overall, German methane emissions declined by 56% from 1990 to 2007, as shown in Figure 5. But the total amount stemming from agriculture stayed nearly constant, at 21 842 484 t CO_2-equ. Of agricultural emissions in 2007, 76% stemmed from enteric fermentation and 24% came from manure management processes. (DÄMMGEN, 2009) Hence, looking at the development of methane emissions resulting from manure management, agricultural soils and enteric fermentation, abatement efforts in methane emissions failed to have major impacts.

[4] Methane is the end product of the chemical reduction of carbon compounds under anaerobic conditions (CLEMENS et al., 2002:p.203; BURTON and TURNER, 2003:p.89).

[5] The values derived by SMITH at al. (2008) have been adjusted for the non-additivity of the individual options. In reality, interactive effects between practices can occur.

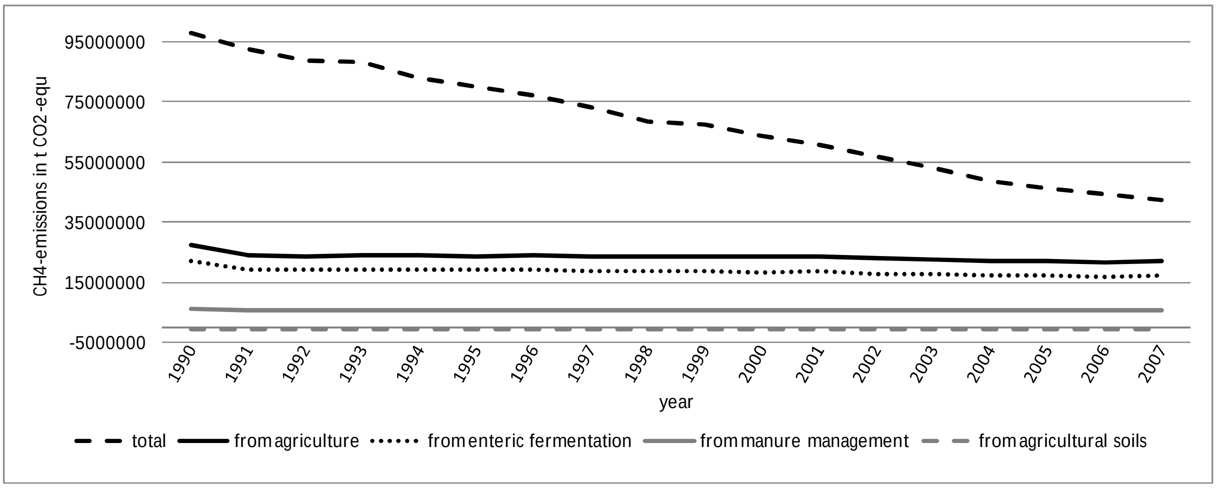

Figure 5: Methane emissions in t CO_2-equ. from 1990 to 2007 in all of Germany and separated by area of agricultural production

(own illustration following DÄMMGEN, 2009; UBA, 2009)

2.2 Nitrous Oxide

N_2O emissions are mainly related to microbial nitrogen transformation processes in soils and in manure, which are controlled by manure management and application as well as application of fertilizers. Following FRENEY (1997), soils are meant to be the most important natural source of N_2O production, being responsible for 90% of overall agricultural N_2O emissions. As nitrous oxide emissions originate out of nitrogen, controlling the nitrogen content in the manure and adjusting nitrogen applications to demand are the most readily controllable. As nitrous oxide stems from imperfect denitrification[6] and nitrification[7] of nitrogen in agricultural production processes, all factors influencing rates of imperfect nitrogen conversion are important for controlling N_2O production rates (CHADWICK and JARVIS, 2004:p.70). Nitrous oxide is an intermediate product of an aerobic process, where the availability of oxygen is too low for an optimal nitrification process (SIBBESEN and LIND, 1993). These processes affecting N_2O rates are not only relevant for agricultural soils, but also occur with different surface types of stacked or stored manure, in dung storage areas or on differently constituted stable floors (ROTZ et al., 2010:p.1271). When there is no oxygen available at all, for example in liquid manure without a layer of scum, the potential for N_2O outgassing is relatively low (CLEMENS et al., 2002:p.204). Nevertheless there are several environmental factors affecting nitrous oxide emissions that are not controllable by the farm, for example temperature, dry

[6] Formation of nitrogen gas from nitrate reduction (anaerobic) (MONTENY et al., 2006:p.165).

[7] Transformation of ammonium to nitrate (aerobic) (MONTENY et al., 2006:p.165); for a detailed description of nitrification and denitrification see BURTON and TURNER (2003: pp.58-64), AMON (1998:p.14).

matter content and soil conditions. A detailed description of the influence of these factors on the rate of N_2O emissions is given e.g. by HARTUNG (2002:pp.193-194). Other factors regarding manure and fertilizer management can be actively controlled (e.g. fitting available N to plant requirements, application technique, rates and times, manure type, stocking densities and type of production system). BOUWMAN (1996), for example, appraised the application of N fertilizer as the main factor in nitrous oxide emission rates from agricultural soils. BROWN et al. (2001:p.1448) also defined fertilizer, animal manure application and urine deposition by grazing livestock as major sources. The housing system also plays a significant role, just as floor conditions and ventilation rates are also important influencing factors.

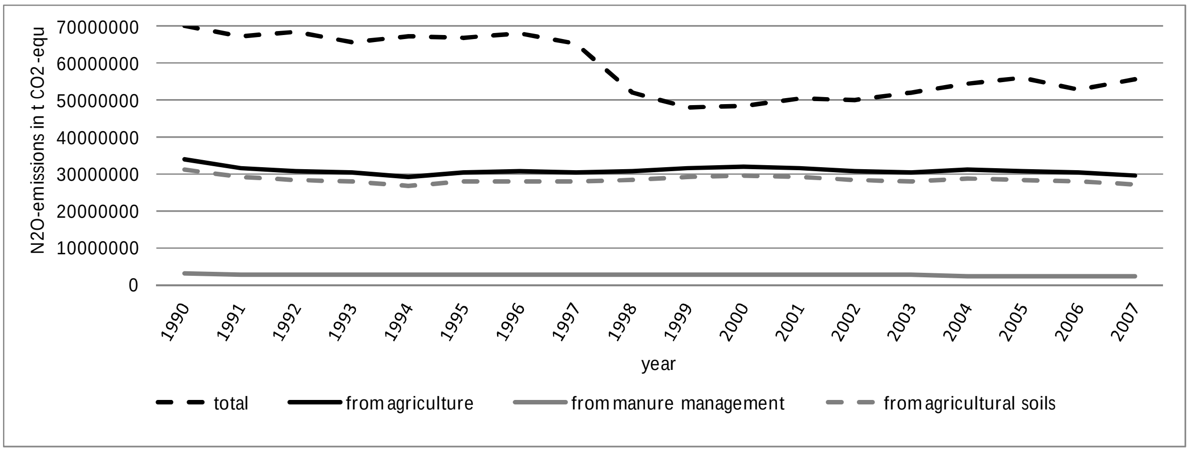

Figure 6: Nitrous oxide emissions in t CO_2-equ. from 1990 to 2007 in all of Germany, and separated by sector of agricultural production

(own illustration following DÄMMGEN, 2009; UBA, 2009)

Total nitrous oxide emissions from Germany decreased significantly until 2007. But emissions from agriculture (sum of N_2O from manure management and soils) stayed nearly constant over time, subject only to small variations (Figure 6).

2.3 Carbon dioxide

Multiple processes assimilate and emit CO_2 from dairy farms. Cropland activities assimilate carbon dioxide from the atmosphere through photosynthetic activity during crop growth, and emit CO_2 through plant and soil respiration and manure decomposition. As described by CHIANESE et al. (2009a), croplands act as a net sink over a full year, meaning that plants assimilate more carbon dioxide as biomass than they emit during crop growth. In contrast, it is possible agricultural soil is a net source when permanent grassland is ploughed, which leads to large gaseous emissions of CO_2. So the CO_2 balance between removal by and emissions from agricultural soil is not certain, as also shown in a study by the EPA (2006). In addition, soil emissions and animal respiration are major sources of CO_2 on dairy farms, followed by less meaningful emissions of CO_2 from manure storage systems and barn flooring (BURTON and TURNER, 2003:p.89). (ROTZ et al., 2010:p.1266). Furthermore, general tillage techniques impact carbon sequestration rates.

3 Main sources of GHGs

As mentioned in the preceding paragraphs, four sources of GHG production in dairy farming can be identified. Animals as production units by ruminant fermentation, processing of the accumulated excreta, emissions from fertilizer practice and GHGs from soil cultivation are accountable for CO_2, CH_4 and N_2O emissions as visualized in the following figure.

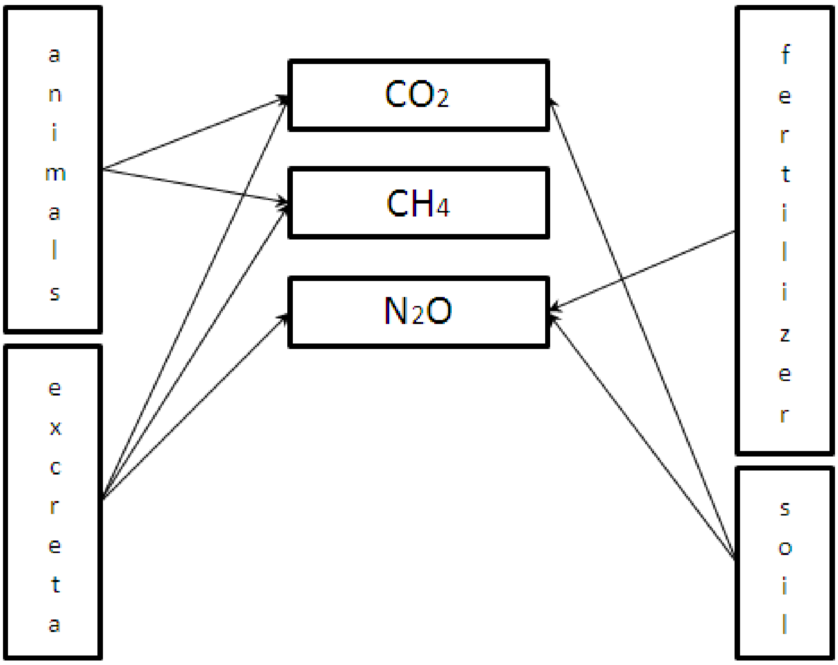

Figure 7: Main sources of GHGs in dairy production

(own illustration following HARTUNG and PHILLIPS, 1994:p.174; EC, 2010:p.44)

The main sources of CO_2 in dairy production are soil cultivation followed by animal respiration and excreta. Methane is primarily caused by enteric fermentation processes and manure management. For example, methane emissions from enteric fermentation and manure management accounted for 2/3 of the overall global methane emissions from agriculture in 2005 (EPA, 2005:pp.54-65). High nitrous oxide emission rates are principally generated by sources of high nitrate compounds or activities with large influences on their application, such as animal excreta and fertilizer use in combination with land cultivation.

4 Global warming potential

The above-mentioned greenhouse gases from agricultural dairy production do not have exactly the same origins in the production process; gaseous emission rates of CH_4, N_2O and CO_2 have different abetting factors. Circumstances that boost the emission rates of the different gases can even compete against each other, which means e.g., conditions lowering CH_4 emissions lead to higher N_2O emission rates and vice versa. This is caused by the different milieus in which the responsible chemical processes of gaseous emissions proceed. CH_4 emissions are normally supported by anaerobic circumstances, whereas nitrous oxide gases out in higher rates in an aerobic milieu (MONTENEY et al., 2001:p.130; WWF, 2007:p16). Focusing on this, trade-off effects can occur between the levels of emissions of different GHGs with changing production processes and conditions on the farm.

Furthermore, the different GHGs have unequal global warming potentials (GWP) (on the basis of 100 years global warming potential), and so can be expressed in CO_2-equivalents (CO_2-equ.) to obtain a uniform quantifying parameter. As denoted in the table below, different levels of GWP can intensify the aforementioned trade-offs between the gases. For example, changing a production process that lowers, on the one hand, emissions of CO_2 by one kilogram but on the other hand increases the emission of N_2O by one kilogram would lead to an overall increase in emissions of 309 kg CO_2-equ. The reason for this is that the GWP of one kg of nitrous oxide is 310 times that of one kg of carbon dioxide. The results of such trade-offs between different types of GHGs can be derived from the following table.

Table 5: Global warming potentials of the different greenhouse gases expressed in CO_2-equivalents per unit of the specific gas

(own illustration following UBA, 2009:p.57)

Greenhouse gas	composite	GWP (in CO2e)
Carbon Dioxide	CO_2	1
Methane	CH_4	21
Nitrous Oxide	N_2O	310

In terms of potential mitigating possibilities at the farm level by changing production processes or restructuring the overall production portfolio, the abatement effectiveness of the mitigation options always have to be evaluated with a view to their impacts on the accruement of other GHG types and their GWPs.

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