DANISH EMISSION INVENTORIES FOR AGRICULTURE

Inventories 1985 – 2011

Scientific Report from DCE – Danish Centre for Environment and Energy No. 108 2014

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Data sheet

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Abstract: Regulations in international conventions obligate Denmark to prepare annual emission inventories and document the methodologies used to calculate emissions. The responsibility for preparing the emissions inventory for agriculture is undertaken by the Danish Centre for Environment and Energy (DCE), Aarhus University, Denmark. This report contains a description of the emissions from the agricultural sector from 1985 to 2011 and includes a detailed description of methods and data used to calculate the emissions, which is based on international guidelines as well as national methodologies. The emission is calculated by using an Integrated Database model for Agricultural emissions (IDA), which covers all aspects of the agricultural inputs and estimates both greenhouse gases and air pollutants; methane (CH_4), nitrous oxide (N_2O), ammonia (NH_3), particulate matter (PM), non-methane volatile organic compounds (NMVOC) and other pollutants, which mainly are related to the field burning of agricultural residue such as NO_x, CO_2, CO, SO_2, heavy metals, dioxins, PAHs, HCB and PCBs. The largest contribution to agricultural emissions originates from livestock production, which is dominated by production of cattle and swine. The agricultural NH_3 emission from 1985 to 2011 has decreased from 116 800 tonnes NH_3 to 71 300 tonnes NH_3, corresponding to a reduction of approximately 39 %. The emission of greenhouse gases in 2011 is estimated at 9.7 million tonnes CO_2 equivalents and reduced from 13.4 million tonnes CO_2 equivalents in 1985. Since 1990, which is the base year of the Kyoto protocol a reduction of 23 % is obtained. Improvements in feed efficiency, the utilisation of nitrogen in livestock manure and a significant decrease in the consumption of synthetic fertiliser are the most important explanations for the reduction of NH_3. This has furthermore resulted in a significant reduction of N_2O emission, which is the main reason for a considerable fall in the total greenhouse gas.

Keywords:	Agriculture, NH_3, CH_4, N_2O, emission, ammonia, methane, nitrous oxide, particulate matter, greenhouse gas, inventory, Denmark.
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Preface

On behalf of the Ministry of the Environment and the Ministry of Climate, Energy and Building, Danish Centre for Environment and Energy (DCE) at Aarhus University (AU) is responsible for the calculation and reporting of the Danish national emission inventory to EU directives, the United Nations Framework Convention on Climate Change (UNFCCC) and the United Nations Economic Commission for Europe's Convention on Long Range Transboundary Air Pollution (UNECE CLRTAP). This documentation report for agricultural emissions has been externally reviewed as a key part of the general national inventory QA/QC plan.

The report has been reviewed by Heidi Ravnborg from the Danish Environmental Protection Agency.

Summary

International conventions obligate Denmark to prepare annual emission inventories and document the methodologies used to calculate emissions. The responsibility for preparing the emission inventory for agriculture in Denmark is undertaken by DCE - the Danish Centre for Environment and Energy, Aarhus University (AU). This report is an updated version of NERI Technical Report No. 810 published in 2011. The following chapters of the report include a detailed description of methods and data used to calculate the emissions.

The emissions from the agricultural sector include the greenhouse gases: methane (CH_4) and nitrous oxide (N_2O) as well as the air pollutants: ammonia (NH_3), particulate matter (PM), non-methane volatile organic compounds (NMVOC) and other pollutants specifically related to the field burning of agricultural residues such as nitrogen oxides (NO_x), carbon dioxide (CO_2), carbon monoxide (CO), sulphur dioxide (SO_2), heavy metals, dioxins, polycyclic aromatic hydrocarbons (PAHs), hexachlorobenzene (HCB) and polychlorinated biphenyls (PCBs).

The emission calculation is based on the *Integrated Database model for Agricultural emissions* (IDA). The model covers all aspects of the agricultural inputs and estimates both greenhouse gases and air pollutants. The largest contribution to agricultural emissions originates from livestock production and most of the input data are sourced from Statistics Denmark and from the Danish Centre for Food and Agriculture (DCA), Aarhus University. These data include the extent of the livestock production, land use, Danish standards for feed consumption and excretion. Furthermore, the estimation of nitrogen from leaching and runoff is based on data collected in connection with the Danish Action Plans for the Aquatic Environment. The emission inventory reflects the actual conditions for the Danish agricultural production. In cases where no Danish data are available, default values recommended by the Intergovernmental Panel on Climate Change (IPCC) and the European Monitoring and Evaluation Programme (EMEP) are used.

Approximately 96 % of the total NH_3 emission originates from the agricultural sector as does approximately 17 % of total greenhouse gas emission.

The agricultural ammonia emission from 1985 to 2011 has decreased from 116 800 tonnes of ammonia NH_3 to 71 300 tonnes NH_3, corresponding to a reduction of approximately 39 %. Converted to ammonia nitrogen (NH_3-N), the 2011 emission is estimated to 58 700 tonnes NH_3-N. Most of this ammonia emission is related to livestock manure and mainly from the production of swine and cattle.

Regarding NH_3 emission it has to be noted that the reported emission under the EU Directive - National Emissions Ceilings Directive (NECD) does not include emission from growing cops and ammonia treated straw. The NH_3 emission from all sectors in Denmark reported under NECD in 2011 is thus estimated to 69 500 tonnes, where the agricultural sector contributes with 65 500 tonnes NH_3.

The emission of greenhouse gases in 2011 is estimated at 9.7 million tonnes CO_2 equivalents and is reduced from 13.4 million tonnes CO_2 equivalents in 1985. Since 1990, which is the base year of the United Nations Framework Convention on Climate Change a reduction of 23 % is obtained.

The emission of CH_4 is primarily related to cattle and swine production, which contributed 73 % and 22 %, respectively. The CH_4 emission in 2011 is estimated to 198 gigagram (Gg), or given in CO_2 equivalents as 4.2 million tonnes.

The emission of N_2O primarily originates from transformation of nitrogen compounds in agricultural fields. The main sources are related to the use of livestock manure, synthetic fertiliser and nitrogen leaching and runoff. The emission of N_2O in 2011 is estimated to 17.8 Gg, corresponding to 5.5 million tonnes CO_2 equivalents.

Biogas plants that process animal slurry reduce the emission of CH_4 and N_2O. A methodology to estimate the emission reductions is not provided in the IPCC guidelines. The calculation of a lower emission from biogas treated slurry is based on the content of volatile solids and nitrogen. In 2011 approximately 6 % of all slurry was treated in biogas plants and the lower emission of greenhouse gases as a consequence of biogas treated slurry has resulted in a lower emission of 0.04 million tonnes CO_2 equivalents, corresponding to 0,4%.

Improvements in feed efficiency, the utilisation of nitrogen in livestock manure and a significant decrease in the consumption of synthetic fertiliser are the most important explanations for the reduction of NH_3. This development has furthermore resulted in a significant reduction of N_2O emission, which is the main reason for a considerable decrease in the total greenhouse gas emission. There has been a reduction in CH_4 emissions as a consequence of a decrease in the number of cattle. However, this trend is partially counteracted by changes in animal housing towards more slurry-based systems.

Sammenfatning

Hvert år opgøres bidraget af ammoniak og drivhusgasser fra Danmark. I forbindelse med en række internationale konventioner har Danmark, udover opgørelsen af emissionerne, også forpligtet sig til at dokumentere hvorledes emissionerne opgøres. Denne rapport er en opdatering af DMU faglig rapport nr. 810 publiceret i 2011.

Rapporten omfatter derfor dels en opgørelse, og dels en beskrivelse af metoden for beregning af landbrugets emissioner af drivhusgasserne: metan (CH_4) og lattergas (N_2O), luftforureningskomponenterne: ammoniak (NH_3), partikler (PM), flygtige organiske forbindelser (NMVOC) og andre stoffer, der er relateret til markafbrænding af afgrøderester fra landbruget som kvælstofilter (NO_x), kuldioxid (CO_2), kulilte (CO), svovldioxid (SO_2), tungmetaller, dioxiner, polycykliske aromatiske kulbrinter (PAH'er), hexaklorbenzen (HCB) og polyklorerede bifenyler (PCB'er). Opgørelsen omfatter perioden fra 1985 til 2011.

Landbrugets emissioner er beregnet på grundlag af en databasebaseret model kaldet IDA - Integrated Database model for Agricultural emissions. Størstedelen af emissionerne er relateret til husdyrproduktionen og langt de fleste inputdata er hentet fra Danmarks Statistik og det Danske Center for Fødevarer og Landbrug (DCA) ved Aarhus Universitet. Disse data omfatter bl.a. omfanget af husdyrproduktionen, arealanvendelse, normdata for foderindtag og dyrenes nitrogenudskillelse via gødningen, som er nogle af de vigtigste parametre for emissionsberegningen. Endvidere er beregningen for udvaskning af kvælstof til vandmiljøet baseret på beregninger foretaget i forbindelse med vandmiljøplanerne. Emissionsopgørelsen tager således højde for de faktiske forhold, der gør sig gældende for den danske landbrugsproduktion. For de områder hvor der ikke forefindes nationale data anvendes standardværdier fra The Intergovernmental Panel on Climate Change (IPCC) og The European Monitoring and Evaluation Programme (EMEP).

Langt størstedelen af den samlede NH_3-emission, svarende til ca. 96 %, kan henføres til landbrugssektoren, mens ca. 18 % af den totale drivhusgasemission stammer fra landbruget.

Ammoniakemissionen sker i forbindelse med omsætningen af kvælstof. Størstedelen af emissionen kommer fra husdyrgødning, hvor produktionen af svin og kvæg udgør de største bidragydere. Emissionen fra landbrug er fra perioden 1985 til 2011 faldet fra 116.800 tons NH_3 til 71.300 tons NH_3 svarende til en reduktion på 36 %. Opgjort som ammoniakkvælstof (NH_3-N) svarer emissionen i 2011 til 58 700 tons.

Det skal bemærkes, at NH_3-emissionen afrapporteret til EU´s direktiv for nationale emissionslofter (NEC) ikke omfatter emissionen fra voksende afgrøder og ammoniak behandlet halm. Således er den samlede NH_3-emission fra alle sektorer afrapporteret til NEC-direktivet opgjort til 69.500 tons NH_3 i 2011, hvoraf landbruget bidrager med 65 500 tons NH_3.

Den samlede emission af drivhusgasser fra landbrugssektoren i 2011 er 9,7 mio. tons CO_2-ækvivalenter. I perioden fra 1985 er emissionen faldet fra 13,4 mio. tons CO_2-ækvivalenter. Siden 1990, som er klimakonventionens basisår, er emissionen faldet fra 12,5 mio. tons CO_2-ækvivalenter hvilket svaret til en reduktion på 23 %.

Emissionen af CH_4 stammer primært fra kvæg (73 %) og svin (22 %). Den samlede emission af CH_4 er opgjort til 198 gigagram (Gg) i 2011 svarende til 4,2 mio. tons CO_2-ækvivalenter.

Som for NH_3's vedkommende er emissionen af N_2O knyttet til omsætningen af kvælstof. De største bidragsydere er emissionen fra handels- og husdyrgødning samt fra kvælstofudvaskningen fra landbrugsjorden. Den samlede emission i 2011 er opgjort til 17,8 Gg N_2O, svarende til 5,5 mio. tons CO_2-ækvivalenter.

Anvendelse af husdyrgødning i biogasanlæg reducerer emissionen af CH_4 og N_2O. Metoden for hvordan dette skal opgøres, er ikke beskrevet i IPCC guidelines, hvorfor den reducerede emission er opgjort på baggrund af danske antagelser. I 2011 behandles ca. 6 % af den samlede mængde gylle i biogasanlæg. Det forventes, at der fra biogasbehandlet gylle forekommer en lavere emission af drivhusgasser, hvilket er beregnet til at udgøre 0,04 mio. tons CO_2-ækvivalenter, svarende til 0,4 %.

De væsentligste forklaringer på reduktionen af NH_3, er en forbedring i fodereffektivitet, en bedre udnyttelse af kvælstofindholdet i husdyrgødningen og på baggrund heraf, et markant fald i anvendelsen af kvælstof i handelsgødning. Denne udvikling har samtidig betydet et markant fald i N_2O-emissionen, hvilket er den væsentligste årsag til reduktion i den samlede udledning af drivhusgasser fra landbruget. Der er sket en reduktion i CH_4-emissionen fra fordøjelsesprocessen som en konsekvens af faldet i antallet af kvæg. Dog er denne reduktion delvis modvirket af en omlægning i staldtyper fra systemer med fast gødning til flere gyllebaserede systemer, hvorfra der udledes en højere emission.

1 Introduction

As a signatory to international conventions Denmark is under obligation to prepare annual emission inventories for a range of pollutants. For agriculture, the relevant emissions to be calculated are ammonia (NH_3), the greenhouse gases (GHG): methane (CH_4) and nitrous oxide (N_2O), and other pollutants such as non-methane volatile organic compounds (NMVOC), particulate matter (PM) and a series of other pollutants related to the burning of crop residues on fields. The Danish Centre for Environment and Energy (DCE) under Aarhus University is responsible for calculating emissions and reporting the annual emission inventory. Most of the calculations are based on data collected from Statistics Denmark and the Danish Centre for Food and Agriculture (DCA), Aarhus University. In addition to the reporting of emission data, Denmark is obliged by the conventions to document the calculation methodology. This report, therefore, includes both a review of the emissions for the period 1985–2011 and a description of the methodology on which calculation of emissions is based.

The 1999 Gothenburg Protocol, under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP), and the EU's NEC Directive on national emission ceilings (2001/81/EC) commit Denmark to reduce NH_3 emissions from all sectors to 69 000 tonnes NH_3 by 2010. This ceiling is almost achieved, the NH_3 emission is 69 332 tonnes in 2010 and 68 508 tonnes in 2011. In 2011, 96 % of the total NH_3 emission in Denmark came from the agricultural sector, the remainder from the energy sector and industrial processes. It is important to point out that the Danish emission inventory reported under the NEC directive does not include the emission of NH_3 from crops, or from NH_3 treated straw.

Denmark has ratified the Kyoto Protocol under the UNFCCC. Under the Kyoto Protocol Denmark committed to reduce the emissions by 8 % compared to the base year. However, between EU Member States a burden sharing agreement was reached. Under this agreement Denmark committed to reduce the emission of greenhouse gases, measured in CO_2 equivalents, by 21 % from the level in the base year to the annual average in the first commitment period (2008-2012). In 2011, the agricultural sector contributed 17 % to the total emission of greenhouse gases in Denmark, measured in CO_2 equivalents. The relatively large contribution is due to the emission of CH_4 and N_2O from the sector. These gases have a higher global warming effect than CO_2. Measured in GWP (Global Warming Potential), the effects of CH_4 and N_2O are, respectively, 21 and 310 times stronger than that of CO_2 (IPCC, 1997).

The IPCC has developed guidance documents on how greenhouse gas emissions should be calculated. The two documents relevant to agriculture currently used under the UNFCCC is the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997) hereafter the IPCC Guidelines and the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000) hereafter the IPCC GPG. The guidelines are prepared for use in all countries based on a division of different climatic regions into different geographic locations. The guidelines, however, do not always represent the best method at the level of the individual country due to the different national circumstances. The IPCC, therefore, advocates the use, as far as possible, of national figures where data are available.

A good basis for calculating the emissions from the agricultural sector for Denmark is by making use of the extensive databases generated when:

a. calculating the normative values for feed consumption and nitrogen excretion associated with livestock husbandry (Poulsen, 2012; Poulsen et al., 2001; Poulsen & Kristensen, 1997; Laursen, 1994),

b. estimating the nitrogen content in crops (Kristensen & Kristensen, 2002; Kyllingsbæk, 2000; Høgh-Jensen et al., 1998) and

c. estimating nitrogen leaching (Børgesen & Grant, 2003 Waagepetersen et al., 2008, Windolf et al., 2011 and Windolf et al., 2012).

Agricultural emissions are calculated in an integrated national model complex (Integrated Database model of Agricultural emissions, IDA). This means that the calculation of emissions of NH_3, greenhouse gases and other pollutants have the same basis, i.e. the number of livestock, the distribution of types of livestock housing, fertiliser type, land use, etc. Changes in the emission of NH_3 will therefore have a direct effect on emissions of N_2O.

The emission inventory is continuously being improved with the availability of new knowledge. Over time, changes will be made to reflect changes in both emission factors and in the methodology in the IPCC Guidelines and in the national inventories. In the emission inventory, the aim is to use national data as far as possible. This causes high requirements for the documentation of data, especially in areas where the method used and the national data differ significantly from the IPCC's recommended standard values.

This report is an updated version of NERI Technical Report No. 810 (Mikkelsen et al., 2011). The report starts with an introductory overview of emissions in the period from 1985 to 2011, describing the changes in agricultural activities that have influenced the emissions. Thereafter, the IDA model used to calculate the emissions is described and a detailed description is provided on how the emissions for the individual pollutants are calculated.

2 Trends in agricultural emissions 1985-2011

This chapter describes the development in the agricultural emissions of air pollutions and greenhouse gases from 1985 to 2011. The first group includes pollutants involved in air pollution, i.e. ammonia (NH_3), nitrogen oxides (NO_x), particulate matter (PM), non-methane volatile organic compounds (NMVOC) and other air pollutants (SO_2, CO, heavy metals, PAHs, dioxins, PCBs and HCB), which all have to be reported under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). Emissions of other air pollutants are only related to the field burning of agricultural residues. The second group includes the direct greenhouse gases, which have to be reported to the Kyoto Protocol under the Climate Convention, i.e. methane (CH_4) and nitrous oxide (N_2O). Pollutants that have an indirect effect on greenhouse gas emissions, i.e. NMVOC and (NO_x) from growing crops, carbon monoxide (CO) and sulphur dioxide (SO_2) from field burning, have to be estimated and reported to both the UNFCCC and the CLRTAP. Table 2.1 gives an overview of the conventions, the required reporting format and which pollutants they cover.

Table 2.1 Overview of conventions and pollutants.

Convention	Report format	Pollutants
The United Nations Framework Convention on Climate Change (UNFCCC). Including the Kyoto Protocol.	Data: CRF (Common Reporting Format) Report: NIR (National Inventory Report)	Direct greenhouse gases; CH_4, N_2O, CO_2[1] Indirect greenhouse gases; NMVOC, NO_x, CO, SO_2[1]
The UNECE Convention on Long-Range Transboundary Air Pollution. Including 8 protocols.	Data: NFR (Nomenclature For Reporting) Report: IIR (Informative Inventory Report)	Main Pollutants (NH_3, NO_x NMVOC, SO_2) Particulate Matter (TSP, PM_{10}, $PM_{2.5}$) Other pollutants (CO) Priority metals (Pb, Cd, Hg) Other metals (As, Cr, Cu, Ni, Se, Zn) PAHs (benzo(a)pyrene, benzo(b)fluoranthene, benzo-(k)fluoranthene, Indeno(1,2,3-cd)pyrene) Dioxins and furans (PCDD/-F) Polychlorinated biphenyls (PCBs) Hexachlorobenzene (HCB)
EU's Directive on national emission ceilings (NECD) (2001/81/EC)	NFR (Nomenclature For Reporting)	NH_3 (excl. emission from crops and NH_3 treated straw) NMVOC, NO_x, SO_2

[1] In the present CRF format it is not possible to report CO_2 and SO_2 from field burning of agricultural residues. However, the CO_2 emission from field burning is seen as CO_2 neutral.

It must be noted that CO_2 removals/emissions from agricultural soils are not included in the emission inventory for the agricultural sector. According to the IPCC guidelines this removal/emission should be included in the LULUCF sector (Land-Use, Land-Use Change and Forestry) (Gyldenkærne et al., 2005). The same comment applies to the emission related to agricultural machinery (tractors, harvesters and other non-road machinery) these emissions are reported in the energy sector.

It should also be noted that the agricultural emissions include two non-agricultural activities, i.e. emissions from horses in riding schools and from synthetic fertiliser used in parks, golf courses and sports grounds. These emission sources cover approximately 1 % of the total agricultural emissions.

2.1 Air pollutants

Table 2.2 shows the agricultural contribution of emissions to the national total in 2011. The main part of the NH_3 emission (96 %) is related to the agricultural sector, while the agricultural part of TSP and PM_{10} are 32 % and 21 %, respectively. The agricultural contribution to the total emissions of $PM_{2.5}$, NMVOC, SO_X and NO_X is low (<1 % - 4 %). Emissions of HCB and PCB will be included in the annual emission inventory from year 2014 and the agricultural emission is expected to contribute with less than 1 % of the total.

Table 2.2 Emission 2011, reported to UNECE, January 2013.

	NH_3	TSP	PM_{10}	$PM_{2.5}$	NMVOC	SO_X	NO_X
National total, Gg	74	38	29	23	81	15	132
Agricultural total, Gg	71	12	6	1	2	<1	<1
Agricultural part, %	96	32	21	4	2	<1	<1

2.1.1 NH_3

Approximately 96 % originates from the agricultural sector and the remainder from the energy sector, industrial processes and waste. Most of the NH_3 emissions from agricultural activities relate to livestock production, the remaining 15 % - 20 % from the use of synthetic fertiliser, growing crops, NH_3 treated straw, the field burning of agricultural residues and sewage sludge applied to fields as fertiliser.

Figure 2.1 shows the emissions divided into the different sources. The emission of NH_3 from the agricultural sector decreased from 96 Gg NH_3-N in 1985 to 59 Gg NH_3-N in 2011, which corresponds to a 39 % reduction.

The significant decrease in NH_3 emissions is a consequence of an active national environmental policy over the last 20 years. A string of measures have been introduced by action plans to prevent the loss of nitrogen from agriculture to the aquatic environment, for example the NPO (Nitrogen, phosphor, organic matter) Action Plan (1986), Action Plans for the Aquatic Environment (1987, 1998, 2004), the Action Plan for Sustainable Agriculture (1991) and the Ammonia Action Plan (2001). These actions plans and initiated measures have brought about a decrease in animal nitrogen excretion, improvement in use of nitrogen in manure and a fall in the use of synthetic fertiliser, all of which have helped reduce the overall NH_3 emission significantly.

Emission from 'Straw' includes both emissions from NH_3 treated straw and from field burning of agricultural residues. As a result of livestock regulations (BEK, 2002) NH_3 treatment of straw was banned from 1 August 2004. Field burning of agricultural residues has been prohibited in Denmark since 1990 (BEK, 1991) and may only take place in connection with the production of grass seeds on fields with repeated production and in cases of wet or broken bales of straw.

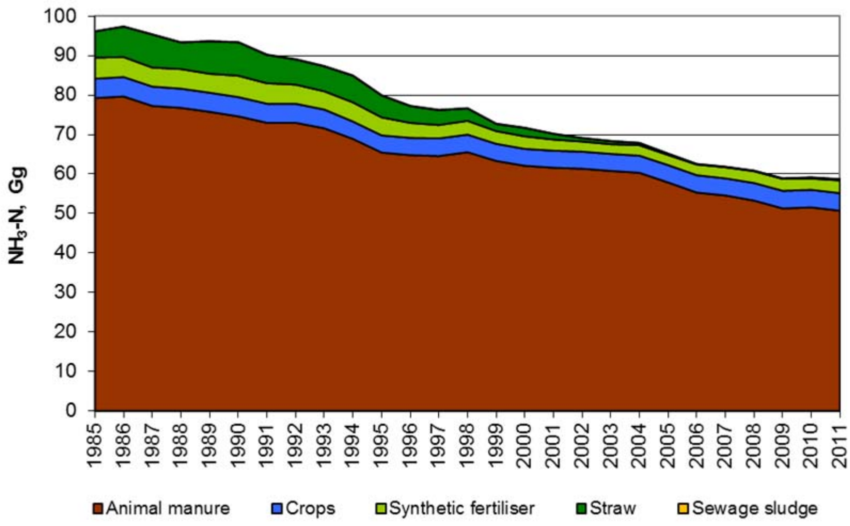

Figure 2.1 NH_3-N emissions in the agricultural sector, 1985 to 2011. Straw includes NH_3 treated straw and field burning of agricultural residues.

The total NH_3 emission is strongly correlated to a decrease in the emission from livestock production.

It is important to highlight the difference between the NH_3 emission expressed in nitrogen NH_3-N and that expressed in total NH_3. The conversion factor is 17/14, corresponding to the difference in the molecular mass. In appendix A, the trend for NH_3 emission from 1985 to 2011 from different sources is expressed in both NH_3-N and NH_3.

NH_3 emission from animal manure

In 2011, animal manure, including manure disposed on grass, contributed approximately 87 % to the total NH_3 emission from agriculture. From 1985 the emission from animal manure has decreased by 36 %. There are several reasons for this decrease.

Figure 2.2 shows the annual NH_3 emissions from the main livestock categories. Most of the emission from manure originates from the production of cattle and swine. In 1985 approximately 44 % of the emission came from cattle and 46 % from swine. In 2011, the contribution from cattle had decreased to 35 %. The share of the emission from fur farming and poultry production has increased, while that from swine is nearly unaltered (43 %).

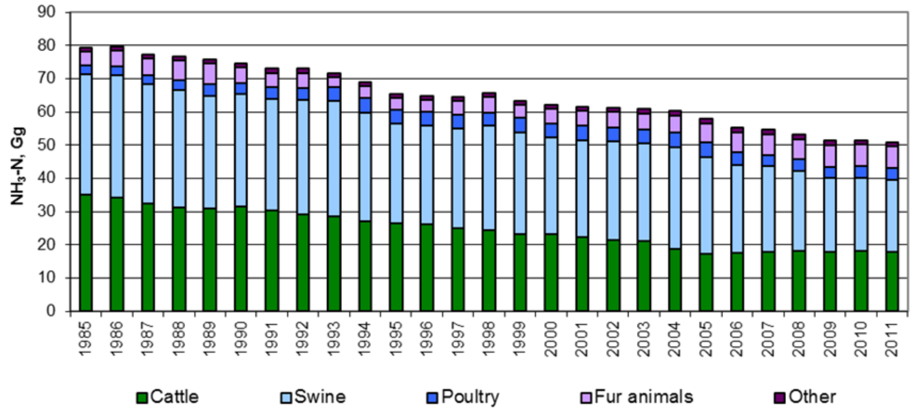

Figure 2.2 NH_3-N emissions from animal manure contributed by the different livestock categories. 'Other' includes horses, sheep, goats and deer.

It is noteworthy however that while the share of emissions from swine is stable, the total emission from swine has decreased by 40 % despite a considerable increase in pork production from 14.7 million produced fattening pigs in 1985 to 21.9 million in 2011. One of the most important reasons for this is the improvement in feed efficiency. In 1985, the nitrogen excretion for a fattening pig was an estimated 5.09 kg N (Poulsen & Kristensen, 1997). In 2011, that figures were considerably lower at 2.82 kg N per fattening pig produced (Poulsen, 2012). Due to the large contribution from the pig production, the lower level of N-excretion has a significant influence on total agricultural emissions.

Figure 2.3 shows the different sources, i.e. from manure handling in animal housing, manure storage, application to fields and from grazing animals.

The overall decrease is a consequence of the general requirement to improve the utilisation of nitrogen in the manure - e.g. requirements to a larger part of the nitrogen in manure has to be included in the farmers' nitrogen accounting. This has forced farmers to consider the manure as a resource instead of a waste product. Especially the emission from application and storage of manure has decreased significantly.

Regarding the field application of animal manure, considerable changes have taken place. From the beginning of the 1990s slurry has increasingly been spread using trailing hoses. From the late 1990s the practice of slurry injection or mechanical incorporation into the soil has increased. For 2011 it is estimated that as much as 76 % for cattle slurry and 37 % for swine slurry is applied using injection/incorporation techniques (Birkmose, 2012). This development is in addition to general environmental requirements also a consequence of a ban on broad spreading from 2003. From 2011, slurry applied on fields with grass for feeding or fields without crop cover, has to be injected directly into the soil (BEK no. 915 of 27/06/2013). However, the injection requirements are not required if the slurry has been acid treated either in housing or during application to soil.

From 2006 a considerable fall in the emission is seen, which is due to the requirement to cover manure heaps.

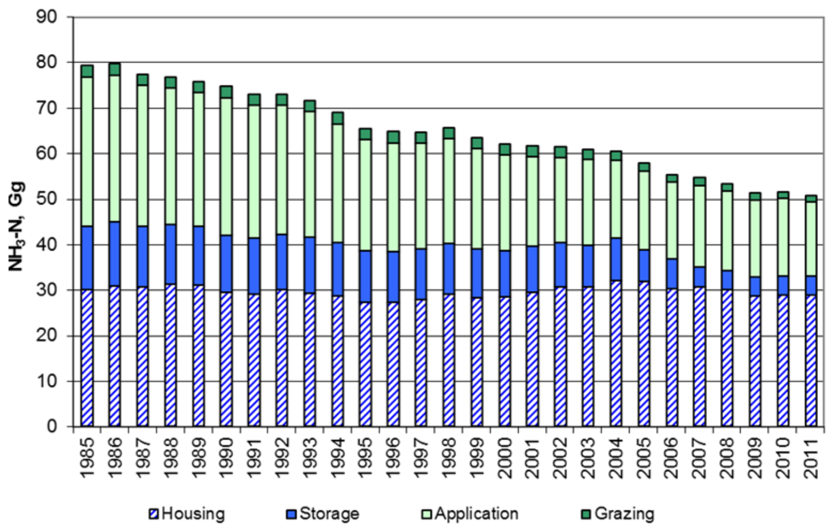

Figure 2.3 NH_3-N emissions from animal manure, 1985 to 2011.

The goal of further reduction of the NH_3 emission could be achieved by focusing on establishment of emission reduction technologies in animal housing.

NH_3 emissions from agricultural soils

In 2011, NH_3 emission related to the agricultural soils contributed 13 % to total agricultural emissions, this mainly stems from the use of synthetic fertiliser and from growing crop as shown in Figure 2.4.

The Danish inventory includes the emission from growing crops, although no methodological guidance is provided in the EMEP/EEA Guidebook. Studies have demonstrated that growing crops can emit NH_3 (Schjoerring & Mattsson, 2001), but it is quite uncertain how much NH_3 is emitted from growing crops under different geographic and climatic conditions. Denmark does not report NH_3 from growing crops or from ammonia treated straw under the EU NEC Directive, because these emission sources were not included in the Danish inventory at the time when emission ceilings were negotiated.

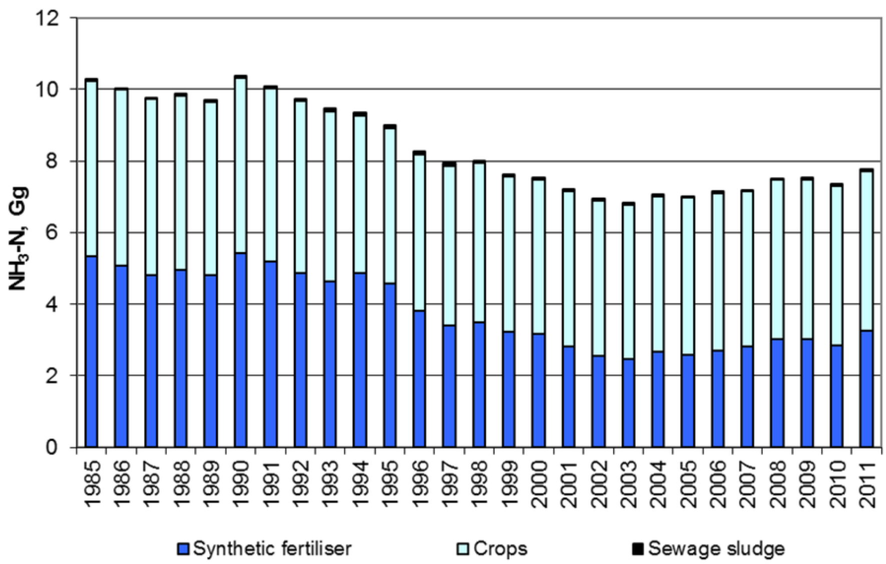

Figure 2.4 NH_3-N emission from synthetic fertiliser, crops and sewage sludge, 1985-2011.

Due to the requirement to improve the utilisation of nitrogen in animal manure, the use of synthetic fertilisers has decreased dramatically. The amount of nitrogen applied to soils from synthetic fertilisers in 2011 is almost halved compared with the amount in 1985. Since 2007, is seen a slight increase, which is mainly due to an increase in the use of nitrogen solutions, which have a high emission factor (EF).

The emission from growing crops follows a downward trend due to a reduction in the agricultural area.

2.1.2 PM

Emission of particulate matter (PM) originates from livestock housing, field operations such as soil cultivation and harvesting, and the field burning of agricultural residues. The current emission inventory does not include emissions from field operations.

The PM emissions from the agricultural sector mainly consist of larger particles. In the reporting under CLRTAP PM is reported as the total suspended particles (TSP), PM_{10} and $PM_{2.5}$ (Particulate matter with diameter of less than 10 µm and less than 2.5 µm). TSP emission from the agricultural sector contributes 31 % to the national TSP emission in 2011 and the emission shares for PM_{10} and $PM_{2.5}$ are 20 % and 6 % respectively. Most of this comes from animal production. The emission from the field burning of agricultural residues, contributes less than 1 % to the agricultural emission.

Figure 2.5 shows the TSP emission from the agricultural sector from 1985 to 2011. Emission from field burning of agricultural residues decreases significantly from 1989 to 1990 due to a ban of burning agricultural residues. From 1990 burning of residues may only take place in connection with production of grass seeds on fields with repeated production and in cases of wet or broken bales of straw.

Since 1985 the emission from livestock increases and this is mainly due to changes in the production of swine. The changes in the total emission for each livestock category mainly reflect the changes in the number of animals, but are also effected by the distribution of animals in subcategories and changes in housing type.

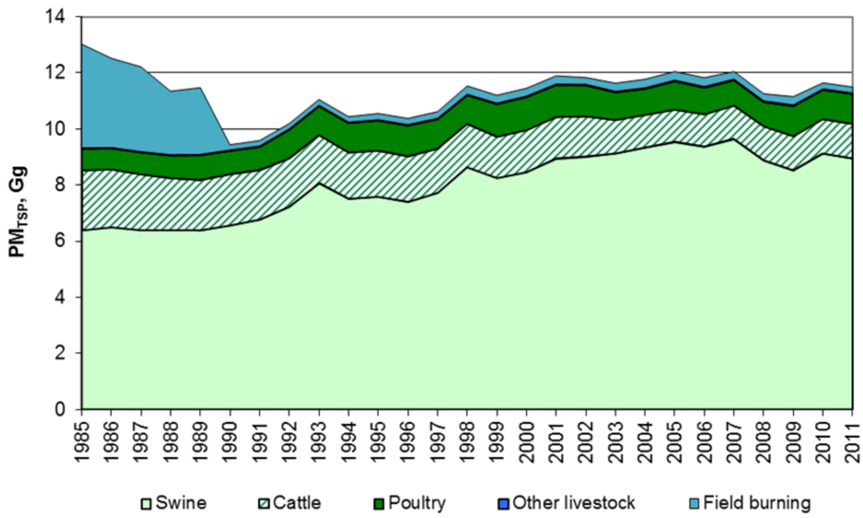

Figure 2.5 Emission of total suspended particles (TSP) from the agricultural sector, 1985 to 2011. Other livestock includes horses, sheep and goats.

2.1.3 NMVOC

Non-Methane Volatile Organic Compounds (NMVOC) is included in the reporting requirements for emission inventories under both CLRTAP and UNFCCC. The reason for including NMVOC in the reporting requirements to the UNFCCC is that NMVOC are considered an indirect greenhouse gas. NMVOC contribute to the formation of tropospheric ozone, therefore it is included in the reporting requirements under CLRTAP.

An estimate of the emission from field burning of agricultural residues and from growing crops and grass is included in the emission inventory. Agriculture contributed with 2.15 Gg NMVOC in 2011, corresponding to 3 % of the national NMVOC emission. From 1985 the emission has decreased mainly due to the ban on field burning. Since 1990 a small decrease in emission has occurred due to a decrease in the farmed area.

Currently, the emission inventory only covers NMVOC emission from growing crops. The updated EMEP/EEA guidebook (2013) contains a methodology and default emission factors for NMVOC emissions from animal husbandry and manure management. If applied, a considerably increase of agricultural emissions is expected.

2.1.4 Other air pollutants

Other air pollutants include NO_x, CO, SO_2, heavy metals, dioxins, PAHs, PCBs and HCB. These are estimated from the field burning of agricultural residues and HCB also emits from use of pesticides. In 2011 NO_x, CO, SO_2, heavy metals and dioxin from field burning contributed less than 1 % to the total national emission, while PAHs contributed with around 2 %. From 1989 to 1990 all emissions decrease significantly due to the banning of field burning.

Emissions related to the energy consumption from agricultural plants and machinery, such as tractors, harvesters, etc., is not included in the agricultural sector, but included in the energy sector.

2.2 Greenhouse gases

Table 2.3 shows the agricultural contribution of emissions to the national total in 2011. The agricultural emission contribution of N_2O and CH_4 is 91 % and 76 %, respectively.

Table 2.3 Emission 2011, reported to UNFCCC, January 2013.

	N_2O	CH_4
National total, Gg	19	262
Agricultural total, Gg	18	198
Agricultural part, %	91	76

Table 2.4 shows the development in greenhouse gas emissions calculated in CO_2 equivalents. The overall emission in 1985 are estimated to 13 420 Gg, decreasing to 9 672 Gg in 2011, corresponding to a 28 % reduction. Since 1990, the base year of the United Nations Framework Convention on Climate Change (UNFCCC) for CH_4 and N_2O, the emission has been reduced by 23 %. N_2O has the highest global warming potential of the two gases and is the largest contributor to the overall agricultural emission of greenhouse gases. CO_2 is estimated for field burning of agricultural residues, but it is not reported in the Common Reporting Format (CRF) because this is not possible in the present format. The CO_2 emission from field burning is considered biogenic and would therefore not count in the national total, but would only be reported as a memo item, which is also the case for CO_2 emissions from combustion of biomass in the energy sector.

Table 2.4 Development in the emission of greenhouse gases, 1985-2011, measured in Gg CO_2 equivalents. For all years and distributed on main sources see Appendix B and C

	1985	1990	1995	2000	2005	2008	2009	2010	2011
CH_4	4 702	4 242	4 239	4 048	4 043	4 106	4 095	4 165	4 151
N_2O	8 718	8 303	7 353	6 423	5 809	5 837	5 503	5 449	5 521
Total	13 420	12 545	11 592	10 471	9 852	9 943	9 598	9 614	9 672

2.2.1 CH_4

The CH_4 emission primarily originates from livestock digestive processes, with a smaller contribution from animal manure particularly slurry. Field burning of agricultural residues is also included as a source of emission, but contributes less than 1 % to total agricultural CH_4 emissions.

The trend in CH_4 emissions from 1985 to 2011 is presented in figure 2.6 and shows a reduction from 224 Gg CH_4 to 198 Gg CH_4 in 2011, corresponding to 12 %. From 1985 to 2011 the emission from enteric fermentation has decreased mainly due to a decrease in the number of cattle. A contrasting development has taken place in emission from manure management. Structural changes in the sector have led to a move towards the use of slurry-based housing systems, which have a higher emission factor than systems with solid manure.

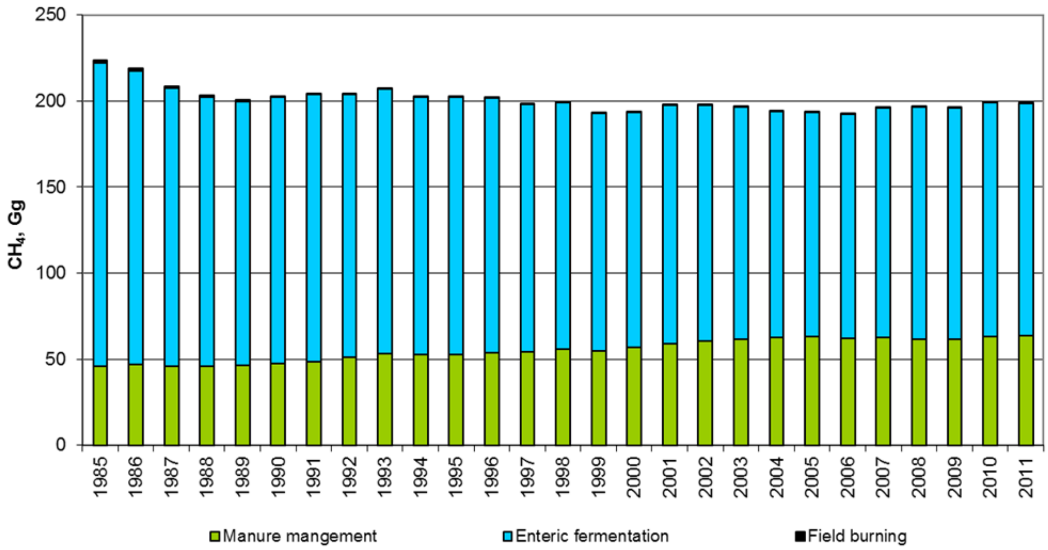

Figure 2.6 CH_4 emission 1985-2011, Gg CH_4 per year.

In 2011 approximately 6 % of slurry was treated in biogas plants. Investigations indicate a lower emission of CH_4 and N_2O from biogas treated slurry (Sommer et al., 2001) and this effect is included in the emission inventory. In 2011 the biogas treatment has lowered the CH_4 emission with 1.11 Gg CH_4, which corresponds to 0.6 % of the total CH_4 emission from the agricultural sector.

2.2.2 N_2O

The emission of N_2O takes place in the chemical transformation of nitrogen and is therefore closely linked with the nitrogen cycle. There is a direct link between the estimation of the NH_3 emission and the estimation of the N_2O emission.

Figure 2.7 presents the trend in the emissions of N_2O in the period 1985 to 2011 and reveals that the emission has decreased from 28.1 Gg N_2O to 17.8 Gg N_2O, which corresponds to a 37 % reduction.

N_2O is produced from a range of different sources, which are presented in figure 2.7. The largest sources are animal manure and synthetic fertilisers applied to soil, and nitrogen leaching and runoff. The reduction in total N_2O emissions is strongly related to a significant decrease in emissions from the use of synthetic fertiliser and in nitrogen leaching and runoff. This development is primarily a consequence of an improved utilisation of nitrogen in animal manure.

Despite the increasing production of swine and poultry, the total amount of excreted nitrogen in manure has decreased by 11 % from 1985 to 2011, which is due to an improved feed efficiency, especially for fattening pigs. A decrease in the total amount of nitrogen also means a decrease in N_2O emissions. Another reason for reduction is the change from previous, more traditional, tethering systems with solid manure to a slurry-based system, because the N_2O emission is lower for liquid manure than for solid manure.

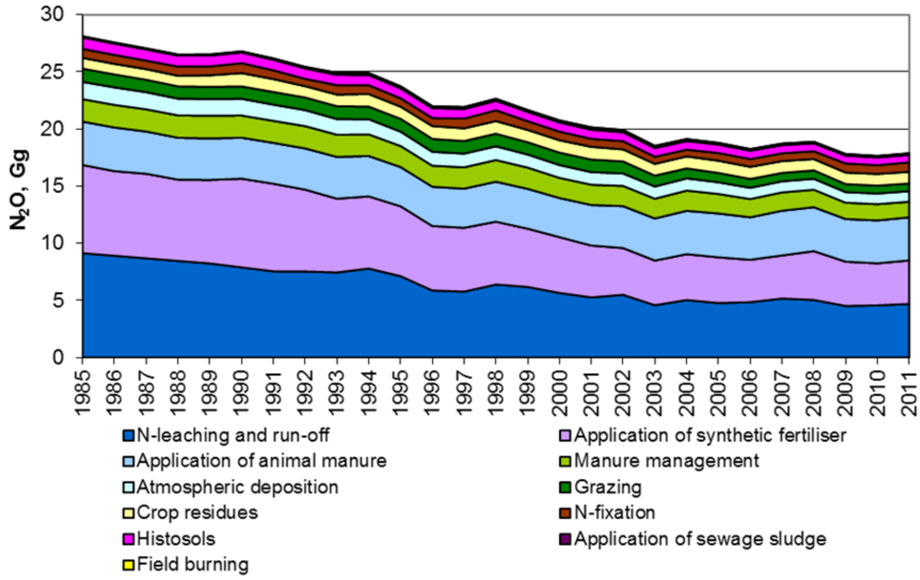

Figure 2.7 Emission of N_2O according to source, 1985-2011.

As mentioned in the section for CH_4, the biogas treatment of slurry also has an effect of lower N_2O emission. Investigations indicate that biogas treated slurry applied on soil has a lower N_2O emission. For 2011, the biogas treated slurry lowered the N_2O with 0.06 Gg, which corresponds to a 4 % reduction of the N_2O emission from manure management in 2011.

3 Description of the model IDA

A comprehensive model complex called "Integrated Database model for Agricultural emissions" (IDA) is used to store input data and to calculate the agricultural emissions. The emission calculation includes greenhouse gases, NH_3, PM, NMVOC and other pollutants related to the field burning of agricultural residues, namely NO_x, CO_2, CO, SO_2, heavy metals, dioxins, PAHs, PCBs and HCB from use of pesticides.

3.1 Methodology

The main principle in the estimation of the emission is an activity, a, multiplied with an emission factor, EF, set for each activity (*i*). The overall emission is calculated as the sum of the emissions from all activities, see Equation 3.1.

$$E_{total} = \sum a_i \bullet EF_i \qquad \text{(Eq. 3.1)}$$

Activity data for reporting in the agricultural sector could be, e.g. the number of cattle. The activity data for estimating emissions in the database is typically disaggregated into several different subcategories, which for cattle, for example, are dairy cattle, calves, heifers, bulls and suckling cattle and again divided into different breeds and weight classes.

The emissions are estimated on the basis of international guidelines. The emission calculations for the greenhouses gases are in accordance with the methods in the IPCC Guidelines (IPCC, 1997 and IPCC, 2000). The calculation of air pollutant emissions are in accordance with the methodologies described in the EMEP/EEA Guidebook (EMEP, 2009). National values and methodology approach are used where these better reflect the Danish agricultural conditions.

3.2 Data references – sources of information

Data input for emission calculations are collected, evaluated and discussed in collaboration with a range of different institutions involved in agricultural research and administration. The organisations include, for example, Statistics Denmark, Danish Centre for Food and Agriculture at Aarhus University, the Danish Agricultural Advisory Service, the Danish Environmental Protection Agency and the Danish AgriFish Agency.

Table 3.1 provides an overview of the various institutions and organisations who contribute national data in connection with the preparation of the agricultural emissions inventory.

Table 3.1 Organisations contributing input data to the preparation of the emissions inventory.

References	Link	Abbreviation	Data / information
Danish Centre for Environment and Energy, Aarhus University	http://dce.au.dk	DCE	- data collecting - emission calculations - responsible for QA/QC - reporting
Statistics Denmark – Agricultural Statistics	www.dst.dk	DSt	- livestock production - milk yield - slaughtering data - export of live animal - poultry - land use - crop production - crop yield
Danish Centre for Food and Agriculture, Aarhus University	http://dca.au.dk/	DCA	- N-excretion - feeding situation - animal growth - N-fixing crops - crop residue - N-leaching/runoff - NH_3 emission factor
The Danish Agricultural Advisory Service	www.lr.dk	DAAS	- housing type (until 2004) - grazing situation - manure application time and methods - estimation of extent of field burning of agricultural residue
Danish Environmental Protection Agency	www.mst.dk	EPA	- sewage sludge used as fertiliser - industrial waste used as fertiliser
Danish AgriFish Agency	http://naturerhverv.fvm.dk	DAFA	- synthetic fertiliser (consumption and type) - housing type (from 2005) - sewage sludge used as fertiliser (from 2005 based on the register for fertilization) - number of animals from the Central Husbandry Register
The Danish Energy Agency	www.ens.dk	DEA	- manure treated in biogas plants

3.3 Integrated database model for agricultural emissions

The **I**ntegrated **D**atabase for **A**gricultural emissions (IDA) model complex is designed in a relational database system (MS Access). Input data are stored in tables in one database called IDA_Backend and the calculations are carried out as queries in another linked database called IDA.

Most emissions relate to livestock production, which basically is based on information on the number of animals, the distribution of animals according to housing type and, finally, information on feed consumption and excretion.

IDA operates with 38 different livestock categories, according to livestock type, weight class and age. These categories are subdivided into different housing types and manure types, which results in 247 different combinations of livestock subcategories and housing/manure types (Table 3.2). For each of these combinations, information on e.g. feed intake, digestibility, nitrogen excretion and CH_4 conversion factors is attached. The emission is calculated from each of these subcategories and then aggregated to the main livestock categories.

Table 3.2 Livestock categories and subcategories.

Main livestock categories	Subcategories	Number of subcategories divided into housing type and manure type system
Dairy cattle[1]	Dairy Cattle	34
Non-dairy cattle[1]	Calves (<½ yr), heifers, bulls, suckling cattle	120
Sheep	Including lambs	1
Goats	Including kids (meet, dairy and mohair)	3
Horses	<300 kg, 300-500 kg, 500-700 kg, >700 kg	4
Swine	Sows, weaners, fattening pigs	36
Poultry	Hens, pullets, broilers, turkeys, geese, ducks, ostriches, pheasants	42
Other	Mink, fitchew, foxes, finraccoon, deer	7

1) For all subcategories, large breeds and Jersey cattle are separately identified.

Data are collected from the organisations mentioned above (Table 3.1) and processed and prepared for import to the database. This step is done in spread sheets. The data are imported and stored in the database called "IDA-backend" which also stores the emission factors for all pollutants. All emission calculations are done in IDA, which is linked to IDA-backend. This means that calculations of pollutants all use the same data on number of animals, crop area, amount of synthetic fertiliser, etc. The calculated emissions and additional information are uploaded to the CRF and NFR templates via a conversion database. An overview of the data process is shown in figure 3.1.

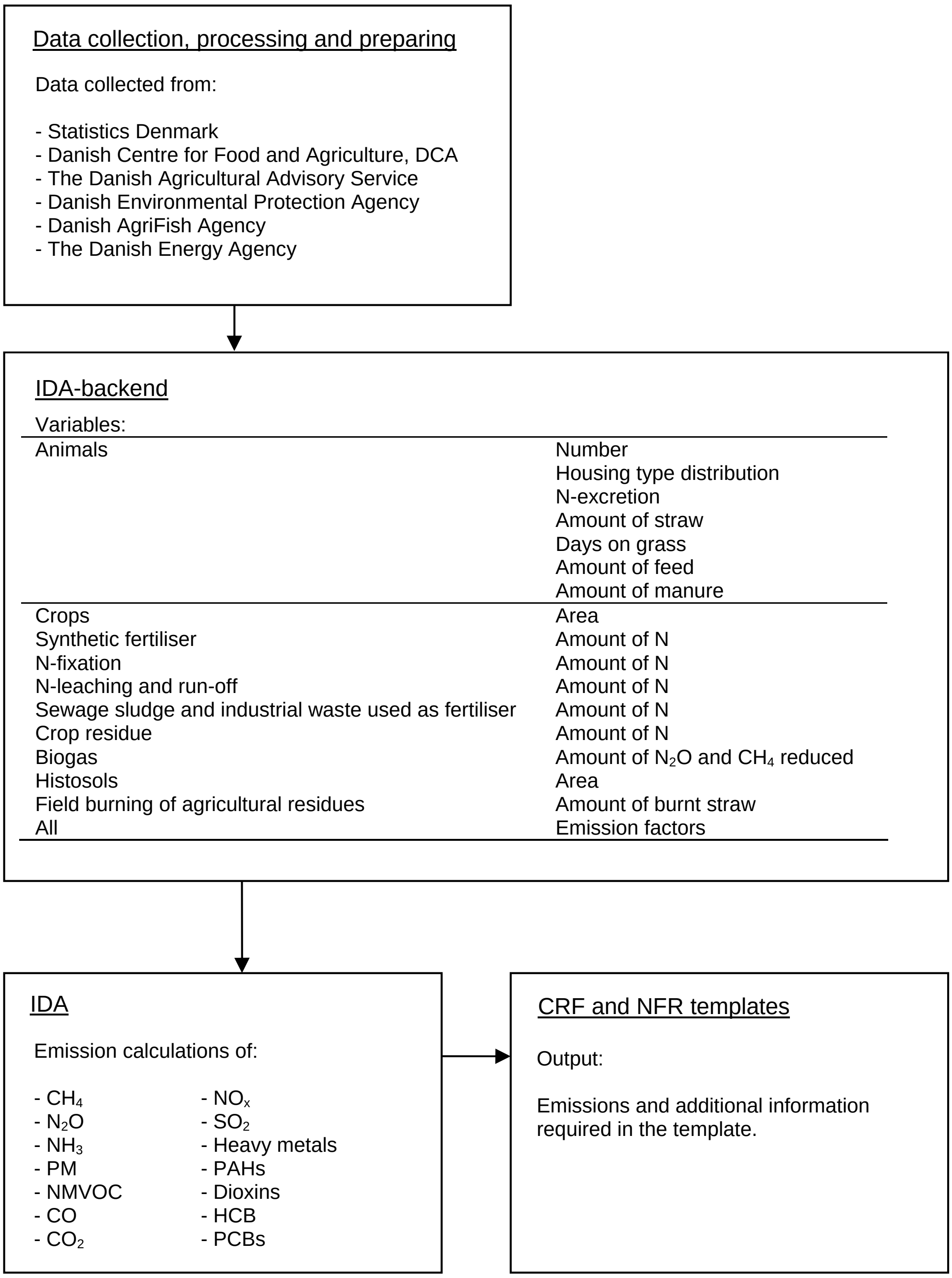

Figure 3.1 Overview of the data process for calculation of agricultural emissions.

4 Livestock population data

In 2011 livestock production was the main source of the agricultural emissions, contributing 86 % of the NH_3 emission and approximately 61 % of the greenhouse gas emission. To calculate the agricultural emission, a series of input data is used. Some values are obtained as default values from guidelines and some are estimated based on national values, which closer reflect the Danish agricultural conditions. Table 4.1 lists the most important national variables, and shows that some variables are used to calculate both NH_3 and greenhouse gas emissions. These variables (number of animals, distribution of housing types and estimated days on pasture and in housing) are described in this chapter. The remaining variables are included in the relevant pollutant chapters.

Table 4.1 Pollutants and variables.

Pollutants	National variables
NH_3, N_2O, CH_4	- No. of animal
	- Housing type/manure type
	- Days in housing and on pasture
NH_3, N_2O	- N-excretion (depends on feed intake)
NH_3	- Conditions for storage and application of manure on agricultural soil
CH_4	- Feed intake (amount and composition)
	- Manure excretion (amount, content of dry matter and volatile solids)

4.1 Livestock population

Livestock production figures are primarily based on the agricultural census from Statistics Denmark (DSt), see appendix D for numbers of livestock 1985-2011. The emissions from bulls, fattening pigs and poultry are based on slaughter data.

DSt does not include farms below 5 ha, therefore approximate numbers for horses has been added to the number published by DSt. This procedure is in agreement with the Danish Agricultural Advisory Service (DAAS). In the agricultural census for 2011 the number of horses is estimated at approximately 61 000. Including horses on small farms and riding schools, however, the number rises to approximately 155 000 (Clausen, E., 2012). Data on the number of sheep and goats are based on the Central Husbandry Register (CHR), which is the central register of farms and farm animals of the Ministry of Food, Agriculture and Fisheries.

The inventory furthermore includes emissions from deer, ostrich and pheasants, but these animal categories are not included in DSt. Data on the number of deer and ostrich are based on the CHR, while the number for pheasants is based on expert judgement DCE – formerly NERI (Noer, 2000) and the pheasant breeding association (Stenkjær, 2009).

The normative figures for feed intake and N-excretion are for some livestock categories, e.g. dairy cattle and sows, given for a year animal, which means the average number of animals, present within the year. This corresponds to the definition of annual average population (AAP) in the EMEP/EEA Guidebook (EMEP/EEA, 2009). For other livestock categories such as bull calves, bulls, weaners, fattening pigs, pullets and heifers (1985-2002), the normative figures are given per animal produced.

Below follows a description of how the livestock production is calculated for each animal category.

4.1.1 Cattle

Cattle are divided into six main categories and for each of these categories distinction is made between large breeds and Jersey cattle (Table 4.2). The categories are dairy cattle**,** bull calves, heifer calves, bulls more than 6 months destined for slaughter, heifers more than 6 months to be used for breeding purposes, and suckling cattle. The categories are further divided into different housing systems and manure types.

Data regarding the distinction between large breed and Jersey cattle were, until 2000, collected via special calculations from DSt. From 2001 the figures on Jersey cattle have been provided by DAAS, and are based on registrations from yield control exercises covering approximately 90 % of dairy cattle.

Table 4.2 Main categories of cattle.

	Proportion of Jersey cattle (%) in the total cattle population 2011[1]
Dairy cattle	13.5
Heifer calves, 0 - 6 months	10.3
Heifers, 6 months to calving	9.4
Bull calves, 0-6 months	2.7
Bulls, 6 months to slaughter age	4.0
Suckling cattle	0

[1] Source: Flagstad, 2012.

In order to calculate the emission, the number of animals has to be quantified for each of the categories.

Dairy cattle

The annual average population of dairy cattle is based on DSt.

Heifers

The number of heifers is calculated by two different methodologies, which is due to a change in the Danish Normative System in 2003. This change in the calculation has no impact on emissions.

From 1985 to 2002, the normative figures for N-excretion are given per animal produced, which is described in Mikkelsen et al. (2006). From 2003 and onwards the normative figures are changed so the values of feed intake and N-excretion represent AAP (annual average population), which are based on the number of animals reported by DSt.

From 2003, the number of heifer calves (< ½ year) per year is calculated as:

a) $$no_{L} = no_{DSt} \cdot (1 - J) \qquad \text{(Eq. 4.1a)}$$

b) $$no_{J} = no_{DSt} \cdot J \qquad \text{(Eq. 4.1b)}$$

Example for 2011:

$$no_L = 158101 \cdot (1 - 0.103) = 141817$$

where: no_{DSt} = number of heifers <½ year given by DSt
no_L = number of large breed heifers <½ year
no_J = number of Jersey heifers <½ year
J = fraction of Jersey heifers

Bulls

The normative figures from DCA represent feed intake and N-excretion per animal produced, therefore the emission calculation has been based on the number of animals produced.

The production of both bulls and bull calves is based on data on slaughter provided by DSt. Animals discarded during the slaughtering process and export of live animals is taken into account.

Number of total bulls and bull calves produced

For the calculation of bulls > 6 months is the number of slaughtered young bulls, bulls and steers, exported adult cattle and discard cattle given by DSt.

Number of bulls produced per year:

$$no_{bulls} = no_{y\,b} + no_b + no_s + no_{ex\,a} + no_{dis} \qquad \text{(Eq. 4.2)}$$

where: no_{bulls} = number of bulls
$no_{y\,b}$ = number of slaughtered young bulls
no_b = number of slaughtered bulls
no_s = number of slaughtered steers
$no_{ex\,a}$ = number of exported adult cattle
no_{dis} = number of discarded cattle

Number of bull calves < 6 months is calculated based on the number of bulls:

$$no_{bull\ calves} = no_{bulls} + no_{v\,c} + no_{ex\,c} \qquad \text{(Eq. 4.3)}$$

where: $no_{bull\ calves}$ = number of bull calves
no_{bulls} = number of bulls
$no_{v\,c}$ = number of veal calves
$no_{ex\,c}$ = number of exported calves

Example from 2011:

$$no_{bulls} = 55\,800 + 190\,300 + 11\,600 + 4\,900 + 3\,000 = 265\,600$$
$$no_{bullcalves} = 265600 + 3\,700 + 26\,500 = 295800$$

Distribution between large breed and Jersey

An average slaughter weight for large breed cattle and Jersey cattle of 440 kg and 328 kg, respectively, is assumed in the normative figures (Poulsen et al., 2001).

The number of bulls from suckling cattle is counted under the category of bull calves, large breed. It is assumed that the allocation between dairy cattle and suckling cattle is approximately the same for bull and for bull calves. The fraction of suckling cattle is 14.9% in 2011.

The number of bulls/bull calves from suckling cattle is estimated. For the remaining part of cattle the distribution between large breed and Jersey is estimated by using the percentage for Jersey cattle given in Table 4.2.

Equation 4.4:

$$\mathrm{Frac} = \mathrm{no}_{S,\,DSt} / (\mathrm{no}_{D,\,DSt} + \mathrm{no}_{S,\,DSt}) \qquad \text{(Eq. 4.4)}$$

where: Frac = fraction of suckling cattle
$\mathrm{no}_{S,\,DSt}$ = number of suckling cattle given by DSt
$\mathrm{no}_{D,\,DSt}$ = number of dairy cattle given by DSt

The number of respectively large breed and Jersey bulls and bull calves produced is calculated as follows:

Equation 4.5 a) and b):

a) $$\mathrm{no}_{B,\,L} = (\mathrm{no}_B - \mathrm{no}_B \cdot \mathrm{Frac}) \cdot (1 - J) + (\mathrm{no}_B \cdot \mathrm{Frac}) \qquad \text{(Eq. 4.5a)}$$

b) $$\mathrm{no}_{B,\,J} = (\mathrm{no}_B - \mathrm{no}_B \cdot \mathrm{Frac}) \cdot J \qquad \text{(Eq. 4.5b)}$$

where: $\mathrm{no}_{B,\,L}$ = number of large breed bulls produced
no_B = number of bulls produced
$\mathrm{no}_{B,\,J}$ = number of Jersey breed bulls produced
Frac = fraction of suckling cattle
J = percent of Jersey bulls

Calculation example for 2011:

Table 4.3 Number of bulls, 2011.

	No. of animals, DSt	No. of animals produced	Fraction of suckling cattle	No. of bulls produced	
				Large breed	Jersey
Bull calves < ½ year	132 169	295 800	0,149	289 000	6 800
Bulls > ½ year	138 386	265 600	0,149	256 103	9 497

Suckling cattle

The number for suckling cattle is provided by DSt.

4.1.2 Swine

There are three different main swine categories: sows (including piglets up to 7.3 kg), weaners (7.3 to 32 kg) and fattening pigs (32 to 107 kg).

Sows

The number for sows is provided by DSt. Sows include pregnant sows, suckling sows and barren sows.

Weaners and fattening pigs

The normative figures for feed intake and N-excretion for fattening pigs and weaners are provided per pig produced; therefore the emission calculation has been based on the number of animals produced.

The production of both weaners and fattening pigs is mainly based on data on slaughter provided by DSt. Discarded animals during the slaughtering process and export of live animals are taken into account. The calculated emission from weaners and fattening pigs also include the emission related to breeding of boars and barren sows.

The number of fattening pigs is based on the total meat production divided with an average slaughter weight based on the normative figures, which in 2011 was provided to 82 kg (Poulsen, 2012).

Number of fattening pigs produced:

$$no = (\frac{AM}{AS}) + Ex_{fattening} + Ex_{breeding} \qquad \text{(Eq. 4.6)}$$

where:	no	= number of fattening pigs
	AM	= amount of meat produced, kg
	AS	= average slaughter weight, kg
	$Ex_{fattening}$	= export of live fattening pigs, 1000
	$Ex_{bredding}$	= export of live animals for breeding, 1000

Example from 2011:

$$no_{2011} = (\frac{1\,763\,\mathrm{M\,kg}}{82\,\mathrm{kg}}) + 358 \cdot 1000 + 34 \cdot 1000 = 21892\,000 \;\Rightarrow 21.9\,\mathrm{million}$$

The number of weaners is calculated as the number of fattening pigs plus the number of exported live weaners, which has increased significantly in the last ten years from 1.1 million in 2001 to 8.1 million in 2011.

Number of weaners produced:

$$no = no_{fattening} + no_{exported} \qquad \text{(Eq. 4.7)}$$

where:	no	= number of weaners, weight 7-32 kg
	$no_{fattening}$	= total number of produced fattening pigs
	$no_{exported}$	= number of exported living weaners

Example for 2011:

$$no_{2011} = 21.9\ \mathrm{million} + 8.1\ \mathrm{million} = 30.0\ \mathrm{million}$$

The normative feed intake and excretion values for fattening pigs are in 2011 based on a 107 kg live weight, equivalent to 82 kg slaughter weight (Poulsen, 2012). Slaughtering data are as mentioned based on Statistics Denmark. Information on discarded animals is based on data from DAKA, which is a co-operative owned by 16 members and these members represent most of the Danish meat industry. In 2011, the total meat production is estimated at

1 763 million kg meat and the number of living animal exported are 8.5 million (Table 4.4).

Table 4.4 Background data for estimating number of produced fattening pigs and weaners, 2011.

Fattening pigs to slaughter (million kilo meat)	
Delivered to slaughterhouse	1 701
Slaughtered for the producer at slaughterhouse	0.1
Slaughtered at home	1.9
Discarded during the production process	4.2
Transfer to sow unit (million kilo meat)	
Gilt to slaughter	0.5
Breeding period of boars	1.0
Breeding period of barren sows	54.5
Total meat production from pigs, million kilo meat	1 763
Export of living animals (1 000 s)	
Fattening pigs	358
Animals for breeding	34
Weaners	8 121
No of produced animal (1 000 s)	
No. of produced fattening pigs	21 892
No. of produced weaners	30 013

Table 4.5 shows the number of swine other than sows reported by DSt, compared to the calculated number of weaners and fattening pigs produced per year. The number of animals given by DSt represent the number given in AAP, while the emission calculations are based on number of produced swine.

Table 4.5 Number of weaners and fattening pigs, 2011.

	No. of animal, DSt, 1 000 s	No. of produced swine, 1 000 s
Swine (other than sows)	11 869	
Fattening pigs (32-107 kg)		21 892
Weaners (7.5-32 kg)		30 013

4.1.3 Poultry

For poultry, there are four main categories: laying hens, broilers, turkeys and other poultry (geese, ducks, pheasants and ostrich). In the following estimation of the numbers of animals are described.

Laying hens

The category of laying hens includes hens and pullets. The normative figures for hens are based on average annual hens (units of 100). Six main production forms for hens are distinguished between – free-range, organic, barn, battery, aviary as well as production of hens for brooding. The distribution between the different production forms is based on data from DSt.– see Table 4.6.

Hens

The number of laying hens is based on the egg production. The production of eggs divided on production forms are given by DSt. The number of hens within each category is calculated as follows:

$$\mathrm{no}_i = \frac{(\mathrm{a}_i + \mathrm{a}_h \cdot \mathrm{P}_i/100) \cdot 1000\,000}{\mathrm{Y}_i} \qquad \text{(Eq. 4.8)}$$

where:
no_i = number of hens within the production form *i*
a_i = amount of eggs produced for sale in the production form *i*, in million kg
a_h = amount of eggs produced for home sale, in million kg
P = per cent share of the production form *i*
Y_i = production of eggs per hen per year within the production form *i*, in kg

Below is an example calculation of the number of free-range hens in 2011 (100):

$$\mathrm{no}_{\text{Free-range}} = \frac{(4.4 + 8 \cdot 7.6/100) \cdot 1\,000\,000}{18.9} / 100 = 2\,649$$

Calculations of number of hens for brooding due not include eggs produced for home sale.

The category of battery hens is furthermore divided into three different housing systems according to the differences in the handling of manure. These categories are termed manure houses, manure tanks and manure cellar.

Table 4.6 Distribution of hens in different categories in 2011. (100s).

	No of hens, 100s	Pct. distribution on production forms	Number of hens 100s
Hens - total	44 258		
- of which egg layers for brooding	10 588		10 588
- of which egg layers	33 670		
Free-range		8	2 554
Organic		16	5 283
Barn		17	5 805
Battery, manure house		45	15 341
Battery, manure tank		8	2 684
Battery, manure cellar		6	2 003
Aviary		0	0

Pullets

The normative figure for pullets is based on the production of 100 pullets. The production time for pullets is between 112 and 119 days depending on production form (Poulsen et al., 2001), which corresponds to approximately three production cycles during the year (365/112 = 3.3, 365/119 = 3.1). Pullets for production of consumption egg have a 112 days production time while pullets for brooding eggs have 119 days production time. Annual production is determined using the population figure provided by DSt (chicken for breeding) multiplied by the production cycle.

The total number of pullets produced during the year is divided into three main production forms – consumption (net), consumption (floor) and pullets used for brooding eggs. The multiplication factor related to the percentage distribution of the three different production forms is from 1985 to 2004 based on information from the Danish Agriculture & Food Council (Jensen, 2008) and from 2005 based on information from DAFA – see Table 4.7.

Calculation of the total number of pullets produced:

$$no_{pu} = no_{DSt} \cdot \frac{365}{T} \cdot (P/100) \qquad \text{(Eq. 4.9)}$$

where: no_{pu} = number of pullets within a given production form
no_{DSt} = number of pullets given by DSt
T = production time, days
P = percent distribution of the production form

Below is, as an example, the calculation of the number of pullets produced for consumption, net production (100), for 2011:

$$no_{pu} = 17\,963 \cdot \frac{365}{112} \cdot (19.3/100) = 11\,298$$

Table 4.7 Calculation of the number of pullets produced in 2011,100s.

	No. of pullets given in DSt 100s	Distribution on production forms	Production time	Production runs per year	Number of pullets produced per year 100s
		%	days		
Pullets - total (population DSt)	17 936	100			
Consumption, floor		76	112	3.259	44 197
Consumption, net		19	112	3.259	11 298
Egg brooding, floor		5	119	3.067	2 865
Number of pullets produced					58 360

Broilers, turkeys, ducks and geese

Numbers of broilers, turkeys, ducks and geese are based on the number of animals produced. The calculation of production is based on slaughter data from DSt. Export of animals, farmers' private consumption of animals, deaths occurring in the production process are all taken into account.

Data on both export of live broilers, ducks, geese and turkeys and the farmers private consumption have been obtained from DSt.

Calculation method to estimate poultry production:

$$no_{po} = no_{DS} + no_{PC} + no_{E} \qquad \text{(Eq. 4.10)}$$

where: no_{po} = number of the given category of poultry (broilers, ducks, geese or turkeys)
no_{DS} = number of animals delivered to slaughter
no_{PC} = number of animals slaughtered at home for private consumption
no_{E} = number of live animals exported

Example for the number of broilers produced in 2010 (in 1 000s):

$$no_{po} = 106\ 074 + 500 + 9\,380 = 115\ 954$$

The calculated number of broilers, turkeys, ducks and geese produced is compared in Table 4.8 with the figures for the number of average annual animals reported by DSt. The number of average annual animals represents the number of housing places.

Table 4.8 Number of broilers, turkeys, ducks and geese, 2011.

	No. of animal, DSt, 1 000s	No. of produced animals 1 000s
Broilers	12 528	115 954
Turkeys	212	961
Ducks	230	721
Geese	7	18

Pheasants and ostriches

DSt has no data on the number of pheasants and ostriches produced. The number of pheasants is based on expert judgement (Noer, 2009.) and the pheasant breeding association and is estimated at 1 062 500 in each of the years 1985-2011. Pheasants are bred for hunting and this is estimated as unaltered in the period. The number of ostriches is based on information obtained from the Central Husbandry Register (CHR), which is the central register for farm data of the Ministry of Food, Agriculture and Fisheries, (see Table 4.9). The production of ostrich in Denmark started in 1993 and the number of ostrich from 1985 to 1992 has therefore been set at zero.

Table 4.9 Number of ostrich 1985 to 2011.

	1985	1995	2000	2005	2008	2009	2010	2011
Ostrich	0	3 333	8 889	3 661	461	358	358	191

4.1.4 Horses

There are four different weight classes for horses: small ponies up to 300 kg, lighter breeds – 300-500 kg, medium-weight breeds – 500-700 kg and large breeds – more than 700 kg. DAAS estimates that the distribution in these groups is 25, 34, 38 and 3 %, respectively.

The figures from DSt only includes horses on farms larger than 5 ha. However, a study of pets undertaken by DSt has indicated that a significant number of horses are found on smaller hobby farms and riding schools that are below 5 ha. The total number of horses in the inventory is based on the horse breeding register managed by DAAS.

In 2011, 61 476 horses were listed by DSt, as opposed to 155 000 according to DAAS figures. DAAS has estimated the number of horses in 2000 to 150 000 and in 2008 to 190 000. The numbers in between are interpolated. Number of horses in 2009 to 2011 is based on a new judgement from DAAS, which shows a decrease in number of horses. Table 4.10 shows the number of horses registered by, respectively, DSt and DAAS.

Table 4.10 Number of horses 1985 to 2011 (1 000s).

	1985	1990	1995	2000	2005	2008	2009	2010	2011
DSt[1]	32	38	18	40	54	60	58	60	61
DAAS[2]	140	135	143	150	175	190	178	165	155

[1] Agricultural units > 5 ha.

[2] Total number of horses incl. horses on small farms and riding schools.

4.1.5 Sheep, goats and deer

The normative figures for sheep and goats are based on average annual breeding ewes/goats including lambs and kids, because this corresponds to the unit in the normative data. It is expected that a number of sheep and goats are to be found on farms below 5 ha and thus the actual number is higher than reported by DSt. Therefore, data on the number of sheep and goats are based on the Central Husbandry Register (CHR).

The production of deer is included in the Danish inventory and covers animals bred for meat on farms (in enclosures) and not deer in the wild. No data on the number of deer are available from DSt, thus the number of deer is based on CHR.

4.1.6 Fur animals

The production of fur animals is calculated as the population of mink, fitchew, foxes and finraccoon as stated by DSt.

4.2 Housing system

For each livestock category, the number of animals is divided into a range of different housing systems. The housing system is a determinant factor for how the animal manure is handled and therefore decisive for the distribution into liquid and solid manure systems.

No systematic record of the distribution of the different housing types exists until 2004. Therefore, the distribution from 1985 to 2004 is based on expert judgement. For cattle and swine, the distribution is based on information from Rasmussen (2003) and Lundgaard (2003). The distribution of housing systems for fur animals is obtained from Risager (2003). The housing distribution for poultry is determined on the basis of efficiency controls by the Danish Agriculture & Food Council (Jensen, 2008). From 2005 onwards, the distribution of the different housing types is based on information from the Danish AgriFish Agency (DAFA) on farm nitrogen budgets, which farmers, by law have to submit annually.

Appendix E presents the distribution of the different housing types for all livestock categories. Table 4.11 and Table 4.12 show the estimated distribution of housing types from 1985 to 2011 for dairy cattle and fattening pigs, the two most important livestock categories.

The structural development in the agricultural sector has influenced the change in housing types. New housing facilities have been built and most of the tethered housings have been replaced by larger loose-housing facilities. In 1985, 85 % of the dairy cattle were kept in tethered stalls and in 2011 this had been reduced to 10 %. In the case of fattening pigs, many solid floor systems have been replaced by a system with slatted floors. The consequence of this development is that, more of the animal manure is handled as slurry.

Table 4.11 Dairy cattle distributed on main housing types.

	1985	1990	1995	2000	2005	2008	2009	2010	2011
Housing type				%					
Tethered housing	85	79	73	46	20	14	12	12	10
Loose-housing with beds	14	18	21	43	70	79	82	82	85
Deep litter	1	3	6	11	10	7	6	6	5

Table 4.12 Fattening pigs distributed on main housing types.

	1985	1990	1995	2000	2005	2008	2009	2010	2011
Housing type					%				
Fully slatted floor	29	51	60	58	53	53	54	54	53
Partly slatted floor	30	23	24	31	38	41	41	41	43
Solid floor	40	22	11	5	3	2	2	2	1
Deep litter	1	4	5	6	6	4	3	3	3

4.3 Number of days in housing and on pasture

A proportion of the manure from dairy cattle, heifers, suckling cows, sheep, goats, horses and deer is deposited on the field during grazing. It is assumed that on average 5 % of the manure from dairy cows is excreted directly onto the field during grazing in 2011, which translates to 18 days on pasture. The equivalent estimate for suckling cows is 224 days, with 132 days for heifers, 183 days for horses, 265 days for sheep and goats and 365 for deer (Aaes, 2013, Poulsen et al., 2001), Table 4.13.

The number of grazing days for dairy cattle has decreased in the period 2002-2007 and grazing days for heifers has decreased from 1990-2007 due to the structural development towards larger farms (See Appendix F). A production with a large numbers of cattle makes it difficult to drive the animals to pasture because it is time consuming.

Table 4.13 Number of grazing days corresponding to the proportion of N in manure deposited on the field during grazing, 2011.

	Grazing days
Cattle:	
Dairy Cattle	18
Calves and bulls	0
Heifers	132
Suckling Cattle	224
Swine:	
Sows, weaners and fattening pigs	0
Sows, outdoor	365
Poultry:	
Hens, pullets, broilers, turkeys, ducks and ostrich	4[a]
Geese and pheasant	365
Other:	
Horses	183
Sheep and goats	265
Deer	365
Fur animals	0

[a] Weighted average for all poultry subcategories

5 NH_3 emission

Figure 5.1 shows the NH_3 emissions from different sources in 2011. The emission from the handling of animal manure constitutes 84 % of the total NH_3 emission. The emissions from growing crops and synthetic fertilisers contribute 8 % and 5 %, respectively. The remainder comes from grazing animals (3 %) and less than 1 % is from other sources such as sewage sludge and industrial sludge, applied to agricultural land, the field burning of agricultural residues and NH_3 treated straw. Appendix A shows the NH_3 emissions from all sources for the period 1985 – 2011.

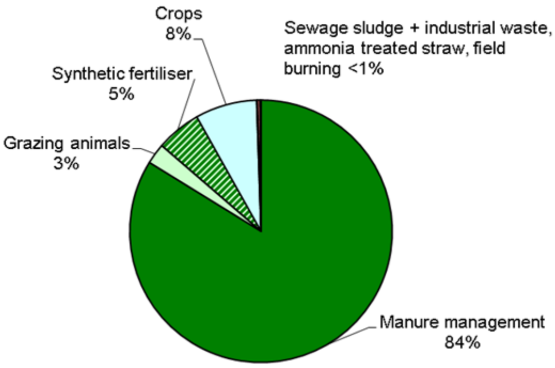

Figure 5.1 NH_3 emissions, 2011.

5.1 Animal manure

5.1.1 Total N and TAN

The emission of NH_3 from manure management is calculated on the basis on nitrogen excreted from livestock. Most of the N excreted that is readily degradable and broken down to NH_4-N is found in the urine. Previously, the emission calculation has been based on the total N content in manure for all manure types. However, the relationship between NH_4-N and total N will not remain constant over time due to changes in feed composition and feed use efficiency.

In order to be able to implement the effect of NH_3-reducing measures such as improvements in feed intake and composition in the emission inventory, it is necessary to calculate the emission based on the Total Ammonia Nitrogen (TAN) content, which has been done to the extent possible. From 2007 the calculation of NH_3 emission from liquid manure is based on TAN. For solid manure and deep litter an emission factor for total N is still used.

The normative figures for both total nitrogen excretion and the content of TAN are provided by DCA.

5.1.2 Methodology

The NH_3 emission occurs wherever the manure is exposed to the atmosphere in livestock housings, manure storages, after application of manure to the fields and from the manure deposited by grazing animals. The total NH_3 emission from animal manure is calculated as:

$$AM_t = AM_h + AM_s + AM_{ap} + A_g \qquad \text{(Eq. 5.1)}$$

where: AM_t = total ammonia emission
AM_h = emission from manure in livestock housing
AM_s = emission from manure storage
AM_{ap} = emission from manure application to fields
AM_g = emission from manure deposited by animals on grass

For each of the elements above, NH_3 losses are calculated for each individual combination of livestock category and housing type. The time the livestock spends indoors and outdoors (grazing), respectively, is taken into account.

$$\text{a) } AM_h = no \cdot Nex_a \cdot \left(1 - \frac{D_g}{365}\right) \cdot EF_h \qquad \text{(Eq. 5.2a)}$$

$$\text{b) } AM_s = no \cdot Nex_h \cdot \left(1 - \frac{D_g}{365}\right) \cdot EF_s \qquad \text{(Eq. 5.2b)}$$

$$\text{c) } AM_{ap} = no \cdot Nex_s \cdot \left(1 - \frac{D_g}{365}\right) \cdot EF_{ap} \qquad \text{(Eq. 5.2c)}$$

$$\text{d) } AM_g = no \cdot Nex_a \cdot \left(\frac{D_g}{365}\right) \cdot EF_g \qquad \text{(Eq. 5.2d)}$$

where: no = number of animals
Nex_a = N excretion from animals, kg head^{-1} yr^{-1}
Nex_h = N excretion in housing unit, kg head^{-1} yr^{-1}
Nex_s = N excretion in storage unit, kg head^{-1} yr^{-1}
D_g = days on grass during the year (see Table 4.13)
EF = emission factor for the given unit (housing, storage, application or grass)

The emission calculation for fattening pigs in 2011 housed on fully slatted flooring is shown below as an example, based on normative figures and emission factors given in Table 5.1. In 2011, 21.9 million fattening pigs were produced (Table 4.5). Of these, 53 % are housed for 365 days a year in housing systems with fully slatted floor.

Table 5.1 Normative figures and emission factors for one produced fattening pigs in 2011 (DCA).

Normative figures, kg N per produced animal			Emission factors, EF, pct. NH_3-N of TAN		
TAN ex animal	TAN ex housing	TAN ex storage	Housing unit	Storage	Application
1.86	1.42	1.75	24	2.9	10.78 (slurry)

Calculation of the emission from fattening pigs housed on fully slatted floor:

$$AM_h = (21\,892\,113 \cdot 0.53) \cdot \frac{1.86}{1\,000} \cdot (1 - \frac{0}{365}) \cdot \frac{24}{100} = 5\,179 \text{ tonnes } NH_3\text{ - N}$$

$$AM_s = (21\,892\,113 \cdot 0.53) \cdot \frac{1.42}{1\,000} \cdot (1 - \frac{0}{365}) \cdot \frac{2.9}{100} = 478 \text{ tonnes } NH_3\text{ - N}$$

$$AM_{ap} = (21\,892\,113 \cdot 0.53) \cdot \frac{1.75}{1\,000} \cdot (1 - \frac{0}{365}) \cdot \frac{10.78}{100} = 2\,189 \text{ tonnes } NH_3\text{ - N}$$

$$AM_{total} = 5179 + 478 + 2189 = 7\,846 \text{ tonnes } NH_3\text{ - N} \Rightarrow 9\,527 \text{ tonnes } NH_3$$

N-excretion and emissions given in NH_3-N for all main livestock categories are shown in appendix G.

5.1.3 Normative figures for nitrogen in animal manure

The normative values for nitrogen excretion are estimated by DCA based on research results (Laursen, 1994; Poulsen & Kristensen, 1997; Poulsen et al., 2001; Poulsen, 2012). The normative figures are since 2002 adjusted annually to take account of the changes in feed composition and feed use efficiency. Values for N ex animal are provided in Appendix H for the most important livestock categories and in Appendix I based on TAN for 2007 to 2011.

For heifers a change in methodology has taken place. From 1985 to 2002 the normative figures for N ex was provided for each produced animal. This has changed form 2003, where the N ex covers N ex per AAP (annual average population – see definition in section 4.1). For animal categories for which N ex is based on produced animal, this is noticed as a footnote in Appendix H and I.

Appendix G shows the total N-excretion for the different main livestock categories from 1985 to 2011 as well as the NH_3 emission for the different main livestock categories.

5.1.4 Emission factors

Housing unit

The emission factors for housing vary according to the combination of housing and manure type. As an example, the emission factors for cattle housing units are given in Table 5.2 based on values in the report on normative standards (Poulsen et al., 2001, Poulsen, 2012). For emission factors for other livestock types see appendix J.

Table 5.2 NH_3 emission factors for housing units.

Cattle		Urine	Slurry	Solid manure	Deep litter manure
		TAN	TAN	Total N	Total N
Housing type		Pct. loss of TAN ex animal		pct. loss of N ex animal	
Tethered	urine and solid manure	10	-	5	-
	slurry manure	-	6	-	-
Loose-housing with beds	slatted floor	-	16	-	-
	slatted floor and scrape	-	12	-	-
	solid floor	-	20	-	-
	drained floor	-	8	-	-
	solid floor with tilt and scrape	-	8	-	-
	solid floor with tilt	-	12	-	-
Deep litter	all	-	-	-	6
	+ solid floor	-	-	-	6
	+ slatted floor	-	16	-	6
	+ slatted floor and scrape	-	12	-	6
	+ solid floor and scrape	-	20	-	6
Boxes	sloping bedded floor	-	16	-	-
	slatted floor	-	16	-	-

Denitrification of the N in animal manure, where the NH_4-N undergoes nitrification to N_2, N_2O and NO_X, can occur to a large degree with the use of deep litter bedding. This loss is subtracted from storage. The loss of N_2O is included in the calculation of greenhouse gases.

Storage

The emission factors used for storage are listed in Table 5.3 and are based on normative figures (Poulsen et al., 2001 and Poulsen, 2012).

Table 5.3 NH_3 emission factors for storage units.

			Urine	Slurry[1]	Solid manure	Deep litter	Pct. of solid manure stored in heap on field
Cattle		Total N	2	2.1	4	1	35
		TAN	2.2	3.5	-	-	-
Swine	Sows	Total N	2	2.4	19	6.5	50
		TAN	2.2	2.9	-	-	-
	Weaners	Total N	2	2.4	19	9.8	-
		TAN	2.2	2.9	-	-	-
	Fattening pigs	Total N	2	2.4	19	9.8	75
		TAN	2.2	2.9	-	-	-
Poultry	Hens and pullets	Total N	-	2	7.5	4.8	95
	Broilers	Total N	-	-	11.5	6.8	85
	Turkeys	Total N	-	-	-	8	-
	Ducks and geese	Total N	-	-	-	6.8	-
Fur animals		Total N	0	3.1	11.5	-	-
		TAN	0	3.1	-	-	-
Horses, sheep and goats		Total N	-	-	-	4	-

[1] It is assumed that 5 % of slurry tanks in swine production and 2 % in cattle production are not fully covered or have an inadequate floating cover. The emission factors were higher in the previous years (see appendix K).

Liquid manure

The emission from urine is, according to the normative figures, an estimated 2 % of total N ex housing unit and 2.2 % of TAN ex housing unit from a closed urine tank.

Due to legislation from 2003 all slurry tanks have to be fully covered or have established a floating cover. As not all slurry tanks have a fixed cover or a full floating cover, this is taken into account in the inventory (COWI, 1999 and 2000). It is assumed that the covered capacity has increased in recent years as a result of the stricter regulations on the management of slurry tanks. However, it is difficult to achieve full floating cover all day of the year, some emission can take place during filling and mixing of manure in the tank. Therefore, it is assumed that floating/fixed covers are absent on 5 % of slurry tanks in swine production and on 2 % in cattle production.

The correction for the lack of floating/fixed covers for total N ex housing unit is based on normative figures (Poulsen et al., 2001), while the correction for TAN is based on Hansen et al. (2008). The emission factor for swine slurry with and without a floating/fixed cover is 2 % and 9 % of total-N ex housing unit and 2.5 and 11.4 % of TAN, respectively. For cattle slurry the factor is approximately 2 % with floating/fixed cover and 6 % of total-N ex housing and 3.4 and 10.3 % of TAN, respectively. Calculation examples of NH_3-N emission factor based on TAN for swine and cattle slurry are shown in Equation 5.3. The unit is kg NH_3-N per kg TAN.

$$\text{a) Emission}_{\text{swine slury}} = (0.95 \cdot 2.5\%) + (0.05 \cdot 11.4\%) = 2.9\% \qquad \text{(Eq. 5.3a)}$$

$$\text{b) Emission}_{\text{cattle slurry}} = (0.98 \cdot 3.4\%) + (0.05 \cdot 10.3\%) = 3.5\% \qquad \text{(Eq. 5.3b)}$$

The emission factors for 2011 for swine (corrected), cattle (corrected) and fur animals are 2.9 %, 3.5 % and 3.1 %, respectively. Emission factors for all years are shown in appendix K.

Solid manure

The volatilization from solid manure is based on normative figures (Poulsen et al., 2001). From august 2006 the law stipulates that manure heaps should be covered, but also here a correction of the emission factor is made for the ones not covered. A calculation example of the correction for swine manure is shown in Equation 5.4. The unit is kg NH_3-N per kg TAN.

$$\text{Emission}_{\text{swine manure}} = (0.5 \cdot 0{,}25\%) + (0.5 \cdot 0{,}13\%) = 19\% \qquad \text{(Eq. 5.4)}$$

Emission factors for cattle, swine, poultry, and fur animals are 4 %, 19 %, 7.5 % (broilers 11.5 %) and 11.5 %, respectively. See emission factors and factors for correction in appendix L.

The emission from deep litter bedding is based on normative figures (Poulsen et al., 2001). The calculation of the emission from cattle, sows, fattening pigs, hens and broilers takes into account that a proportion of the manure is applied directly to the field and, therefore, not stored in the field manure heap. The report containing normative figures estimates percentage of manure stored in the field manure heap (Poulsen, 2012), see Table 5.3.

Denitrification

Table 5.4 lists the emission factors for denitrification of solid manure and deep litter based on normative figures (Poulsen et al., 2001 and Poulsen, 2012). The emission factors are estimated on the basis of measurements in Danish cattle and swine housing units. The factors for the remaining livestock categories are not measured directly; however, they are estimated relative to the denitrification from cattle and swine units. The fact that a certain proportion of the manure is stored in the field manure heap is taken into account (Poulsen et al., 2001).

Table 5.4 Denitrification associated with storage of solid manure and deep litter in the field manure heap.

	Denitrification in percent of total N ex housing unit	
	Solid manure	Deep litter
Cattle	10	5
Swine	15	15
Poultry	10	10
Horses, sheep and goats	-	10

Field application of manure

A change in practice of manure application has taken place as a result of change in crop pattern and increasing environmental demands. A rise in growing of winter cereals from 1985 to 2011 has led to a shift from manure application in autumn to early application in spring and changes in application technology. The requirement for an improved N utilisation in manure has also led to a greater proportion of slurry being injected or incorporated directly into the soil. Two further NH_3 reducing measures should also be mentioned. Following the legislation (BEK, 2002) a ban on traditional broad spreading of liquid manure was introduced, and manure applied to areas without vegetation had to be incorporated into the soil within six hours of application, both effective from 1 August 2003. From 2011, slurry applied on fields with grass for feeding or fields without crop cover, has to be injected directly into the soil (BEK no. 915 of 27/06/2013). However, the injection can be substituted by acidification of the slurry. In future, acid treated slurry during spreading of manure on fields is expected to expand. Acidification reduce the pH value and thus reduce ammonia emission, because a larger part of the nitrogen is converted to ammonium, which does not evaporate as easy as ammonia. It is expected that the reducing effect of the acid treated slurry will be implemented in the emission inventory, when data are available for how much manure is acidified. To calculate the emission from application of manure to agricultural land, three different weighted emission factors are used. These distinguish between solid manure, liquid manure from swine and liquid manure from cattle and other livestock.

Changes in application practices and technological improvements driven by environmental legislation have led to a decrease in the weighted emission factors – see Table 5.5. The emission factor from liquid cattle manure have decreased from 33.0 % in 1985 to 13.1 % in 2011, corresponding to a 60 % reduction due to approximately two thirds of the slurry now being injected/incorporated directly into the soil. A smaller reduction has taken place for liquid swine manure and solid manure.

Table 5.5 Percentage loss of NH_3 from application of liquid manure (NH_3-N of TAN ex storage) and solid manure (NH_3-N of N ex storage).

Weighted emission factor		1985	1990	1995	2000	2005	2008	2009	2010	2011
Liquid manure	Cattle[1]	33.0	34.3	30.3	27.2	14.1	14.3	14.3	14.3	13.1
	Swine	17.3	17.9	15.3	13.8	11.1	11.0	11.0	11.0	10.8
Solid manure		9.6	7.9	7.5	6.8	6.7	6.4	6.4	6.4	6.7

[1] Value for cattle is also used for all other animal types, except for swine.

Calculation of the weighted emission factor

The weighted emission factor is calculated for each year and in two stages. EF_w is calculated first as the sum of the proportion of manure applied under a given application practice (i) multiplied by the associated emission factor for this application practice.

$$EF_w = \sum MA_i \cdot EF_i \qquad \text{(Eq. 5.5)}$$

where:
- EF_w = weighted emission factor, kg NH_3-N kg N^{-1} yr^{-1}
- MA_i = nitrogen in manure applied under a given application practice i, kg N yr^{-1}
- EF_i = emission factor for the application practice i, kg NH_3-N kg N^{-1} yr^{-1}

Secondly is calculated EF_{wt} which includes emission reducing technology, such as acidification of manure in connection with application.

$$EF_{wt} = p_t \cdot (EF_w - EF_t) \qquad \text{(Eq. 5.6)}$$

Where:	EF_{wt}	= weighted emission factor including technology, kg NH_3-N kg N^{-1} yr^{-1}
	p_t	= percentage of the manure treated by the technology *t*
	EF_w	= weighted emission factor by application practice
	EF_t	= emission factor for manure treated by the technology *t*

A given application practice is determined by different combinations of variables such as application time, application methods, length of time between application and incorporation of manure, and stage of crop growth.

Application time

a. spring-winter (bare soil, crops, grass)
b. spring-summer (grass)
c. late summer-autumn (rape, seed grass)

Application method

a. injection/direct incorporation
b. trailing hoses
c. broad spreading (prohibited for liquid manure from 2003)

Length of time between application to land and incorporation of manure

a. 6 or 4 hours
b. less than 12 hours
c. more than 12 hours
d. more than a week

Stage of crop growth

a. bare soil
b. growth

There is no annual statistical information on how the farmer handles the manure application in practice. The calculations are based on a study of a limited number of farms, sales figures for manure application machinery as well as development trends in LOOP areas (catchments included in the national monitoring programme for the aquatic environment) (Andersen et al., 2001).

The estimate for application practice in 2001 and 2002 is, in addition to data from LOOP areas (Grant et al., 2002; Grant et al., 2003), based on information from the organisation for agricultural contractors (Kjeldal, 2002) and a questionnaire survey of application practice implemented by Danish Agriculture (2002) involving 1.600 farmers. From 2003 onwards the estimate of application practice is based on expert judgment (Birkmose, 2012).

The assumed application practice for the years 1985 – 2011 is shown in appendix M.

Emission factor

The emission factor used for each combination of application practice (equation 5.5) is based on information from Hansen et al. (2008), see Table 5.6.

The emission will be relatively high in the beginning of the growing season, when the plants, by virtue of their small size, do not contribute significant to shade or shelter. With applications later in the season the emission will be significantly lower, despite the higher air temperatures, as a result of the larger leaf area available. In addition to the shade and shelter effect provided by the leaves, which lowers the emission, a proportion of the NH_3 in gaseous form will be absorbed by the leaves themselves.

In accordance to Danish livestock regulations, the maximum time between application and incorporation of manure has been reduced from 12 to 6 hours from BEK (2002). It is assumed that the decrease in the emission factor resulting from this reduction will be 33 % (Sommer, 2002).

Table 5.6 Emission factors for application of animal manure.

		Emission factor under application			
		Liquid manure			
Crop stage A)	Application time	Injected/incorporated direct		Trailing hoses	
		B) hours	NH_3-N in pct. of TAN in manure	B) hours	NH_3-N in pct. of TAN in manure
-	March	0	1.6	4	10.7
-	April	0	1.8	4	11.6
+	March	> 1 week	24.5	> 1 week	26.9
+	April	> 1 week	26.7	> 1 week	28.6
+	May	0	-	> 1 week	26.0
+	Summer	0	32	> 1 week	43.2
-	Summer	0	2.1	4	13.8
+	Autumn	0	28.6	> 1 week	38.6
-	Autumn	0	1.9	4	12.4
		Liquid manure		**Solid manure**	
		Broad spreading		Traditional	
		B) hours	NH_3-N in pct. of TAN in manure	B) hours	NH_3-N in pct. of total in manure
-	Winter-spring	< 12	18.5	4	5.0
-	Winter-spring	> 12	20.1	6	10.0
-	Winter-spring	> 1 week	48.6	> 1 week	16.0
+	Spring-summer	> 1 week	73.5	> 1 week	20.0
+	Late summer-autumn	> 1 week	72.0	> 1 week	14.0
-	Late summer-autumn	< 12	23.0	4	3.0
-	Late summer-autumn	> 12	23.0	6	8.0
-	Late summer-autumn	> 1 week	23.0	> 1 week	11.0

A) - indicate bare soil + indicate growth.

B) Length of time before incorporation into soil.

Grazing

Part of the manure from dairy cattle, heifers, suckling cows, sheep, goats, horses and deer is deposited on the field during grazing (See Chapter 4.3).

An emission factor of 7 % of the total nitrogen content is assumed for volatile NH_3-N, which is based on studies of grazing cattle in the Netherlands and the United Kingdom (Jarvis et al., 1989a; Jarvis et al., 1989b; Bussink, 1994). The emission factor is used for all animal categories.

5.2 Synthetic fertilisers

Data on the use of synthetic fertiliser is based on the sale estimations collected by DAFA (2012). Emission factors are based on the values given in EMEP/EEA Guidebook (EMEP, 2009).

The emission from synthetic fertilisers depends on type as well as amount used. Data for consumption (Table 5.7), fertiliser type and nitrogen content (Table 5.8) are obtained from the DAFA (2012), which is based on the total sale from all fertiliser suppliers.

The AgriFish Agency estimates that 1–2 % of synthetic fertilisers is used in parks, golf courses and sports grounds, etc. (Knudsen, 2010) – i.e. areas that are not directly associated with agricultural activities. However, the 1–2 % of the emission from these sources is included in the emission from agriculture.

Table 5.7 Synthetic fertiliser consumption 1985 – 2011, Gg N.

	1985	1990	1995	2000	2005	2008	2009	2010	2011
Used in agriculture	398	400	316	251	206	220	200	190	197
Other	6	6	6	6	2	2	2	2	2
Total	404	406	322	257	208	223	202	192	199

Emission factors for the various fertiliser types are based on the recommendations in the EMEP/EEA Guidebook (EMEP, 2009) – see Table 5.8. The same emission factors are applied for all years.

Table 5.8 Consumption and emission factors used for synthetic fertiliser, 2011.

	Emission factor, Pct. of N in fertiliser	Consumption, Gg N
Fertiliser type:		
Calcium nitrate + boron	1.4	0.4
Ammonium sulphate	1.4	6.2
Calcium ammonium nitrate and other nitrate types	0.9	94.9
Ammonium nitrate	0.9	8.6
Liquid ammonia	2.0	6.0
Urea	12.8	0.4
Other single fertilisers	6.3	25.2
Magnesium fertiliser	1.4	0.0
NPK fertiliser	0.9	48.1
Diammonium phosphate (18-20-0)	1.4	1.1
Other NP fertilisers	1.4	4.0
NK fertilisers	0.9	2.3
Total consumption of fertiliser		197[1]
Emission factor - weighted average	1.6	

[1] Including consumption relating to parks, sports grounds etc. – representing approximately 1 %.

Since 1985, there has been a significant decrease in the use of synthetic fertiliser (Table 5.7). This is mainly due to stricter requirements to the utilisation of nitrogen in manure and requirements to handling of manure applied to the soil. Another reason is changes in the distribution of the different types of fertiliser. Use of urea, which has a high emission factor, has decreased and constitutes today less than 1 % of the total nitrogen used as fertiliser. In average 1.6 % of the total nitrogen used in synthetic fertiliser is emitted as NH_3 in 2011.

Table 5.9 NH_3-N emission from synthetic fertilisers 1985 – 2011, tonnes NH_3-N.

	1985	1990	1995	2000	2005	2008	2009	2010	2011
Agriculture	5 322	5 427	4 573	3 169	2 573	3 005	3 020	2 857	3 243
Other	50	50	50	50	18	19	17	16	17
Total	5 272	5 378	4 523	3 119	2 555	2 986	3 003	2 841	3 226

5.3 Crops

Plants exchange NH_3 with the atmosphere both by absorbing and expelling NH_3. The amount can vary significantly depending on the plant's stage of development, conditions surrounding the application of the fertiliser and climatic conditions at the particular location. A study from Schjoerring and Mattsson (2001) indicate an emission of up to 5 kg NH_3-N per hectare. Based on a literature study the emission from growing crops is estimated to 2 kg N per ha for crops in rotation and 0.5 kg per ha for grass and clover (Gyldenkærne & Albrektsen; 2013).

The size of the cultivated area is based on information from Statistics Denmark.

Table 5.10 Emission factor used for crops, kg N per ha.

All crops ex grass	2
Grass/clover in a rotation	0.5
Permanent/long-term grass	0.5

From 1985 to 2011 the NH_3 emission from growing crops has decreased from approximately 4 900 to 4 500 tonnes of NH_3-N corresponding to a small reduction of 9 %, which is due to a decrease in the area with crops.

5.4 Sewage sludge

Some of the sludge from wastewater treatment and the manufacturing industry are applied as fertiliser to agricultural soil. Information on the amount of sewage sludge applied is obtained from reports prepared by the Danish Environmental Protection Agency, where the latest one is DEPA, 2009. From 2005 and onwards the amount of N applied from wastewater treatment is based on the fertiliser accounts controlled by DAFA. Farmers with more than 10 animal units[1] have to be registered and have to keep accounts of the N content in manure, received manure or other organic fertiliser.

The N content varies from year to year and is usually 4–5 % of the total amount of sludge. An emission factor of 3 % of the N content in sludge is used, based on information from the Danish Environmental Protection Agency (Bielecki, 2002). For sludge incorporated into soil within six hours of application the emission factor is expected to be halved, i.e. 1.5 %. Concerning the application to fields it is assumed that 25 % of the sludge is not incorporated, while the remaining 75 % is incorporated within six hours. This gives a weighted emission factor of approximately 1.9 %, same for all years.

$$\mathrm{EF}_{\text{sewage sludge}} = 0.25 \cdot 0.03 + 0.75 \cdot 0.015 = 0.01875 \text{ NH}_3\text{-N of N applied}$$

[1] A Danish animal unit is defined as 100 kg Nex Storage from an average housing system. This corresponds to e.g. 0.75 large breed dairy cattle or 36 fattening pigs.

Table 5.11 shows an increasing amount of sewage sludge being applied to agricultural soil from 1985 to the mid-1990s, which is replaced by a decrease until 2008 due to use of the product in industrial processes, e.g. in cement production and the production of sandblasting materials. Since 2008 is seen a slight increase of the amount of sewage sludge applied to soils.

Table 5.11 Emission from sewage sludge applied to agricultural land 1985-2011.

	1985	1990	1995	2000	2005	2008	2009	2010	2011
Sewage sludge applied to agricultural soil, Gg dry matter	50	78	112	84	46	50	63	57	55
N-content, pct.	4.0	4.0	4.1	4.3	4.8	4.8	4.8	4.8	4.8
N applied to agricultural soil[a], tonnes NH_3-N	2 000	3 100	4 600	3 600	2 200	2 400	3 000	2 700	2 600
NH_3-N emission, tonnes NH_3-N	38	58	87	68	41	45	56	50	49

[a] rounded values.

The NH_3 emission from industrial sludge is assumed to be negligible because most of it is immobilised in organic matter (Andersen et al., 1999), which is why there is no estimate for this source.

5.5 NH_3 treated straw

NH_3 treated straw was until 2006 used as cattle feed. By law in 2006 the NH_3 treatment of straw was banned. However, due to wet weather conditions a dispensation to the law was given in 2010 and 2011. The addition of NH_3 promotes the breakdown of the straw, which aids the digestion processes. It is assumed that the sale of NH_3 in the second half of the year is used for the treatment of straw with NH_3 and the NH_3 sales are obtained from the suppliers. Emissions from NH_3 treated straw are not included when it comes to the EU NEC directive.

The emission from ammonia treatment of straw is estimated to 65% kg NH_3-N per kg N added to straw. This estimate is based on few studies and depends on the dry matter content in straw and the storage conditions (Andersen et al., 1999). There is no statistics regarding how the farmers handle the ammonia treated straw in practice, so emission factor at 65 % is highly uncertain.

Table 5.12 shows that since 1985 there have been a considerable decrease in the emission from NH_3 treated straw until the ban in 2005.

Table 5.12 Emission from NH_3 treated straw, 1985-2011, tonnes NH_3-N.

	1985	1990	1995	2000	2005	2006-2009	2010	2011
Consumption of NH_3-N	8 285	12 912	8 406	3 125	329	NO	300	300
Emission of NH_3-N	5 385	8 393	5 464	2 031	214	NO	195	195

NO – Not occurring.

6 PM emission

PM emissions originate from the housing of livestock, from field operations (harvesting and cultivation of soil), the handling of crop products (storage and transport) and from field burning of agricultural residues. In the Danish inventory only PM from livestock and from field burning is included.

A methodology, for calculating PM emissions from field operations, is provided in the 2013 edition of the EMEP/EEA Guidebook, but it is needed to investigate if default values in the Guidebook reflect the Danish agricultural conditions.

The PM emissions from the agricultural sector mainly consist of larger particles. In the reporting under CLRTAP particulate matter is reported as TSP, PM_{10} and $PM_{2.5}$. Tiny airborne particles or aerosols that are smaller than 100 µm are collectively referred to as total suspended particles (TSP). PM_{10} is the fraction of suspended particulate matter with an aerodynamic diameter of 10 µm or smaller and $PM_{2.5}$ represents particles smaller than 2.5 µm.

Agriculture accounts for 31 % of the total TSP emission in 2011 and the emission shares for PM_{10} and $PM_{2.5}$ are only 20 % and 6 % respectively. Most agricultural emissions originate from livestock and a description of the calculation methodology is set out below. Emissions from the field burning of agricultural residues contribute less than 1 % to the agricultural emissions. The calculation from field burning is described in Chapter 7.

6.1 Livestock production

The emission of PM is estimated for the years 1985-2011, but only reported in the Danish inventory for the years 2000 to 2011 in line with the reporting guidelines (UNECE, 2009).

The emissions from animal production include dust from housing systems for cattle, swine, poultry, horses, sheep and goats. In 2011 these emissions, expressed as TSP, were an estimated 11.29 Gg. Of this, 79 % relates to swine production. The emission from cattle and poultry contributed 11 % and 10 %, respectively.

6.1.1 Calculation method

The estimation of the PM emission is based on the EMEP/EEA Guidebook (EMEP, 2009) part B, chapter 4B, where the scientific data are based mainly on an investigation of PM emissions from North European housings (Takai et al., 1998). The PM emission is calculated using equation 6.1 and thus distinguishes between emission from liquid and solid manure.

$$PM_{10} = no \cdot \left(1 - \frac{D_G}{365}\right) \cdot \left(EF_{PM_{10}} \cdot B + EF_{PM_{10}} \cdot B\right) \qquad \text{(Eq. 6.1)}$$

where:
PM_{10} = emission of PM_{10}
no = number of average annual population (AAP – see definition in section 4.1)
D_G = actual days on grass
$EF_{PM10, S\ or\ L}$ = emission factor for solid or liquid manure

$B_{S\ or\ L}$ = percent of solid or liquid manure

The main types of housing are divided into subcategories with a distinction for each category between solid and slurry-based housing systems. Besides the distinction between liquid and solid manure, the PM emission is furthermore related to the number of days the animal is housed. The PM emission from grazing animals is considered negligible. Number of grazing days 2011 is listed in Table 4.13.

Table 6.1 shows emission of PM from livestock, see appendix N for PM emission for all years distributed on the different animal categories. PM emission is reported in the inventory for the years 2000-2011.

Table 6.1 PM emission from livestock 1985-2011, Gg.

	1985	1990	1995	2000	2005	2008	2009	2010	2011
TSP	9.33	9.25	10.33	11.18	11.74	11.01	10.86	11.43	11.29
PM_{10}	4.64	4.64	5.26	5.70	5.86	5.44	5.50	5.73	5.68
$PM_{2.5}$	1.22	1.15	1.21	1.24	1.21	1.16	1.16	1.20	1.20

The main part of the emission of PM from livestock originates from swine housings. The emission increases from 1985 to 2000 mainly due to increase in number of animals. In the period 2000 to 2011, the emission of PM from livestock is almost unaltered, but from 2009 to 2010 the emission increased (TSP increases 5 %), mainly due to an increase in the number of swine.

6.1.2 Emission factors

The emission factors for PM_{10} and $PM_{2.5}$ are those recommended in the EMEP/EEA Guidebook, (EMEP, 2009). However, calves and weaners are not included and therefore the 2006 edition of the Guidebook (EMEP, 2006) is used for these. Emission factors for sheep and goats are based on Fontelle et al. (2011). The same emissions factors are used for all years.

In Takai et al. (1998), dust emission from housings is categorised as "inhalable dust". This is defined as particles that can be transported into the body via the respiratory system. "Inhalable dust" equates approximately to TSP (Hinz, 2002). Estimation of TSP is based on the conversion factors for inhalable dust into PM_{10} given in the Guidebook (EMEP, 2009). The conversion factor for cattle, horses, sheep and goats is 0.46, for swine 0.45 and poultry 1.00.

Table 6.2 shows the emission factors for livestock. The emission factors are given for the various housing systems and separated into solid or slurry-based systems.

Table 6.2 PM emission factors from animal housing systems, kg per AAP (defined in section 4.1).

		Emission factor		
Livestock category	Manure type	TSP	PM_{10}	$PM_{2.5}$
Cattle:				
Dairy cattle	Solid	0.78	0.36	0.23
	Slurry	1.52	0.70	0.45
Calves < ½ year	Solid	0.35	0.16	0.1
	Slurry	0.33	0.15	0.1
Beef cattle	Solid	0.52	0.24	0.16
	Slurry	0.70	0.32	0.21
Heifer[1]	Solid	0.57	0.26	0.17
	Slurry	0.93	0.43	0.28
Suckling cattle[2]	Solid	0.52	0.24	0.16
	Slurry	0.70	0.32	0.21
Swine:				
Sows	Solid	1.29	0.58	0.094
	Slurry	1.00	0.45	0.073
Weaners	Solid[3]	0.40	0.18	0.029
	Slurry	0.40	0.18	0.029
Fattening pigs	Solid	1.11	0.50	0.081
	Slurry	0.93	0.42	0.069
Poultry:				
Laying hens	Solid	0.017	0.017	0.002
	Slurry	0.270	0.270	0.052
Broilers	Solid	0.350	0.350	0.045
Turkeys	Solid	0.032	0.032	0.004
Other poultry	Solid	0.032	0.032	0.004
Other:				
Horses	Solid	0.39	0.18	0.12
Sheep	Solid	0.133	0.061	0.018
Goats	Solid	0.133	0.061	0.018

[1] Average of “calves” and “dairy cattle”.

[2] Assumed the same value as for “Beef cattle”.

[3] Same as slurry-based systems.

6.2 Field operations

In the EMEP/EEA Guidebook a methodology is provided to account for PM emissions from field operations, which includes emissions from crop harvesting, cultivation of soil, and the cleaning and drying of crops (EMEP, 2009). Harvesting is the predominant source of PM and the emission depends on crop and soil type, cultivation method and the weather before and during work.

6.2.1 Calculation method

The methodology provided in the EMEP/EEA Guidebook on emission calculations from field operations is shown below:

$$E_{PM} = EF_{PM} \cdot AR \cdot no \qquad \text{(Eq. 6.2)}$$

where: E_{PM} = emission of PM_{10}, $PM_{2.5}$ or TSP, kg a^{-1}
EF_{PM} = emission factor for crop and operation type, kg ha^{-1}
AR = area of crops, ha

no = production cycles, the number of times the operations are performed, a^{-1}

Emission calculations should be made for each crop and operation type. Data needed to complete the emission calculations are crop production, operation types and operation procedures. A first estimate is not yet provided, so the quantification of the agricultural contribution is still unknown.

6.2.2 Emission factors

Emission factors for crops and operation type are given in Table 6.3 (EMEP, 2009). Emission factors for wet climate conditions are the most comparable for Danish conditions. Emission factors for TSP are not available.

Table 6.3 Emission factor for PM_{10} and $PM_{2.5}$ for agricultural crop operations, kg per ha.

Crop	Soil cultivation	Harvesting	Cleaning	Drying
PM_{10}				
Wheat	0.25	0.49	0.19	0.56
Rye	0.25	0.37	0.16	0.37
Barley	0.25	0.41	0.16	0.43
Oat	0.25	0.62	0.25	0.66
Other arable	0.25	NAV[2]	NAV[2]	NAV[2]
Grass[1]	0.25	0.25	NO	NO
$PM_{2.5}$				
Wheat	0.015	0.02	0.009	0.168
Rye	0.015	0.015	0.008	0.111
Barley	0.015	0.016	0.008	0.129
Oat	0.015	0.025	0.0125	0.198
Other arable	0.015	NA	NA	NA
Grass[1]	0.015	0.01	NO	NO

[1]Grass includes hay making only.

[2]NAV = not available.

Information on how the field operations typically are performed for each crop type in Denmark is needed. This includes e.g. estimates on the average number of field operations and type of machinery used during production of the different crop types. Furthermore, it has to be considered if the default values provided in the EMEP/EEA Guidebook reasonably reflect Danish agricultural conditions or if national values are available.

7 Field burning of agricultural residues

The field burning of agricultural residues has been prohibited in Denmark since 1990 (LBK, 1989; BEK, 1991) and may only take place in connection with the production of grass seeds on fields with repeated production (straw from seeds of grass) and in cases of wet or broken bales of straw (mixed cereals). The amount of burnt straw from the grass seed production is estimated at 15 % of the total amount produced. The amount of burnt bales or wet straw is estimated at 0.1 % of the total amount of straw. Both estimates are based on an expert judgement provided by the Danish Agricultural Advisory Service (Feidenhans'l, 2009). The total production is based on data from DSt.

Field burning produces emissions of a series of different pollutants: NH_3, CH_4, N_2O, NO_x, CO, CO_2, SO_2, NMVOC, PM, heavy metals, dioxins, PAHs, HCB and PCBs. Default values given by the EMEP/EEA Guidebook (EMEP, 2009) are used for NH_3, NO_x, CO, SO_2, NMVOC, PM, heavy metals (except for Cu) and dioxins. For Cu and for PAHs, emission factors are based on Jenkins (1996) and for N_2O, CH_4 and CO_2 the emission factors are based on Andreae & Merlet (2001). Emission factors for HCB are based on Hübner (2001) and for PCBs on Black et al. (2012).

The equation for calculating the emission is shown below. The parameters used for the calculation of emissions are given in Table 7.1**Error! Reference source not found.** and the EF's are provided in Table 7.3. EF is the same for all years.

$$Emi = BB \cdot \frac{EF}{1\,000} \cdot FO \qquad \text{(Eq. 7.1)}$$

$$BB = \frac{CP \cdot FB \cdot FR_{DM}}{1\,000}$$

where
- Emi = emission of pollutants, Gg
- BB = total burned biomass, Gg dry matter (DM)
- CP = crop production, t
- FB = fraction burned in fields
- FR_{DM} = dry matter fraction of residue
- EF = emission factor, g per kg DM
- FO = fraction oxidized

Table 7.1 Parameters for estimating emissions from field burning, 2011.

	Crop production tonnes	Fraction burned in fields	Dry matter fraction of residue[a]	Total biomass burned Gg DM	Fraction oxidized[b]
Mixed cereals	5 436 000	0.001	0.85	4.62	0.90
Straw from seeds of grass	281 975	0.15	0.85	35.95	0.90

[a] DAAS (2005).

[b] IPCC (1997).

7.1 Conversion of EF for HCB

The emission factor for HCB from field burning of agricultural residue is given by Hübner (2001) as 10 000 µg per ha. This factor has been converted to the unit g per tonnes by following equation:

$$EF_{Used} = \frac{\frac{EF_{Hubner}}{Y}}{1\,000\,000} \quad \text{(Eq. 7.1)}$$

Where: EF_{Used} = emission factor in g per tonnes
EF_{Hubner} = emission factor given by Hübner (2001), 10 000 µg per ha
Y = yield in tonnes per ha

Table 7.2 Emission factor for HCB from field burning of agricultural waste.

	Yield, tonnes per ha	EF, g per tonnes
Straw from cereals	3.4	0.003
Straw from seed production	5	0.002

7.2 Emissions

Figure 7.1 shows the trend of the emission of NH_3, PM_{10}, $PM_{2.5}$, CH_4 and NMVOC from field burning for 1985-2011. The large decrease of the emissions in 1990 is due to the ban on field burning of agricultural residues. The trend of the emission of the remaining pollutants is similar to the ones shown. Emissions for all pollutants and all years are shown in appendix T.

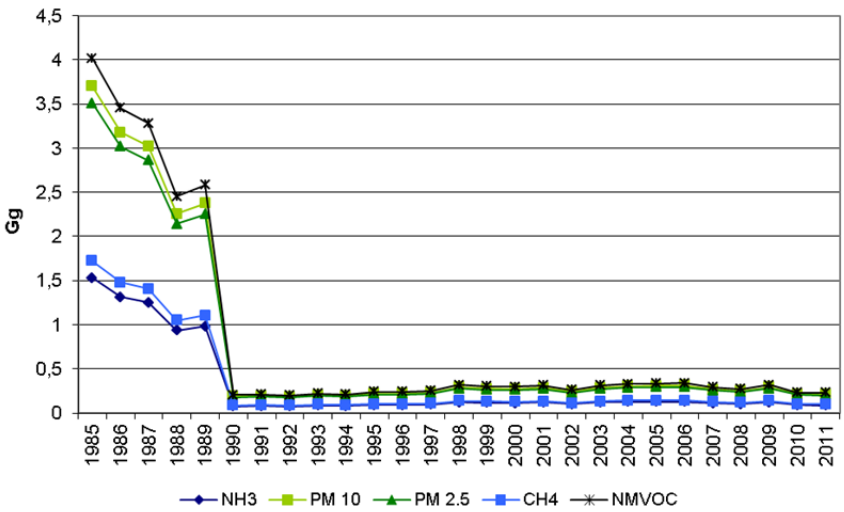

Figure 7.1 Trend of the emission of selected pollutants from field burning of agricultural residues.

Table 7.3 shows the emission of all pollutants from field burning of agricultural residues for the year 2011. See Appendix T for emissions for all years.

Table 7.3 Emission factors and emissions for the different pollutants from field burning of agricultural residues, 2011.

Pollutant	EF	Unit for EF	Emission 2011	Unit for emission
NH_3	2.4	g per kg DM	0.09	Gg
CH_4	2.7	g per kg DM	0.10	Gg
N_2O	0.07	g per kg DM	0.003	Gg
NO_x	2.4	g per kg DM	0.09	Gg
CO	58.9	g per kg DM	2.15	Gg
CO_2	1.515	kg per kg DM	55.32	Gg
SO_2	0.3	g per kg DM	0.01	Gg
NMVOC	6.3	g per kg DM	0.23	Gg
PM				
TSP	5.8	g per kg DM	0.21	Gg
PM_{10}	5.8	g per kg DM	0.21	Gg
$PM_{2.5}$	5.5	g per kg DM	0.20	Gg
Metals				
Pb	0.865	mg per kg DM	0.03	Tonnes
Cd	0.049	mg per kg DM	0.002	Tonnes
Hg	0.008	mg per kg DM	0.0003	Tonnes
As	0.058	mg per kg DM	0.002	Tonnes
Cr	0.22	mg per kg DM	0.01	Tonnes
Ni	0.177	mg per kg DM	0.01	Tonnes
Se	0.036	mg per kg DM	0.001	Tonnes
Zn	0.028	mg per kg DM	0.001	Tonnes
Cu	0.0003	mg per kg DM	0.00001	Tonnes
Dioxins	500	ng TEQ per t	0.02	g/TEQ
PAHs				
Benzo(a)pyrene	2 787	μg per kg DM	0.10	Tonnes
benzo(b)fluoranthene	2 735	μg per kg DM	0.10	Tonnes
benzo(k)fluoranthene	1 073	μg per kg DM	0.04	Tonnes
Indeno(1,2,3-cd)pyrene	1 017	μg per kg DM	0.04	Tonnes
HCB - mixed cereals[1]	0.003	g per t		
HCB - grass seed[1]	0.002	g per t		
HCB			0.09	kg
PCBs - mixed cereals	3	μg TEQ per t		
PCBs - grass seed	0.05	μg TEQ per t		
PCBs			0.00002	kg

[1] See Chapter 11.2 for conversion of EF from the unit ha to g per t.

References: EMEP, 2009, Jenkins, 1996, Andreae & Merlet, 2001, Hübner, 2001

8 HCB emission from use of pesticides

Hexachlorobenzene (HCB) is a poisonous substance, which is dangerous to human and animal health. HCB is used as agent in pesticides and some of the pesticides used in Denmark contain HCB, but pure HCB used as pesticide is banned.

There are two sources for HCB emission in the agricultural sector; field burning of agricultural residue and the use of pesticides. Emissions of HCB from field burning of agricultural residues are described in Chapter 7.

8.1 Pesticides

A range of pesticides are used in Denmark. In the period from 1990 to 2011 six types of pesticides containing HCB have been identified as used in Denmark. These are atrazine, chlorothalonil, clopyralid, lindane, pichloram and simazine. Data of amounts of effectual substance used in Denmark are collected from Environmental Protection Agency (EPA), see Table 8.1. The use of atrazine and lindane stopped in 1994 and the use of chlorothalonil and simazine ceased in 2000 and 2004, respectively.

Table 8.1 Amounts of effectual substance used in Denmark, 1990-2011, kg.

	1990	1995	2000	2005	2008	2009	2010	2011
Atrazine	91 294	-	-	-	-	-	-	-
Chlorothalonil	10 512	10 980	7 340	-	-	-	-	-
Clopyralid	16 461	22 587	7 446	5 874	5 137	20 846	9 126	11 841
Lindane	8 356	-	-	-	-	-	-	-
Pichloram	-	-	-	-	-	-	723.6	1 350
Simazine	30 234	19 865	23 620	-	-	-	-	-

The emission is calculated using following equation:

$$\mathrm{E}_{pes} = \sum a_i \cdot \mathrm{EF}_i \quad \text{(Eq. 8.1)}$$

Where: E_{pes} = emission of HCB from pesticides
a_i = amount of effectual substance in the pesticide *i*
EF_i = emission factor for the pesticide *i*

No default emission factors are given in EMEP/EEA Guidebook. Emission factors given in Yang (2006) are used in the calculation of the emissions, see Table 8.2.

Table 8.2 Emission factors for HCB from pesticides, 1990-2011, g per tonnes.

	1990	1995	2000	2005	2008	2009	2010	2011
Atrazine	100	1	1	1	1	1	1	1
Chlorothalonil	500	40	40	10	10	10	10	10
Clopyralid	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Lindane	100	50	50	1	1	1	1	1
Pichloram	100	50	50	8	8	8	8	8
Simazine	100	1	1	1	1	1	1	1

EPA, 2011.

8.2 Emission

Table 8.3 shows the emission of HCB from the agricultural sector for the years 1990-2011. The emission has decreased significantly from 1990 to 2011 due to decrease in use of pesticides containing HCB.

Table 8.3 Emission of HBC, 1990-2011, kg.

	1990	1995	2000	2005	2008	2009	2010	2011
Pesticides	18.28	0.50	0.33	0.01	0.01	0.04	0.02	0.03

9 NMVOC emission

Around 2 % of the total NMVOC emission originates from the agricultural sector. Three emission sources are known: agricultural soils (crops), manure management and field burning of agricultural residues. For the emission from field burning see Chapter 7. In 2011, the emission from agricultural soils contributed 89 % and field burning 11 % to the agricultural emission.

Currently, the emission inventory does not include the NMVOC emissions from manure management.

The emission of NMVOC from agricultural soils is included in the Danish inventory and cover emissions from arable crops and grassland. NMVOC emissions can be influenced by a series of factors, such as temperature and light intensity, plant growth stage, water stress, air pollution and senescence (EMEP, 2009). Because of sparse information on emissions, the EMEP/EEA Guidebook only provides a Tier 1 methodology.

$$E_{pollutant} = AR_{area} \cdot EF_{pollutant} \qquad \text{(Eq. 9.1)}$$

where: $E_{pollutant}$ = amount of pollutant emitted, kg a^{-1}
AR_{area} = area covered by crop, ha
$EF_{pollutant}$ = EF of pollutant, kg ha^{-1} a^{-1}

Activity data, area with arable crops or grassland, are obtained from DSt. In the Danish inventory a national emission factor for NMVOC is used. Emission factors for crops and grass are based on assessments carried out in the beginning of the 1990s (Fenhann & Kilde 1994 and Priemé & Christensen, 1991). The estimated emission factor for arable crops is 393 g NMVOC per ha and 2 120 g NMVOC per ha for grassland.

The total emission of NMVOC from agricultural soils 1985-2011 is listed in Table 9.1.

Table 9.1 NMVOC emission from agricultural soils 1985 – 2011.

	1985	1990	1995	2000	2005	2008	2009	2010	2011
Arable crops, 1000 ha	2 336	2 322	2 064	2 043	2 086	2 107	2 103	2 096	2 102
Grassland, 1000 ha	498	466	446	413	446	490	498	521	516
NMVOC emission, Gg	1.97	1.90	1.76	1.68	1.77	1.87	1.88	1.93	1.92

10 CH_4 emission

The digestive processes in ruminants, predominantly cattle, are the largest source of agricultural CH_4 emissions. The remainder comes from the bacterial breakdown of animal manure under anaerobic conditions (primarily in slurry).

The field burning of agricultural residues is also included as a source of emissions, but contributes less than 1 % to total agriculture emissions of CH_4.

The emission from manure management includes a reduction of emissions due to biogas-treatment of slurry, which is described in section 8.3.

The methodology used to calculate the CH_4 emission is based on guidance given in the 1996 IPCC Guidelines (IPCC, 1997) and the IPCC Good Practice Guidance (IPCC, 2000).

10.1 Enteric fermentation

The CH_4 emission from enteric fermentation can be regarded as an energy loss under the digestion process. It is mainly ruminants that produce CH_4, whereas monogastric animals – i.e. swine, horses, poultry and fur animals – produce CH_4 to a much smaller degree.

The emission is primarily from cattle, which, in 2011, contributed 85 % of the emission from enteric fermentation. The emission from swine production is the second largest source at 11 % and the rest of the animals; horses, sheep, goats, poultry and deer make up the remaining 4 %. The relative contribution from swine production has increased over the years as a result of a production expansion as well as a reduction in the number of cattle.

The calculation of CH_4 production from the digestive system is based on the animal's total gross energy intake (GE) and the CH_4 conversion factor, which is the fraction of gross energy in feed converted to CH_4 – see Equation 10.1.

$$EF_{CH4} = \frac{GE \cdot Y_m \cdot 365}{55.65} \qquad \text{(Eq. 10.1)}$$

Where:

EF_{CH4}	= emission factor of CH_4, kg head^{-1} yr^{-1}
GE	= gross energy intake, MJ head^{-1} day^{-1} (national data)
Y_m	= methane conversion factor, percent of gross energy in feed converted to methane (IPCC, 1997)
55.65	= conversion factor – from MJ to kg CH_4 (IPCC, 1997)

The conversion of MJ to kg CH_4 the value recommended by the IPCC is used. The CH_4 conversion rate Y_m is the extent to which feed energy is converted to CH_4 and varies depending on the breed of animal and the respective feed strategy (IPCC, 1997). Values of Y_m recommended by the IPCC are used for all livestock categories except for dairy cattle and heifers, where a national value is used.

In the Danish emission inventory the difference between summer and winter feed intake is taken into account. Summer feed plans is based on energy content in grass whereas winter feed plans is based on energy content in roughage and concentrates.

$$CH_{4\ \text{enteric,total}} = CH_{4\ \text{enteric,winter}} + CH_{4\ \text{enteric,summer}} \quad \text{(Eq. 10.2)}$$

10.1.1 Emission calculation for poultry and fur animals

For fur animals, poultry, ostrich and pheasants, data on gross energy are not available in the IPCC Guidelines. Based on country-specific information (Hansen, 2010) CH_4 emission from enteric fermentation from fur farming is considered to be not applicable.

The emission calculation for poultry, ostrich and pheasants is calculated by a Tier 1 methodology:

$$CH_{4,\ \text{enteric}} = \sum EF_i \cdot no_i \quad \text{(Eq. 10.3)}$$

Where: EF_i = emission factor for animal category *i*
no_i = number of animals, category *i*

Emission factors used for poultry, ostrich and pheasants are based on the emission factors given by Wang & Huang (2005) (see Table 10.1). EF for broilers with a life cycle of 30-56 days is scaled in proportion to 42 days for broilers given by Wang & Huang (2005). Organic broilers with a life cycle of 81 days are scaled in proportion to the Taiwan country chicken with 91 days of life cycle and pullets with a life cycle of 112-119 days is scaled in proportion to the 140 days given for pullets by Wang & Huang (2005). EF for ducks, geese, turkeys, ostrich chickens and pheasant chicken are scaled by weight in proportion to a broiler with 40 days of life cycle. For laying hens EF for laying hens given by Wang & Huang (2005) is used and for ostrich hens and pheasant hens EF is scaled by weight in proportion to a laying hen.

Table 10.1 EF for poultry in mg CH_4 per head per lifecycle.

	CH_4 emission factor
Broilers, 42 days	15.87
Taiwan country chicken, 91 days	84.82
Pullets, 140 days	3 561
Laying hens, 365 days	10 610

10.1.2 Gross energy intake (GE)

The actual feeding plans provide data for feed units (FU)[2] for each livestock category. To calculate the total gross energy intake, the gross energy per feed unit – defined as GE_{FU} – needs to be estimated.

$$GE_{total} = FU \cdot GE_{FU} \quad \text{(Eq. 10.4)}$$

[2] A feed unit in Denmark is defined as the feed value in 1.00 kg barley with a dry matter content of 85 % (Statistics Denmark, yearbook 2010). For other cereals e.g. wheat and rye one feed unit is 0.97 kg and 1.05 kg, respectively.

The estimate for GE_{FU} is unaltered for all years from 1985 to 2011, while feed units vary from year to year.

Feeding with sugar beets is taken into account because sugar beet feeding gives a higher methane production rate compared to grass and maize due to the high content of easily convertible sugar. Sugar beets are only included in feeding plans for dairy cattle and heifers. The parts of the equation concerning sugar beets are left out for the other livestock categories. The CH_4 emission from enteric fermentation for each livestock category is calculated as shown in the following equations:

a) EF_{winter}:

$$EF_{winter} = FU \cdot \left(\frac{GE_{FU\ winter}}{55.65} \cdot Y_{m,\ excl.\ SB} \cdot \left(1 - \frac{D_G}{365} - \frac{D_{SB}}{365}\right)\right) + \left(\frac{GE_{FU\ winter}}{55.65} \cdot Y_{m,\ incl.\ SB} \cdot \frac{D_{SB}}{365}\right) \quad \text{(Eq. 10.5a)}$$

b) EF_{summer}:

$$EF_{summer} = FU \cdot \frac{GE_{FU\ summer}}{55.65} \cdot Y_{m,\ grazing} \cdot \frac{D_G}{365} \quad \text{(Eq. 10.5b)}$$

Where:
- FU = feeding units
- GE_{FU} = gross energy per feeding unit, MJ per FU
- Y_m = methane conversion factor, feeding with or without sugar beet
- D_G = grazing days
- D_{SB} = days with sugar beet

The calculation of GE_{FU} is based on the composition of feed intake and the energy content in proteins, fats and carbohydrates.

For free-range swine, hens, etc., it is assumed that grazing does not contribute to feed intake; therefore, the GE_{FU} of the feed is based entirely on feeding in housing.

For dairy cows, the energy intake comes out at 18.3 MJ per FU_{cattle} in a standard winter feed (Hvelplund, 2004 and Olesen et al., 2001), regardless of whether the animal grazes or not. For bull calves (< ½ year), as well as bulls older than ½ year, the same energy content value is used as for dairy cows.

For horses, heifers, suckling cattle, sheep and goats an average winter feed plan is provided (Refsgaard Andersen, 2003; Clausen, 2004; Bligaard, 2004; Holmenlund, 2004), on which the calculation of the gross energy content is based - see appendix O. Gross energy for deer is based on feed plans for goats, as their feeding conditions resemble those of deer the most.

The GE_{FU} content in feeds is measured as the energy content per FU, which is assumed not to have changed since 1985. Therefore, changes in feed efficiency are reflected in changes in feed consumption.

10.1.3 CH_4 conversion rate (Y_m)

Studies from DCA have shown a change in feeding practice with maize (whole crop) replacing sugar beet. Higher CH_4 production from sugar beets compared to grass and maize, result in change of the average Y_m for dairy cattle and heifers from 6.78 in 1990 to 5.95 in 2011.

The estimation of the national values of Y_m uses the model "Karoline" developed by DCA with its database of average feeding plans for 20 % of all dairy cows in Denmark obtained from the DAAS (Olesen et al., 2005). DCA has estimated the Y_m for a winter feeding plan for two years, 1991 (Y_m=6.7) and 2002 (Y_m=6.0). Y_m for the years between 1991 and 2002 is estimated by interpolation and for 1990 and 2003 to 2011 by extrapolation where the actual sugar beet area is taken into account. Data for the actual sugar beet and maize area and Y_m for dairy cattle and heifers for 1990-2011 are given in appendix P. Sugar beets are only included in the winter feeding plan and the Y_m is therefore also adjusted for days on the winter and summer feeding plans. It is assumed that the winter feeding plan covers 200 days (Olesen et al., 2005).

10.1.4 CH_4 emission from enteric fermentation

An overview of the most important variables and the implied emission factor (IEF) is shown in Table 10.2. A distinction is made between animals which emissions are calculated based on an annual average population (AAP) (see Table 10.2a) and animals where the emission is based on one produced animal (see Table 10.2b).

Table 10.2a Feed consumption and conversion factors to determine the CH_4 emission from livestock enteric fermentation, Values per AAP[a], 2011.

Livestock category	Feed intake	Gross energy (BE)		Feed on grass	Y_m	IEF[b]
		Winter	Summer			
	FU	MJ per FU		Pct.	Pct.	Kg CH_4 per AAP
Cattle (large breed):						
Dairy cattle	6 944	18.30	18.30	5	5.94	135.65
Heifer calves, < ½ year	1 047	18.30	18.83	-	5.92	20.38
Breeding calves, ½ year to calving	2 094	25.75	18.83	30	5.94	52.15
Suckling cows > 600 kg	2 502	34.02	18.83	61	5.92	66.15
Swine:						
Sows incl. piglets < 7.3 kg	1 535	17.50	17.50	-	0.6	2.88
Other:						
Horses, 600 kg	2 555	29.83	18.83	50	2.5	27.93
Sheep incl. lambs	728	29.95	18.83	73	6	17.17
Dairy goats incl. kids	667	29.95	18.83	73	5	13.11
Deer	668	30	18.83	100	5	11.30
	kg feed	MJ per kg feed				
Battery hens (100 unit)	4 020	17.46	17.46	-	-	1.06
Mink incl. young	229	11.47	11.47	-	-	0

[a] IEF – implied emission factor.

[b] AAP - annual average population – see definition in Section 4.1

Table 10.2b Feed consumption and conversion factors to determine the CH_4 emission from livestock enteric fermentation, Values per produced animal, 2011.

Livestock category	Feed intake	Gross energy (BE)		Feed on grass	Y_m	IEF
		Winter	Summer			
	FU		MJ per FU	Pct.	Pct.	kg CH_4 per prod. animal
Cattle (large breed):						
Bulls calves, < ½ year	619	18.30	18.83	-	4	8.14
Bulls, ½ year to slaughter, 440 kg	1 280	18.30	18.83	-	4	20.38
Swine:						
Weaners, 7.3-32 kg	48	16.46	16.46	-	0.6	0.09
Fattening pigs, > 32 kg	214	17.25	17.25	-	0.6	0.40
	kg feed	MJ per kg feed				
Broilers, 40 days (1 000)	4 280	18.99	18.99	-	-	0.01
Ostrich	-	-	-	-	-	0.66
Pheasant (100 unit)	-	-	-	100	-	0.47
Geese (100 unit)	2 800	18.19	18.19	100	-	0.005
Turkeys, cock/hen (100)	5 070/2 430	18.55	18.55	-	-	0.01
Ducks (100)	975	18.19	18.19	-	-	0.003

The total CH_4 emission from enteric fermentation 2011 is estimated to 135 Gg CH_4 and the major part is related to the dairy production - see Table 10.3

Table 10.3 CH_4 emission from enteric fermentation

	Emission 2011
	Gg CH_4
Cattle:	
Dairy cattle	75.11
Heifer calves, < ½ year	3.14
Heifer, ½ year to calving	24.22
Bull, calves < ½ year	2.39
Bulls, ½ year to slaughter	4.44
Suckling cows	6.31
Swine:	
Sows incl. piglets < 7.3 kg	3.06
Weaners, 7.3-32 kg	2.58
Fattening pigs, > 32 kg	8.70
Poultry:	
Hens	0.06
Broilers	0.0015
Other poultry	0.0004
Other:	
Horses	3.38
Sheep (incl. lambs)	1.61
Goats (incl. kids)	0.16
Deer	0.09
Mink incl. Young	0
Total	135.25

10.2 Manure management

CH_4 gas production from animal manure is calculated on the basis of the energy in animal manure, taking into account housing conditions as manure type and use of straw for bedding based on information from Poulsen et al. (2001).

Housing type determines the manure type and the CH_4 production varies depending on the manure type. Anaerobic conditions, as found in slurry, promote CH_4 formation, while CH_4 production is low in solid manure. Developments in recent years, where more livestock are housed in open housing units and in slurry-based housing systems, have led to a relatively high CH_4 production.

CH_4 formation from manure management is calculated on the basis of the IPCC Guidelines, where the proportion of volatile solids (VS) of the organic matter is determined. The determination of VS is country-specific and based on the amount of manure excreted (Equation 10.6 and 10.7).

$$\mathrm{VS_{housing}} = \mathrm{VS_{manure}} + \mathrm{VS_{straw}} \qquad \text{(Eq. 10.6a)}$$

$$\mathrm{VS_{manure}} = \frac{\mathrm{m}}{365} \cdot \mathrm{DM_M} \cdot \mathrm{VS_{DM}} \cdot (365 - \mathrm{g_1}) \qquad \text{(Eq. 10.6b)}$$

$$\mathrm{VS_{straw}} = \mathrm{s} \cdot \mathrm{DM_S} \cdot \left(1 - \frac{\mathrm{ash}}{100}\right) \cdot (365 - \mathrm{g_2}) \qquad \text{(Eq. 10.6c)}$$

$$\mathrm{VS_{grass}} = \frac{\mathrm{m}}{365} \cdot \mathrm{DM_M} \cdot \mathrm{VS_{DM}} \cdot \mathrm{g_1} \qquad \text{(Eq. 10.7)}$$

Where:
VS = volatile solids, kg animal^{-1} year^{-1}
m = amount of manure excreted, kg animal^{-1} year^{-1}
DM = dry matter of (M) manure or (S) straw, pct
VS_{DM} = volatile solids of dry matter, pct
g_1 = feeding days on grass, days year^{-1} [3]
g_2 = actual days on grass, days year^{-1}
s = amount of straw, kg animal^{-1} year^{-1}
ash = ash content in straw, %

The ash content in straw is set to 4.5 % (DAAS, 2005). Dry matter content in manure is based on the normative data (Poulsen, 2012). The VS of dry matter is 78 % for cattle, horses, sheep, goats and deer. For swine, poultry and fur animals the VS of dry matter is 75 %. The number of days on grass is shown in Table 10.5. The amount of manure excreted and straw used depends on housing type and is given in the normative figures table (Poulsen, 2012).

The amount of CH_4 produced is determined from Equation 8.8, where VS is multiplied with the maximum CH_4 formation capacity B_0, which varies for each livestock type. The maximum CH_4 conversion factor, MCF depends on the actual temperature and storage conditions. Denmark has a cold climate and, therefore a relatively low MCF.

$$\mathrm{CH_4} = \left(\mathrm{VS_{housing}} \cdot \frac{\mathrm{MCF}_{i,j}}{100} \cdot \mathrm{B}_{0,i}\right) + \left(\mathrm{VS_{grass}} \cdot \frac{\mathrm{MCF}_{i,j}}{100} \cdot \mathrm{B}_{0,i}\right) \qquad \text{(Eq. 10.8)}$$

Where: CH_4 = CH_4 emission for the given livestock category, kg CH_4 animal^{-1} year^{-1}

[3] Actual days on grass are the number of days the heifer is out of the housing. Feeding days on grass is higher than actual days on grass due to a higher feed intake during grazing compared to the period in housing. Feeding days on grass is a conversion of this higher feed intake to days on grass.

$VS_{housing}$	= volatile solids from housings, kg dry matter animal^{-1} year^{-1}
VS_{grass}	= volatile solids from grazing, kg dry matter animal^{-1} year^{-1}
B_0	= maximum CH_4 producing capacity for manure produced by livestock category (*i*) (IPCC, 1997)
MCF	= CH_4 conversion factor for a given livestock category (*i*) and a given manure type (*j*) (IPCC, 1997)

Table 10.4 lists the MCF factors used. Default values for MCF provided in the IPCC guidelines for the CH_4 production are used. For liquid systems, the MCF of 10 % in the Reference Manual (IPCC, 1997) is used.

The revised 1996 IPCC Guidelines contains a default MCF of 10 % for liquid manure/slurry, which is based on the research of Hashimoto & Steed (1993) and Woodbury & Hashimoto (1993). This MCF value was changed to 39 % in the IPCC Good Practice Guidance (2000), without any scientific argumentation, documentation or specific references. The IPCC 2006 Guidelines (IPCC, 2006) has reverted to an MCF value of 10 % with reference to judgement of the IPCC Expert Group in combination with Mangino et al. (2001) and Sommer et al. (2000).

The CH_4 emission from liquid systems is very sensitive to temperature effects. Basically most of the manure in Denmark is stored under cold conditions (5-10°). The CH_4 formation practically stops at 5° C (Mangino et al., 2001) and therefore there are no plausible arguments for why 39 % of the total CH_4 capacity should be released under Danish conditions. Danish studies confirm this assumption (Husted, 1994; Sommer et al., 2000). Furthermore, scientific articles based on measurements in Canada, where conditions are similar to those in Denmark, support the 10 % value (Massé et al., 2003, Massé et al., 2008). A Swedish review taking into account both the cold climate and the fact that the slurry containers usually have a surface cover, also supports a MCF for liquid manure of 10 % (Dustan, 2002).

Considering the agricultural conditions in Denmark and the present scientific knowledge as described above, an MCF of 10 % for urine/slurry is more appropriate under Danish conditions than the MCF of 39 % recommended by the IPCC GPG (IPCC, 2000). The Danish decision to use an MCF of 10 % is, as demonstrated above, backed by several scientific papers as well as both the 1996 IPCC Guidelines (IPCC, 1997) and the 2006 IPCC Guidelines (IPCC, 2006).

Several countries with comparable climatic conditions use an MCF for urine/slurry at the same level as the recommended in the revised IPCC 1996 Guidelines. Sweden and Finland use the same value as Denmark (10 %), Belgium uses 19 %, Germany 13-16 % and Norway and the Netherlands use an MCF below 10 %.

Table 10.4 Values used for CH_4 conversion factor (MCF).

	MCF, %
Solid manure	1
Solid manure, poultry	1.5
Deep litter[a]	10
Urine and slurry	10
Manure excreted outside	10

[a] For farmyard manure < 1 month the MCF is listed as zero (IPCC, 2000 – Table 4.13). Farmyard manure is a system where the manure is accumulated on floor and mixed with straw bedding, which in Denmark is use e.g. in housing of cattle calves.

Animal manure applied to farmland should, according to the IPCC, have the same MCF as solid manure in storage.

Table 10.5 gives an overview of data used to calculate the CH_4 emission and the implied emission factor (IEF) from animal manure covering different categories of livestock. No emission from calves is registered because the MCF factor is zero.

The B0 values used in the inventory, based on IPCC standard values. Here it is demonstrated that the maximum CH_4 formation is significantly higher in swine manure than in cattle manure.

Table 10.5a Conversion factors to determine the CH_4 emission from animal manure handling, values per AAP[a], 2011.

Livestock category	Days on grass	CH_4 formation capacity	IEF[b]
	g (act grazing days)	B_0 m^3 CH_4 per kg VS	kg CH_4 per AAP[a]
Cattle (large breed):			
Dairy cattle	18	0.24	33.59
Heifer calves, < ½ year	0	0.17	0
Heifer, ½ year to calving	132 (111)	0.17	9.04
Suckling cows, > 600 kg	224	0.17	11.98
Swine:			
Sows incl. piglets < 7.3 kg	0	0.45	6.87
Poultry:			
Hens, battery (100 units)	0	0.32	4.36
Other:			
Horses, 600 kg	182.5	0.33	2.95
Sheep incl. lambs	265	0.19	2.82
Goats incl. kids	265	0.17	2.45
Deer	365	0.17	0.30
Fur animals	0	0.48	1.03

Table 10.5b Conversion factors to determine the CH_4 emission from animal manure handling, values per produced animal, 2011.

Livestock category	Days on grass	CH_4 formation capacity	IEF[b]
	g	B_0	
	(act grazing days)	m^3 CH_4 per kg VS	kg CH_4 per prod. animal
Cattle (large breed):			
Bull calves, < ½ year	0	0.17	0
Bull, ½ year to slaughter, 440 kg	0	0.17	16.34
Swine:			
Weaners, 7.3-32 kg	0	0.45	0.16
Fattening pigs, > 32 kg	0	0.45	0.85
Poultry:			
Broilers, 40 days (1 000 units)	0	0.32	2.29
Ostrich	0	0.32	1.70
Pheasant (100 units)	365	0.32	1.23
Geese (100 units)	365	0.32	1.80
Turkeys (100 units)	0	0.32	2.46
Ducks (100 units)	0	0.32	1.25

[a] AAP - annual average population – see definition in Section 4.1

[b] IEF – implied emission factor

The total CH_4 emission from manure management 2011 is estimated to 63 Gg CH_4 and the main emission originates from the production of dairy cattle and fattening pigs, which has a high proportion of slurry based housing system - see Table 10.6.

Table 10.6 CH_4 emission from animal manure.

Livestock category	Emission 2011
	Gg CH_4
Cattle	
Dairy cattle	18.83
Heifer calves, < ½ year	0[a]
Heifer, ½ year to calving	4.28
Bull, calves < ½ year	0[a]
Bulls, ½ year to slaughter	4.29
Suckling cows	1.17
Swine:	
Sows incl. piglets < 7.3 kg	7.30
Weaners, 7.3-32 kg	4.90
Fattening pigs, > 32 kg	18.52
Poultry:	
Hens	0.22
Broilers	0.26
Other poultry	0.03
Other:	
Horses	0.46
Sheep incl. lambs	0.26
Goats incl. kids	0.03
Deer	0.002
Mink incl. Young	2.85
Total	63.42

[a] The MCF for housings with deep litter < 1 month is considered negligible and therefore estimated 0 % in IPCC (2000).

10.3 Biogas treatment of slurry

In Denmark the first biogas plant was established in 1984 and there are currently around 20 joint plants and around 60 plants operating on farms. In 2011, 2.4 million tonnes of animal manure were treated (Tafdrup, 2009), equivalent to approximately 6 % of all animal manure.

Treating slurry in biogas plants has a lower emission of both CH_4 and N_2O. No description on how to include biogas treated slurry in the inventories is provided in the IPCC guidelines. Therefore, the Danish inventory uses data based on a Danish study (Sommer et al., 2001; Nielsen et al., 2002).

The lower CH_4 emission in biogas treated slurry is based on the amount of organic matter VS. The amount of VS in treated slurry is calculated as the VS percentage of dry matter (DM) which 80 % for both cattle and pig slurry. It is assumed that slurry from cattle stems from dairy cattle and that slurry from swine stems from fattening pigs. The Danish Energy Agency estimates that cattle slurry makes up 45 % and pig slurry 55 % of the total amount of biogas-treated slurry (Tafdrup, 2003).

$$CH4_{\text{lower}} = VS_{\textit{treated slurry}} \cdot B_0 \cdot MCF \cdot 0.67 \cdot E_{CH4,lower} \qquad \text{(Eq. 10.9)}$$

Where:

$CH_{4,R}$	= The amount of lower CH_4 emission from a given livestock type (cattle or swine)
$VS_{\text{treated slurry}}$	= amount of volatile solids from treated slurry
B_0	= maximum CH_4-forming capacity
MCF	= CH_4 conversion factor
$E_{CH4,\text{ lower}}$	= a lower emission from biogas treated slurry. It is assumed that treated cattle slurry is 0.77 compared with untreated slurry and 0.60 for pig slurry
0.67	= conversion from m^3 to kg

Table 10.7 provides the background data used in the calculation of the CH_4 reduction resulting from biogas production.

Table 10.7 Data used in the calculation of VS in biogas-treated slurry and the reduction in the CH_4 emission in 2011.

2011	Slurry biogas treated	DM[a]	VS in treated slurry	MCF	B_0	$E_{CH4,\text{ lower}}$	CH_4 emission in untreated slurry	CH_4 emission in biogas treated slurry	Lower the total CH_4 emission with
	1000 Gg	Pct.	10^6 kg VS	Pct.	m^3 CH_4 pr kg VS		Gg CH_4	Gg CH_4	Gg CH_4
Cattle slurry	1.08	10.3	88.62	10	0.24	0.77	1.43	1.09	0.33
Pig slurry	1.31	6.1	64.15	10	0.45	0.60	1.93	1.16	0.78
Lower emission									1.11

[a] Poulsen et al. (2001 and 2012).

In 2011, the total effect of biogas plants result in a lower CH_4 emission by 1.11 Gg CH_4, which corresponds to 0.6 % of the total CH_4 emission from the agricultural sector. The reduction is expected to rise in the coming years due to increased focus on biogas production as a means of reducing greenhouse gas emissions from agricultural activities.

The effect of the biogas treatment of slurry is subtracted from the emission from dairy cows and fattening pigs in the emission inventory.

11 N_2O emission

The emission of nitrous oxide (N_2O) occurs in the chemical transformation of nitrogen and, therefore, is closely linked with the animal manure management. The emission of N_2O comes from a range of different sources as showed in figure 11.1. The major sources originate from application of animal manure and synthetic fertilisers on soil, and nitrogen leaching and runoff, which in 2011 contributes with 68 % of the total N_2O agricultural emission. The emission from nitrogen leaching represents the largest single emission source at around 26 %.

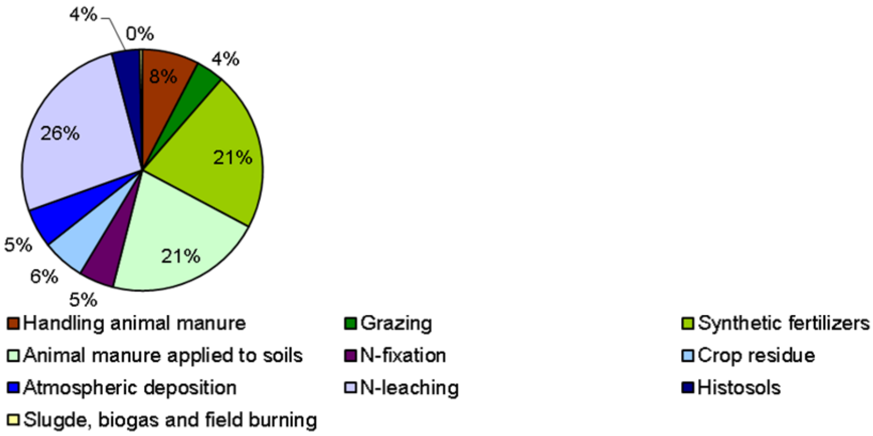

Figure 11.1 Distribution of the N_2O emission in 2011 on sources.

The N_2O emission, given in CO_2 equivalents, contributes 57 % to the total greenhouse gas emission from the agricultural sector in 2011. The following chapters give a survey of the emission factors used and a more detailed description of each emission source. The emission from manure management includes a reduction of emissions due to biogas-treated slurry, which is described in section 11.9.

The calculation of N_2O emission from field burning of agricultural crop residues, which contributes less than 1 % to total agricultural N_2O emissions, is described in Chapter 7.

The methodology used to calculate the N_2O emission is based on guidance given in the 1996 IPCC Guidelines (IPCC, 1997) and the IPCC Good Practice Guidance (IPCC, 2000). Please note that convert from N_2O-N to N_2O, the emission is multiplied by 44/28.

11.1 Emission factors

The emission of N_2O is determined as a fraction of the amount of nitrogen. These fractions vary between sources and are often highly uncertain because the emission to a great extent depends on the local biological and climatic conditions.

The N_2O emission is calculated according to equation 11.1.

$$N_2O = N_i \cdot EF_i \cdot \frac{44}{28} \qquad \text{(Eq. 11.1)}$$

Where: N_i = N content in the source, *i*
EF_i = emission factor applicable for source, *i*

The conversion from N_2O-N to N_2O is carried out by multiplying the respective molecular weights.

Table 11.1 shows the sources from which the N_2O emission is calculated. The calculations are based on standard values for emission factors recommended by IPCC Reference Manual (IPCC, 1997 and 2000).

Table 11.1 Emission factors used to determine the N_2O emission.

Source		Emission factor	
		Unit	IPCC – default values
Handling of manure:			
Solid manure, poultry	EF_{1a}	kg N_2O-N per kg N	0.005
Solid manure, other	EF_{1b}	kg N_2O-N per kg N	0.02
Slurry and urine	EF_2	kg N_2O-N per kg N	0.001
Deep litter	EF_{3a}	kg N_2O-N per kg N	0.02
Deep litter, farmyard manure < 1 month[1]	EF_{3b}	kg N_2O-N per kg N	0.005
Manure deposited under grazing	EF_4	kg N_2O-N per kg N	0.02
Nitrogen applied to agricultural soils:			
Synthetic fertiliser applied to agricultural soils[2]	EF_5	kg N_2O-N per kg N	0.0125
Animal manure applied to agricultural soils [3]	EF_6	kg N_2O-N per kg N	0.0125
Sewage sludge applied to agricultural soils	EF_7	kg N_2O-N per kg N	0.01
Other:			
N-fixing crops	EF_8	kg N_2O-N per kg N	0.0125
Crop residues returns to soils	EF_9	kg N_2O-N per kg N	0.0125
Atmospheric deposition (NH_3 volatilization)	EF_{10}	kg N_2O-N per kg N	0.01
Nitrogen leaching, groundwater	EF_{11a}	kg N_2O-N per kg N	0.015
Nitrogen leaching, rivers	EF_{11b}	kg N_2O-N per kg N	0.0075
Nitrogen leaching, estuaries	EF_{11c}	kg N_2O-N per kg N	0.0025
Cultivation of histosols	EF_{12}	kg N_2O-N per ha	8

[1] Farmyard manure, which is faeces and urine mixed with large amounts of bedding (usually straw) on the floors of cattle or swine housing.
[2] Calculated as the amount of N sold in synthetic fertilisers minus NH_3 emission.
[3] Calculated as N ex storage minus NH_3 emission from application of manure on soils.

The estimated emissions from the different sources are described in the following text.

11.2 Manure management and grazing

The amount of nitrogen in animal manure is based on the normative figures (Poulsen et al., 2001; Poulsen, 2012). Besides animal type, the emission depends on housing type which decides the manure type. Under the anaerobic conditions in slurry and urine the emission of N_2O is considered to be relatively low, while the emission from deep litter systems and solid manure in the housing units is higher. The emission from animal manure management is calculated as shown in equation 11.2.

$$N_2O_{MM} = \sum Nex_{j,i} \cdot EF_{j,i} \cdot \frac{44}{28} \qquad \text{(Eq. 11.2)}$$

Where: N_2O_{MM} = emission of N_2O from manure management and grazing animals

$Nex_{j,i}$ = N excretion from the given animal category (*j*) and manure type (*i*)

$EF_{j,i}$ = emission factor for a given manure animal category (*j*) and manure type (*i*).

As recommended in the IPCC guidelines, an emission factor of 0.005 (EF_{1a}) is used for solid poultry manure and 0.02 (EF_{1b}) for solid manure from other livestock categories. For urine and slurry is used 0.001 (EF_2) and for deep litter is used 0.02 (EF_{3a}). However, for deep litter system with animal manure placed in housing less than one month a lower emission factor of 0.005 is used (EF_{3b}). Farmyard manure is a system where the manure is accumulated on a floor and mixed with straw bedding, which in Denmark is used e.g. in housing of calves. For animal manure applied to grass an emission factor of 0.02 (EF_4) is used. The distribution of nitrogen excretion into housing and grass for each animal category is shown in Chapter 4.3.

Due to a lower emission factor for liquid manure, the development from 1985 to 2011 towards slurry-based housing systems and less cattle on grass has led to a reduction in the emission of N_2O.

The total amount of nitrogen in animal manure (N ex animal) is shown for 1985 to 2011 in figure 11.2 and illustrates a decrease from 311 Gg N in 1985 to 260 Gg N in 2011, which equates to a reduction of 16 %. This reduction should be seen in the light of a significant increase in the swine and poultry production since 1985 and can be explained by the improvements in feed efficiency, which has resulted in a lower N excretion, especially for fattening pigs.

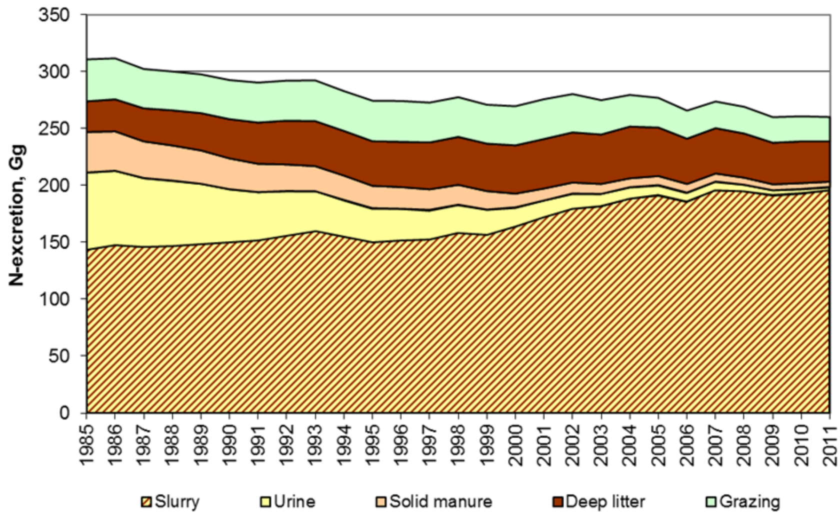

Figure 11.2 Total amount of nitrogen in animal manure (N ex animal).

11.3 Nitrogen applied to agricultural soils

The calculation of N_2O from the application of nitrogen is the sum of N in synthetic fertilisers, N in animal manure and N in the different types of sludge.

$$N_2O_{AS} = ((N_{SF} - NH_{3,\ SF}) \cdot EF_5 + (N_{AM} - NH_{3,\ A}) \cdot EF_6 + (N_{SS} - NH_{3,\ SS}) \cdot EF_7) \cdot \frac{44}{28} \qquad \text{(Eq. 11.3)}$$

Where: N_2O_{AS} = N_2O emission from nitrogen sources applied to agricultural soils
N_{SF} = consumption of N in synthetic fertiliser
$NH_{3,\ SF}$ = NH_3 emission from synthetic fertiliser
N_{AM} = amount of nitrogen in animal manure ex storage
$NH_{3,\ A}$ = NH_3 loss from application of animal manure
N_{SS} = amount of nitrogen in sewage or industrial sludge applied to agricultural soils
$NH_{3,\ SS}$ = NH_3 emission from application of sewage sludge
EF_7 = emission coefficient (see Table 11.1)

All calculations concerning the content of nitrogen in manure ex storage, synthetic fertiliser and sewage sludge are incorporated in the NH_3 emission and therefore described in Chapter 5, likewise the estimates of NH_3 emission.

Table 11.2 shows the total amount of nitrogen from synthetic fertilisers, animal manure and sewage sludge applied to agricultural soils, as well as the emission of N_2O given as both total N_2O and CO_2 equivalents from 1985 to 2011.

The N_2O emission from applications to soils fell from 7.4 Gg N_2O-N in 1985 to 4.9 Gg N_2O-N in 2011 – i.e. 33 % over the period. The reduction is primarily due to the reduction in the use of synthetic fertilisers as a consequence of improvements in the utilisation of nitrogen in animal manure.

Table 11.2 The calculation of N_2O emission from sources of nitrogen applied to agricultural soils.

	1985	1990	1995	2000	2005	2008	2009	2010	2011
N applied to soils					Gg N				
N in synthetic fertilisers	398	400	316	251	206	220	200	190	197
NH_3-N, synthetic fertiliser	5	5	5	3	3	3	3	3	3
N in animal manure (ex storage)	227	214	200	197	212	213	206	208	208
NH_3-N, animal manure	34	31	26	23	17	17	17	17	16
N in sewage sludge	4	5	9	9	8	7	7	7	7
NH_3-N, sewage sludge	0.05	0.06	0.09	0.07	0.04	0.04	0.06	0.05	0.05
N-total applied to soils	590	582	495	431	407	420	394	385	392
Emission									
Gg N_2O-N	7.37	7.28	6.19	5.39	5.08	5.24	4.92	4.81	4.90
Gg N_2O	11.58	11.43	9.72	8.47	7.99	8.24	7.74	7.56	7.71
Gg CO_2 equivalents	3 590	3 545	3 015	2 626	2 476	2 555	2 399	2 343	2 389

11.4 Nitrogen-fixing plants

According to the IPCC guidelines, the total amount of nitrogen from nitrogen-fixing plants should be included as an N_2O emission source.

The estimates regarding the amount of nitrogen fixed in crops are made by DJF (Kristensen & Kristensen, 2002, Kyllingsbæk, 2000, Høgh- Jensen et al., 1998). The calculation of the emission from nitrogen-fixing plants is based on the nitrogen content and the fraction of dry matter for each crop type harvested. The calculation of N-fixation from legumes, peas/barley (wholecrop), peas for conservation, lucerne, grass-clover and catch crop is based on the harvest yield. The calculation for seeds of legume grass crops is based on the cultivated area. Values of yield and area are based on data from DSt. Information on dry matter content and N-content are from the feedstuffs table

(DAAS, 2000). The N-content in roots and stubble is taken into consideration in the calculation as well as the proportion of plant N that can be attributed to nitrogen fixation. The emission is calculated according to equation 9.4.

$$N_2O_{N\text{-fix}} = (\sum((DM_{i,\,yield} \cdot N_{i,\,pct}) \cdot (1 + N_{i,\,pct\ in\ root\ and\ stub})) \cdot Pct_{fix} \cdot EF_8) \cdot \frac{44}{28} \quad \text{(Eq. 11.4)}$$

Where:		
	$N_2O_{N\text{-fix}}$	= N_2O emission from N-fixing crops
	$DM_{i,\,yield}$	= dry matter, yield, kg per ha for crop i
	$N_{i,\,pct}$	= nitrogen percentage in dry matter
	$N_{i,pct\ root\ +\ stub}$	= nitrogen percentage in root and stubble
	Pct_{fix}	= percentage of nitrogen that is fixed
	EF_8	= emission coefficient (see Table 11.1)

The Danish inventory includes emissions from grass-clover, despite the fact that this source is not mentioned in the IPCC reference manual (IPCC, 1997) or Good Practice Guidance (IPCC, 2000). The area with grass and clover made up approximately 20 % of the total agricultural area in 2011, and is for this reason an important source to the national emission from N-fixing crops.

Table 11.3 provides background data for the calculation of the amount of nitrogen from nitrogen-fixing crops.

Table 11.3 Background data for calculation of N content in nitrogen fixing crops.

Crop	DM content[1]	N-content in DM[1]	Straw yield of grain yield[2]	Share, root+ stubble[3]	N in crop (fixed)[3]	N-fixed
	pct.	pct.	pct.	pct.	pct.	kg N per tonnes harvested
Based on yield						
Field peas, grain	85	3.97	-	25	75	-
Field peas, straw	87	1.15	60	-	-	-
Legumes grown to maturity, in total	-	-	-	-	-	37.3
Peas/barley- whole-crop for silage	23	2.64	-	25	80	6.1
Legumes, marrow-stem kale and green fodder	23	2.64	-	25	80	6.1
Lucerne	21	3.04	-	60	75	7.7
Grass, clover fields and fields with an under sown crop	13	4.00	-	75	90	8.2
Peas for conservation[4]	23	2.64	-	25	80	6.1
Fields with catch crop	13	4.00	-	75	90	8.2
Based on area	kg N per ha					
Seeds:						
Red clover	200					
White clover	180					
Black medic	180					

[1] Feedstuff table (DAAS, 2000).
[2] Kyllingsbæk (2000).
[3] Kristensen (2002) and Kyllingsbæk (2000).
[4] Assumed that nitrogen fixing from peas for conservation is 80 % compared to field peas.

Changes in the percentages of nitrogen-fixing plants during the years are taken into account (Table 11.4). Since 1985, there has been a growing production of peas and grass-clover as a result of stricter regulations on the use of nitrogen. The information on nitrogen-fixing crops is provided by DCA (Kyllingsbæk, 2000).

Table 11.4 Estimated share of nitrogen-fixing plants in crops, pct.

	1985	1990	1995	1999-2011
Crops for silage				
Share of peas (whole-crop)[a]	15	30	40	50
Share of peas[b]	40	40	40	40
Legumes, marrow-stem kale and other green fodder				
Share with legumes:	60	60	60	60
-of which share with peas	40	40	40	40
Peas for conservation	80	80	80	80
Grass in rotation				
Share of grass-clover fields	64	74	84	88
Clover pct. in grass-clover fields	20	20	22	30
Grass not in a rotation				
Clover percentage	5	5	5	5
Fields with catch crop				
Share with grass-clover	64	74	84	88
Clover pct.	30	30	30	30

Source: Kyllingsbæk, 2000.

[a]share of peas (whole crop) in proportion to total area of crops for silage.

[b]share of peas in proportion to peas (whole crop).

The nitrogen fixation for each crop type is estimated and presented in Table 11.5. The N-fixation per hectare varies significantly from year to year as a consequence of changes in yield level due to the climatic conditions.

Table 11.5 Variations in N-fixation 1985 – 2011.

	N-fixation per hectare		N- fixation 2011	
	1985-2011	2011	N- fixation	Distribution
	kg N per ha	kg N per ha	tonnes N fix	pct.
Legumes to maturity	95-179	142	1 010	2
Crops for silage	10-38	24	1 385	3
Legumes/marrow-stem kale	0-1	NO	NO	NO
Lucerne	302-517	385	2 669	6
Grass and clover in rotation	40-107	103	33 859	80
Grass not in rotation	6-11	7	1 352	3
Fields with catch crop	6-16	11	1 198	3
Peas for conservation	76-144	114	334	1
Seeds of leguminous grass crops	181-186	182	680	2
Total N-fix			42 487	100

NO = Not occurring.

As illustrated in figure 11.3 and Table 11.6, the level of nitrogen fixation has changed between 30-48 Gg N in 1985 to 2011, which is due to changes in crop types. There is seen a change in increase of the area with grass-clover and a reduction in the area with legumes to maturity (see appendix Q).

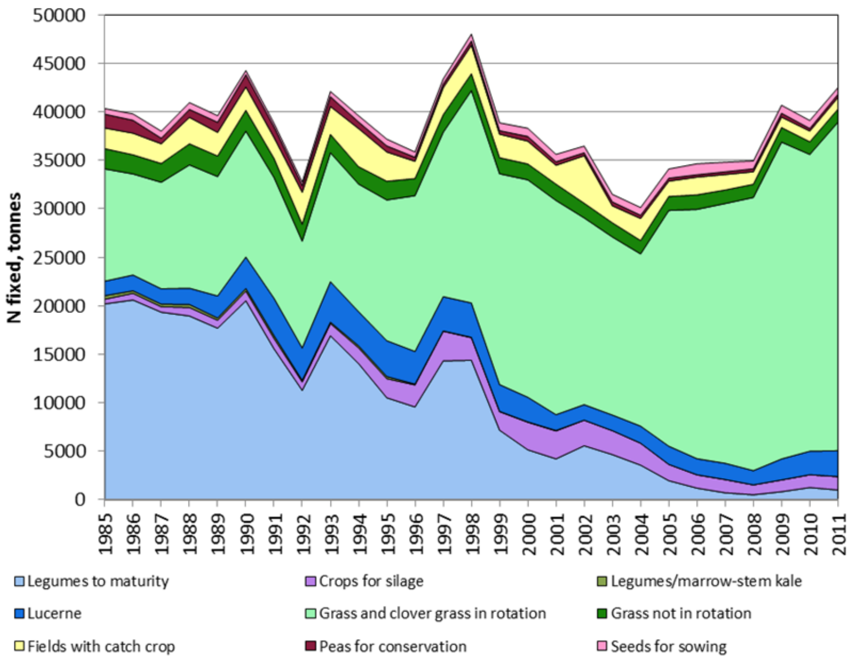

Figure 11.3 Total nitrogen fixation distributed on different crop types 1985-2011.

In 2011, the N content in N-fixing crops is estimated to 42.5 Gg N, which correspond to a N_2O emission of 0.83 Gg. Grass-clover fields were responsible for approximately 80 % of the total N-fixation.

Table 11.6 Emission of N_2O from N-fixing crops, 1985-2011.

	1985	1990	1995	2000	2005	2008	2009	2010	2011
N, Gg	40.3	44.3	37.2	38.3	34.1	34.9	40.7	39.1	42.5
N_2O, Gg	0.79	0.87	0.73	0.75	0.67	0.69	0.80	0.77	0.83
CO_2 eqv., 1 000 Gg	0.25	0.27	0.23	0.23	0.21	0.21	0.25	0.24	0.26

11.5 Crop residues

According to the IPCC guidelines, the nitrogen from crop residues left on the field after harvest should be included as an N_2O emission source. Emissions from crop residues are calculated as the N content in the total aboveground biomass of crop residues returned to the soil in the form of stubble, husks, tops and leaves. Furthermore, the amount of straw left in the field after harvest is taken into account.

The emission from agricultural crop residues is calculated according to Equation 11.5.

$$N_2O_{CR} = \left(\sum AR \cdot \left(\left(\frac{N_{ST}}{no_{PF}}\right) + N_{HU} + N_{PT} + N_{LR}\right) \cdot EF_9\right) \cdot \frac{44}{28} \qquad \text{(Eq. 11.5)}$$

Where:
- N_2O_{CR} = emission of N_2O from crop residue
- AR = area on which a given crop is grown
- N_{ST} = nitrogen derived from stubble, kg per ha
- N_{HU} = nitrogen derived from husks, kg per ha
- N_{PT} = nitrogen derived from plant tops, kg per ha
- N_{LR} = nitrogen derived from leaf litter kg per ha
- no_{PF} = number of years between ploughing

EF_9	= emission factor (see Table 11.1)
44/28	= conversion from N_2O-N to N_2O

Data concerning the cultivated area, unharvest plant tops from beets and potatoes and the amount of unharvest straw are based on information from DSt (2012).

11.5.1 N-content in crops

National values for nitrogen content are provided by DCA (Djurhuus & Hansen, 2003). Calculations are based on relatively few observations, but are at present the best available data. Same values are used for all years.

Table 11.7 shows the estimated N-content in crop residues, ploughing frequency and total N-content in all crop residues from 2011. It is assumed that grass fields on average are ploughed in every other year, lucerne every three years and set-aside fields every 10 years.

In 2011, the N content in residues from crop is estimated to approximately 40 Gg N, where winter wheat and grass/clover is the largest contributors.

Table 11.7 Overview of the N-content in residues from agricultural crops under conditions of normal fertilisation, 2011.

	Stubble	Husks	Tops	Leaf litter	Ploughing frequency	N-content in crop residues	
Crop	kg N per ha	kg N per ha	kg N per ha	kg N per ha	years between ploughing	kg N per ha per year	Gg N per year
Winter wheat	6.3	10.7	-	-	1	17.0	12.32
Spring wheat	6.3	7.4	-	-	1	13.7	0.28
Winter rye	6.3	10.7	-	-	1	17.0	0.95
Triticale	6.3	10.7	-	-	1	17.0	0.77
Winter barley	6.3	5.9	-	-	1	12.2	1.60
Spring barley	6.3	4.1	-	-	1	10.4	4.90
Oats	6.3	4.1	-	-	1	10.4	0.44
Winter rape	6.3	-	-	-	1	4.4	0.66
Spring rape	4.4	-	-	-	1	4.4	0.01
Potato (tops)	4.4	-	48.7	-	1	48.7	1.97
Lucerne	-	-	-	-	3	10.8	0.07
Maize for silage	32.3	-	-	-	1	6.3	1.09
Grain for silage	6.3	-	-	-	1	6.3	0.36
Catch crop	6.3	-	-	-	1	6.3	0.74
Peas for conservation	6.3	-	-	-	1	11.3	0.03
Vegetables	11.3	-	-	-	1	11.3	0.09
Grass field legumes	11.3	-	-	-	2	5.7	0.02
Legume seed	11.3	-	-	-	1	11.3	0.08
Grass seed	11.3	10.7	-	-	2	13.9	0.78
Other plants for seed	6.3	10.7	-	-	2	13.9	0.02
Grass and clover + rotation	6.3	-	-	10.0	2	26.2	8.61
Grass and clover - rotation	32.3	-	-	20.0	-	20.0	3.73
Set-aside	38.8	-	-	15.0	10	18.9	0.08
Total	38.8						39.61

11.5.2 N-content in straw and plant tops from fodder beets

The amount of nitrogen in straw and tops from fodder beets, which are left in the field after harvest, is based on yield levels from DSt, and DM and raw protein contents from the feedstuff table published by DAAS (2000).

Wheat is the largest source of unharvested straw. The amount of N is calculated as the total amount of unharvest straw, multiplied by the DM percentage (85 %) and the raw protein content of the DM (3.3 %). Converting raw protein to N-content uses a conversion factor of 6.25 (Jones, 1941).

For beet tops, it is assumed that factory and fodder beets have the same top yield. The nitrogen content is calculated in the same way as straw. The DM content is 12 % and the raw protein content of the DM is 16.4 %.

The basic data used for calculating the N-content in straw and fodder beet tops are shown in Table 11.8 for year 2011.

Table 11.8 Data used for calculation of N-content in straw and fodder beet tops, 2011.

	Yield	DM	Raw protein of DM	Conversion factor to N	Crop residue
	Gg	Pct.	Pct.		Gg N per year
Straw – not harvested	2 162	85	3.3	6.25	9.70
Fodder beet (tops) – not harvested	791	12	16.4	6.25	2.49
Total					12.19

11.5.3 Emission

Figure 11.4 shows the distribution of nitrogen in crop residues between stubble, husks, plant tops and leaf litter. The total N content in crop residues from 1985 to 2011 is nearly unaltered at approximately 50 Gg N and N_2O emission at approximately 0.3 Gg N_2O (see Table 11.9). However, there has been a little variation for some of the years, particularly for straw and leafs remained.

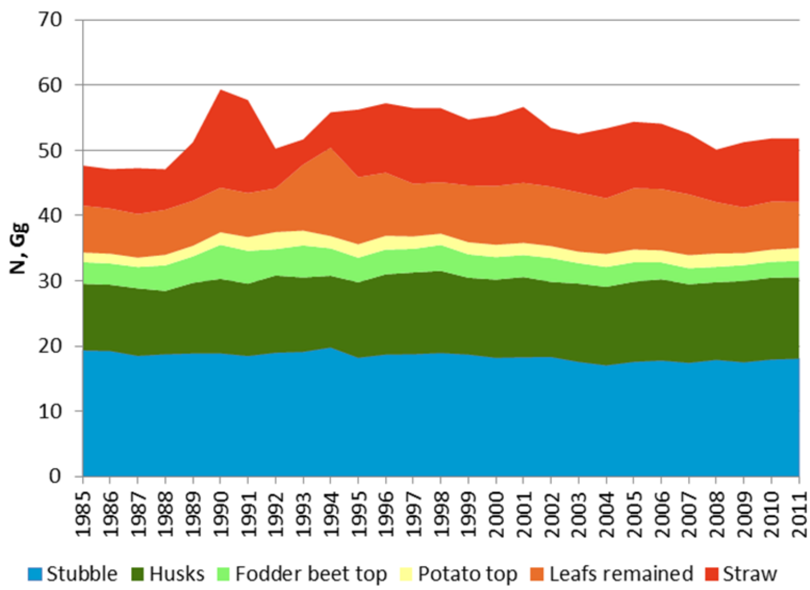

Figure 11.4 N content in crop residues, 1985 – 2011.

Table 11.9 Emission of N_2O from crop residues, 1985-2011.

	1985	1990	1995	2000	2005	2008	2009	2010	2011
N, Gg	47.7	59.3	56.2	55.3	54.4	50.1	51.2	51.8	51.8
N_2O, Gg	0.94	1.17	1.10	1.09	1.07	0.98	1.01	1.02	1.02
CO_2-eqv.,1000 Gg	0.29	0.36	0.34	0.34	0.33	0.31	0.31	0.32	0.32

11.6 Atmospheric deposition

Volatilization of NH_3 and NO_X and their deposition of these gases and products onto soils and the surface of lakes and other water environment cause N_2O emission. Emission of N_2O is calculated based on all NH_3 emission sources; manure management, synthetic fertiliser, sewage sludge used as fertiliser, crops and ammonia treated straw.

Around 96 % of the total NH_3 emission stems from agriculture (Nielsen et al., 2013a). In addition to the formation of N_2O, a release of N_2 and NO_X also occurs. Neither the IPCC Reference manual (IPCC, 1997) nor the IPCC Good Practice Guidance (IPCC, 2000) has a methodology for their quantification and neither are there currently any Danish data.

The emission is calculated as illustrated in Equation 9.6 - i.e. as the total NH_3 emission multiplied by the IPCC standard value for the emission factor of 0.01 (EF_{10}).

$$\mathrm{N_2O_{dep}} = \left(\left(\mathrm{NH_{3,\,MM}} + \mathrm{NH_{3,\,SF}} + \mathrm{NH_{3,\,SS}} + \mathrm{NH_{3,\,C}} + \mathrm{NH_{3,\,A\text{-}straw}}\right) \cdot \mathrm{EF_{10}}\right) \cdot \frac{44}{28} \qquad \text{(Eq. 11.6)}$$

Where:
- N_2O_{dep} = N_2O emission from atmospheric deposition
- $NH_{3,\,MM}$ = NH_3 emission from manure management
- $NH_{3,\,SF}$ = NH_3 emission from synthetic fertiliser
- $NH_{3,\,SS}$ = NH_3 emission from sewage sludge
- $NH_{3,\,C}$ = NH_3 emission from crops
- $NH_{3,\,A\text{-}straw}$ = NH_3 emission from ammonia treated straw
- EF_{10} = emission factor (see Table 11.1).

The total NH_3 emission from all emission sources is shown in Table 11.10 together with the calculated N_2O emission. From 1985 to 2011 the N_2O emission has decreased from 1.5 Gg N_2O to 0.9 Gg N_2O, which equates to a fall of 39 %. As mentioned in Chapter 5 regarding the NH_3 emission, this emission reduction is a consequence of an active environmental policy to reduce the loss of nitrogen to the aquatic recipients.

Table 11.10 Total NH_3 emission and the N_2O emission, 1985 – 2011.

Emission per year	1985	1990	1995	2000	2005	2008	2009	2010	2011
NH_3 emission, Gg NH_3-N	96.2	93.4	80.0	71.7	65.2	60.9	58.9	59.2	58.7
N_2O emission, Gg N_2O	1.51	1.47	1.26	1.13	1.02	0.96	0.93	0.93	0.92
CO_2 emission, 1000 Gg CO_2 eqv.	0.47	0.46	0.39	0.35	0.32	0.30	0.29	0.29	0.29

11.7 Leaching and runoff

Nitrogen, which is transported through the soil, can be transformed to N_2O. The IPCC recommends an N_2O emission factor of 0.025 used, of which 0.015

is for leaching to groundwater, 0.0075 for transport to watercourses (in IPCC definition called rivers) and 0.0025 for transport out to sea (in IPCC definition called estuaries). The N_2O emission from nitrogen leaching is a sum of the emission for all three parts calculated as given in equation 11.7.

$$N_2O_{\text{leaching}} = \left(N_{\text{leach-ground}} \cdot EF_{11a} + N_{\text{leach-rivers}} \cdot EF_{11b} + N_{\text{leach-estuatires}} \cdot EF_{11c}\right) \cdot \frac{44}{28} \qquad \text{(Eq. 11.7)}$$

In connection with the Action Plans for the Aquatic Environment, nitrogen leaching to groundwater, to the watercourses and to the sea has been estimated. The calculation of N to the groundwater is based on two different models; SKEP/Daisy and N-LES (Børgesen & Grant, 2003) carried out by DCA and DCE (see overview of model in appendix R. SKEP/DAISY is a dynamical crop growth model taking into account the growth factors, whereas N-LES is an empirical leaching model based on more than 1500 leaching studies performed in Denmark during the last 15 years. The models produce rather similar results for nitrogen leaching on a national basis (Waagepetersen et al., 2008). The SKEP/Daisy model has estimated the total N leached from 2003-2007 to be from 172 to 159 thousand tonnes N, whereas the N-LES model has estimated the total N leached to be from 163 to 154 thousand tonnes in the same period. An average of the results from the two models is used in the emission inventory.

Data concerning the N-leaching to watercourses and to the sea is estimated based on a national model concept called DK-QN develop by Department of Bioscience, Aarhus University as a part of the National Environmental monitoring Program (NOVANA). DK-QN simulates the monthly runoff and nitrogen loading and is developed based on a two other models. The groundwater/surface model MIKE-SHE, which describes the national and regional water balance and the interaction flow between groundwater and streams and the empirical model DK-N, which includes simulations of monthly sources, loads and skinks of total nitrogen. The model DK-QN has been validated and shows robustness. For a more detailed description refer to Windolf et al. (2011).

Since 1985, the amount of nitrogen leached has almost halved as a result of the significant decrease in consumption of synthetic fertilisers and the improved utilisation of the nitrogen content in animal manure (Table 11.11). The same trend is reflected in the N_2O emission by a decrease from 9.1 Gg N_2O in 1985 to 4.7 Gg N_2O in 2011, or 1 456 Gg CO_2 equivalents in 2011.

Table 11.11 Leaching of nitrogen and associated emissions, 1985 - 2011.

	1985	1990	1995	2000	2005	2008	2009	2010	2011
N-leaching$_{groundwater}$, Gg N	304	267	235	179	160	163	154	151	153
N-leaching$_{rivers}$, Gg N	128	102	104	95	67	80	59	68	73
N-leaching$_{estuaries}$, Gg N	120	100	91	81	56	65	49	55	59
N_2O, Gg	9.13	7.89	7.13	5.66	4.77	5.04	4.52	4.57	4.70
CO_2 eqv.,1 000 Gg	2.83	2.45	2.21	1.75	1.48	1.56	1.40	1.42	1.46

Figure 11.5 illustrates on the first axis the total amount of nitrogen applied as fertiliser on agricultural land in the form of animal manure, synthetic fertiliser and sewage sludge, while the second axis show the amount of N leached to the groundwater. It can be seen that the percentage of N leached compared with the total N applied on soil has been decreased from 43 % in 1985 to 33 % in 2007. From 2008 is used an N-leaching fraction at 33 %.

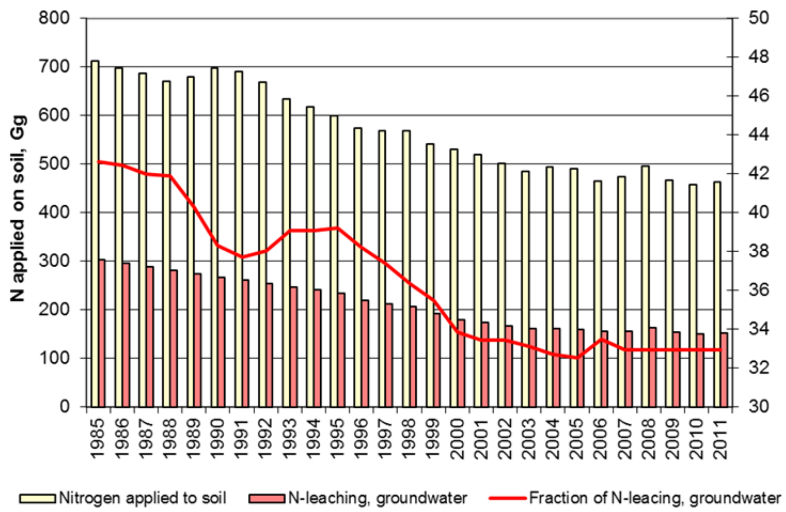

Figure 11.5 Leaching of nitrogen from 1985 to 2011.

11.8 Cultivation of histosols

The cultivation of histosols (humus-rich soils) breaks down organic matter and, thereby, releases both CO_2 and N_2O. The size of the emission depends on the circumstances surrounding cultivation (crop type, rotation, soil management, saturation, pH, etc.). The cultivated area of organics soils is estimated by the Department of Agroecology, Aarhus University.

The calculation of the N_2O emission is based on IPCC guidelines, which recommend an emission of 8 kg N_2O-N per hectare of cultivated organic soils.

$$N_2O_{HIS} = AR \cdot EF_{12} \cdot \frac{44}{28} \qquad \text{(Eq. 11.5)}$$

Where: AR = area of histosols
EF_{12} = emission factor (see Table 11.1)

The emission from cultivation of histosols is decreased from 1.00 Gg N_2O in 1985 to 0.66 Gg N_2O in 2011, which is due to the decrease in the cultivated area.

Table 11.12 Area and N_2O emission for histosols, 1985-2011.

	1985	1990	1995	2000	2005	2008	2009	2010	2011
Cultivated area, ha	79 664	74 473	69 282	64 092	58 901	55 786	54 748	53 710	52 687
N_2O, Gg	1.00	0.94	0.87	0.81	0.74	0.70	0.69	0.68	0.66

11.9 Biogas treatment of slurry

The lower emissions achieved from biogas treated slurry is included in the N_2O emission from manure management (housing and storage). The digestive process of the biogas treatment reduces the dry matter content of the slurry and this leads to a reduced N_2O emission under and after the spreading of the biogas treated slurry.

There is no methodology available in the IPCC Reference Manual (IPCC, 1997) or the IPCC GPG (IPCC, 2000) on how to calculate this reduction.

Therefore is the estimation based on Danish studies (Nielsen et al., 2002, Sommer et al., 2001). The lower N_2O emission is calculated according to equation 11.8:

$$N_2O_{lower} = \left(S_{treated\ slurry} \cdot N_c \cdot E_{N_2O,\ lower} \cdot EF_{N_2O}\right) \cdot \frac{44}{28} \qquad \text{(Eq. 11.8)}$$

where:

where:	N_2O_{lower}	= the amount of lower N_2O emission from a given livestock type (cattle or swine)
	$S_{treated\ slurry}$	= amount of treated slurry, tonnes
	N_C	= content of N in the treated slurry, pct
	$E_{N2O,\ lower}$	= a factor to express the lower emission from biogas treated slurry. It is assumed that treated cattle slurry is 64 % compared with untreated slurry and 60% for pig slurry
	EF_{N2O}	= emission factor for N_2O

The background data for the calculation of the reduction in N_2O emission is shown in Table 11.13.

Table 11.13 Data used in calculation of the reduction in N_2O emission in 2011.

2011	Slurry treated 1000 Gg slurry	Average N-content in slurry Pct.	$E_{N2O,\ lower}$	N_2O emission in untreated slurry Gg N_2O	N_2O emission in biogas treated slurry Gg N_2O	Decrease the total N_2O emission by Gg N_2O
Cattle slurry	1.08	0.00538	0.64	0.07	0.04	0.02
Swine slurry	1.31	0.00541	0.59	0.07	0.05	0.03
Total						0.05

For 2011, the N_2O reduction was 0.05 Gg, which corresponds to a 5 % reduction of the N_2O emission from manure management in 2011. The reduction is subtracted from the emissions from dairy cattle and fattening pigs, respectively.

The total reduction in N_2O from 1990 to 2011, which stems from biogas treatment of manure, is shown in appendix S.

12 Quality assurance and quality control

A first step of development and implementation of a general QA/QC plan for the Danish emission inventory initiated in 2004, which is described in a manual (Sørensen et al., 2005, Nielsen et al, 2012). The manual describes the concepts of quality work and how to handle quality management by using Critical Control Points and a list of Point of Measurements (PM). PM related to the agricultural inventory is listed below in Chapter 12.2 and are primarily connected to data storage and data processing level 1.

This report describes in detail the methods and the data foundation used to estimate the agricultural emissions and together with the National Inventory Report (NIR) and the Informative Inventory Report (IIR), a high degree of transparency is ensured.

The check of comparability with the reporting of other countries is ensured through the international review processes, where a lot of parameters are compared across countries and also compared to the IPCC default. Additionally Denmark has carried out a project of verification, where the emissions from key categories in the Danish inventory were compared against other countries with similar circumstances. (Fauser et al., 2006 and 2013).

One of the key elements to assess the accuracy of the inventory is estimating the uncertainties of the emission estimates. The procedure for estimating the uncertainties is described in Chapter 13.

As quality assurance the most importing aspects are external reviews of the inventory by independent experts. For the Danish agricultural inventory the external review consists of two main elements.

The first element is the international reviews carried out under the UNFCCC and UNECE, these reviews consists of review teams of internationally appointed experts, who are assigned to review the reporting of the different countries. These review teams consists of experts within all sectors and therefore cover the entire emission inventory. The recommendations received by the review teams form an important basis for improving both the inventories themselves but also the documentation.

The second element is the external review of the sectorial reports, such as this one. The sectorial reports are externally reviewed by national or international experts in the field.

The first version of this report (Mikkelsen et al., 2006) was reviewed by Statistics Sweden, who is responsible for the Swedish agricultural inventory and the first updated rapport (Mikkelsen et al., 2011) was reviewed by Nicholas J. Hutchings from the Faculty of Agricultural Sciences, Aarhus University and by Johnny M. Andersen from the Faculty of Life Sciences, University of Copenhagen.

This report was reviewed by Heidi Ravnborg from the Danish Environmental Agency.

12.1 QA/QC plan

The overall framework regarding a QA/QC plan are constructed in form of six stages and each stage focus on quality assurance and quality check in different part of the inventory process. A more detailed set up for stage I, II and III are provided, refer to Appendix U.

The QA/QC procedure is divided in six stages as listed below:

Table 12.1 Stages of QA/QC procedure.

Stage I	Check of input data - check of data input in IDA are consistent with data from external data suppliers
Stage II	Check of IDA data – overall - check of recalculations for total emissions compared with the latest submission (2012) - check of total emissions for the total CO_2 eqv. and for each compound
Stage III	Check of IDA data – specific - check of annual changes of activity data, emission factors, IEF and other important variables as GE, N ex, housing system distribution, grazing days
Stage IV	Check by comparing calculation with estimates from other institutions - the total N ex for all livestock production estimated by DCA - the Register for fertilisation controlled by the Danish AgriFish Agency
Stage V	Check of data registered in the Common Reporting Format (CRF) reported to UNFCCC and Nomenclature For Reporting (NFR) to UNECE - compare data in CRF or NFR with data from IDA
Stage VI	Check of the inventory in general (external review) - check that data is used correctly - check the methodology and the calculations

Stage I: Check of input data

At stage I it is checked that all input data in IDA is consistent with data from the external data suppliers. Data from the Statistics Denmark has to be checked for the livestock production, slaughter data for poultry and pigs, check of land use and crop yield. Data input from the DCA has to be checked for feed intake, N-excretion, manure production, dry matter content and grazing days. Data from the DAFA: distribution of housing systems and the use of nitrogen in synthetic fertiliser.

Stage II: Check of IDA data - overall

Stage II includes check of the overall calculations in IDA. The first step is to compare the inventory with the last reported emission inventory - submission 2012. In the case where an error cover all time series, it can be difficult to identify this error by checking the changes in inter annual values. Therefore, a check of recalculations is needed.

Next step in stage II is a check of total emissions of NH_3, CH_4, N_2O, NMVOC and the other compounds which are related to the field burning of agricultural residues and use of pesticides. For each compound a check of trends of times series 1985-2011 and inter annual changes is provided. Significant jumps or dips from one year to another could indicate an error - otherwise it has to be explained.

Stage III: Check of IDA data - specific

At stage III a check of specific variables in IDA is provided for both inter annual changes and trends for the entire time series. Variables includes activity data, emission factors, IEF and other important key variables such as feed intake, GE, Nex and housing systems distribution.

Stage IV: Check by comparing calculation with estimates from other institutions

The purpose of stage IV is to verify the calculations in IDA, as far as external data estimations are available. For other purposes DCA for some years calculate the overall N excretion from the total livestock production in DK, which could be compared with the survey given in the emission inventory. Another possibility to check some of the IDA estimations is the information in the fertiliser accounts controlled by DAFA. Farmers with more than 10 animal units have to be registered and have to keep accounts of the N content in manure, received manure or other organic fertiliser. These comparisons will properly show some differences, which not necessarily indicate an error, but the most important cause of the difference has to be identified.

Stage V: Check of data registered in CRF and NFR

Stage V primarily focuses on the last reported year and the base year (CRF 1990/NFR 1985), where all activity data, emissions and IEFs are checked. Furthermore, CRF and NFR sum emissions are checked with sum emissions in IDA. If an error is detected a more detailed check is done to find the reason for the error.

Stage VI: Check of the inventory in general

General checks of the inventory include considerations of which data input is used, how they are used in the calculations and whether more accurate data are available. The review of this sectorial report addresses these issues and is a most valuable part of the QA of the agricultural sector.

As a part of the report "Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories" (IPCC, 2000) a verification of emission estimates are provided, which include an inter-country comparison for EU15 countries excluding Luxemburg and including Norway and Switzerland and for some verification steps also including Australia, Canada, Japan, Russian Federation and USA (Fauser et al., 2013). The verification covers 1990, 2000 and 2010 emissions, reported in 2012, for 29 Danish verification key categories, identified by a Tier 1 key source analysis. The agricultural sector contributes with 14 of the verification key categories.

For most of the verification categories the implied emission factor (IEF) show constant time series indicating consistent IEFs from 1990 to 2010 and imply robustness in methodology and underlying data. Comparability of IEF between countries is found for most of the agricultural categories. Some verification categories differ from other countries but can be explained by use of national data, which leads to a larger variation of the IEF values. In general, the Danish IEF is in line with other countries that have comparable agricultural conditions

13 Uncertainties

Uncertainty estimates are based on the methodology described in the IPCC Good Practice Guidance (IPCC, 2000) and the EEA/EMEP Guidebook (EMEP, 2009). The total uncertainty depends on uncertainty values for activity data and uncertainty values for the emission factor.

13.1 Uncertainty values for agricultural air pollutants

13.1.1 Activity data

As mention before, the main part of the emissions depends on the livestock production and uncertainties such as number of animals, feeding consumption, normative figures etc. are relatively low. Uncertainties regarding animal production are very small. Numbers of animals are based on DSt, which has estimated the uncertainties for year 2011 for the main livestock categories swine and cattle as 1.2 % and 0.7 %, respectively. The uncertainty for other categories such as poultry, horses, sheep and goats is a higher. The uncertainty for activity data, which only depends on number of animals the uncertainty value, is estimated to 2 %.

When it comes to NH_3 emission from manure management, the activity data not only includes the number of animal, but also includes estimates for type of housing and thus type of manure, which higher the uncertainty. The uncertainty value is estimated to 5 %.

The overall uncertainty for N-excretion on grass is estimated to 5 %. Besides the number of animal, the uncertainty depends on the assumed number of days on grass and the N-excretion, which is estimated by DAAS and DCA, Aarhus University.

The activity data for synthetic fertiliser depends on the amount of sold fertiliser and the nitrogen content, which is based on information given by the DAFA. Uncertainty for this is considered to be low and is estimated to 3 %.

The uncertainty regarding the ammonia emission sources growing crops, sewage sludge and ammonia treated straw, which is included in the reporting format under "4G Other" (see Table 13.2), is assumed to be 20%. The uncertainty for land use data based on Statistics Denmark is low, while the uncertainty regarding the amount of sewage sludge based on the register for fertilization. The uncertainty for the amount of ammonia used to treatment of straw is also relative high.

An uncertainty of 25 % for the activity for field burning of agricultural wastes is used. The uncertainty is a combination of the uncertainty for area of grass for seed production, which has a low uncertainty, amount of burnt straw and yield, which have a high uncertainty.

For the NMVOC emissions the activity data depends on hectares of arable crops and grassland, which is estimated by Statistics Denmark. For the most common crops the uncertainties are below 5 % and thus the overall uncertainty value is estimated to 2 %.

Activity data for the PM emission depends on the number of animal, why the uncertainty is assumed to be 2 %.

The uncertainty for activity data regarding use of pesticides with HCB is based on annual sales statistic provided by the Environmental Protection Agency and is considered with relatively low uncertainty; 5 %.

13.1.2 Emission factor

The uncertainty regarding the NH_3 emission factor from manure management includes estimates for N–excretion depending on feed intake and emission from three different places in the livestock production; in housing, stored manure and application of manure.

The Danish Normative System for animal excretions is based on data from the Danish Agricultural Advisory Services (DAAS), which is the central office for all Danish agricultural advisory services. DAAS engages in a great deal of research as well as the collection of efficacy reports from Danish farmers for dairy production, meat production, pig production, etc., to optimise productivity in Danish agriculture. Feeding plans from 15-18 % of the Danish dairy production, 25-30 % of pig production, 80-90 % of poultry production and approximately 100 % of fur production are collected annually. These basic feeding plans are used to develop the standard values of the "Danish Normative System". However, due to the large number of farms included in the norm figures, the arithmetic mean can be assumed as a very good estimate with a low uncertainty. In the normative standards (Poulsen et al., 2012) uncertainty values are indicated for emission measurements in housing and varies from 15 -25 %, but there is no specified uncertainty estimates for emission factors for storage and application of manure. The overall uncertainty value for NH_3 emission factor for manure management is estimated to 25%.

The ammonia emission from grazing animals depends on the number of grazing days, the animal type, the temperature and other climatic conditions. No statistics exit on grazing days and are therefore based on an estimated provided of the by The Danish Agricultural Advisory Service. The uncertainty value is estimated to 25 %.

No uncertainty values for the emission factor regarding the synthetic fertiliser are given in the EEA/EMEP guidebook. The Danish inventory assume an uncertainty value of 25 %, which indicated an uncertainty in the translation of the Danish fertiliser types to types specified in the guidebook, but also indicate an uncertainty of the emission factors specified in the guidebook.

The uncertainty regarding the emission from the ammonia emission sources growing crops, sewage sludge and ammonia treated straw is all based on the relative few data and therefore assumed to have a high uncertainty estimated to 50 %.

Uncertainties for field burning are relatively high. The uncertainties for the emission factors for field burning of agricultural residues are based on the EMEP/EEA Guidebook (EMEP, 2009) and Jenkins et al. (1996).

The uncertainty regarding the NMVOC emission from agricultural soils is in the EMEP/EEA Guidebook mentioned as being very a high – may be uncertain by a factor of 30. The uncertainty is set to 500 %.

The uncertainty estimates regarding the PM emission factors from manure management are based on the EMEP/EEA guidebook 2009.

No uncertainty value is provided in EMEP for HCB and PCBs, the uncertainty is assumed to be high and thus estimated to 500 %.

13.1.3 Result of the uncertainty calculation

Table 13.1 shows uncertainty values for activity and emission factors and combined and total uncertainties for the air pollutants.

The total uncertainty for the NH_3 emission inventory is calculated at ±19 %, which is primarily affected by the main emission source manure management. The higher uncertainty values for the field burning of crop residues have only minor effect on the total uncertainty estimate.

A high total uncertainty of around 500 % and 300 % is associated with NMVOC emission, PM emission and almost all pollutants related to field burning of agricultural residues. The high uncertainty level is due to the emission factors uncertainty. An uncertainty between 60 - 35 % is seen for NO_x and Pb from field burning. The uncertainty is lowest for the ammonia emissions and the agricultural ammonia emission inventory thus have an uncertainty at 25 %.

Table 13.2a Uncertainty values for air pollutants, 2011.

Pollutant	NFR category	Emission	Activity data %	Emission factor %	Combined Uncertainty %	Total Uncertainty %
NH_3, Gg	4. Agriculture	71.30				25
NH_3, Gg	4.B Manure management	59.74	5	20	22	19
	4 D1a Synthetic N-fertilisers	3.94	3	25	25	1
	4 D2c N-excretion on pasture	1.81	5	25	25	<1
	4.F Field burning	0.09	25	50	56	<1
	4.G Agriculture other	5.71	20	50	54	4
NMVOC, Gg						446
	4.F Field burning	0.23	25	100	103	
	4.G Agricultural other	1.92	2	500	500	
TSP, Gg						294
	4.B Manure management	11.21	2	300	300	
	4.F Field burning	0.21	25	50	56	
PM_{10}, Gg						289
	4.B Manure management	5.60	2	300	300	
	4.F Field burning	0.21	25	50	56	
$PM_{2.5}$, Gg						256
	4.B Manure management	1.18	2	300	300	
	4.F Field burning	0.20	25	50	56	
HCB	4.G Agriculture other	NE	5	500		

NE: Not estimated. Emission inventory for 2012 include a first estimate of HCB and PCB emissions.

Table 13.3b Uncertainty values for air pollutants – field burning other than PM, 2011.

Pollutant	NFR category	Emission	Activity data %	Emission factor %	Combined Uncertainty %	Total Uncertainty %
PCB	4.F Field burning	NE	25	500		
HCB	4.F Field burning	NE	25	500		
NO_x, Gg	4.F Field burning	0.09	25	25	35	35
CO, Gg	4.F Field burning	2.15	25	100	103	103
SO_2, Gg	4.F Field burning	0.01	25	100	103	103
Pb, tonnes	4.F Field burning	0.03	25	50	56	56
Cd, tonnes	4.F Field burning	0.002	25	100	103	103
Hg, tonnes	4.F Field burning	0.0003	25	200	202	202
As, tonnes	4.F Field burning	0.002	25	100	103	103
Cr, tonnes	4.F Field burning	0.01	25	200	202	202
Cu, tonnes	4.F Field burning	0.00001	25	200	202	202
Ni, tonnes	4.F Field burning	0.01	25	200	202	202
Se, tonnes	4.F Field burning	0.001	25	100	103	103
Zn, tonnes	4.F Field burning	0.001	25	200	202	202
Dioxin, g I-Teq	4.F Field burning	0.02	25	500	501	501
Benzo(a)pyrene, tonnes	4.F Field burning	0.10	25	500	501	501
Benzo(b)fluoranthen, tonnes	4.F Field burning	0.10	25	500	501	501
Benzo(k)fluoranthen, tonnes	4.F Field burning	0.04	25	500	501	501

13.2 Uncertainty values for agricultural greenhouse gases

13.2.1 Activity data

The activity data regarding CH_4 emission from enteric fermentation and manure management only depends on number of animal, which is based on very reliable data from Statistics Denmark thus a low uncertainty at 5 % is used. Activity data for manure management besides number of animal also depends on the housing- and manure type. The uncertainty estimate is assumed to 5 %.

Uncertainty for N_2O activity data which depends on the ammonia emission such as manure management, synthetic fertilizer, manure applied to soils, grassing animal and the atmospheric deposition, the uncertainty reflects the uncertainty value estimated in the ammonia emission inventory – see the combined uncertainty provided in Table 13.1a.

Activity regarding N-fixing crops, crop residue and cultivation of histosols depends on land use data from Statistics Denmark, which has a low uncertainty. However, activity data also depends on the yield and crops N-content, which is much more uncertain. An uncertainty value at 20 % is used. Same uncertainty level is use for application of sewage sludge to agricultural soil and data for the amount of nitrogen leached to groundwater, watercourses and to the sea.

As for the air pollutants an uncertainty of 25 % for field burning of agricultural wastes is used.

13.2.2 Emission factor

The uncertainty value for enteric fermentation is in IPCC guidance estimated to 20 %. Uncertainty regarding the emission factor used for manure management depends on the uncertainty for each variable such as manure excretion, distribution of housing type, content of dry matter in manure and use of straw for bedding. National data is used for these variables, which may reduce the uncertainty compared with use of IPCC default value. It is considered that an uncertainty of 20 % is reliable.

A CH_4 and N_2O uncertainty for field burning is estimated to 50 %, which is based on IPCC guidelines (IPCC, 1997).

The IPCC default value is used to calculate the N_2O emission. The uncertainty estimates mentioned in IPCC guidance is very high, from 200% and for most of the emissions sources up to 500%. A lower uncertainty value at 100% is used in the Danish inventory. This could be considered as an underestimation, but on the other hand an uncertainty N_2O estimate of 500% results in a total uncertainty for agricultural greenhouse gases at 120%, which indicate a very uncertain emission inventory.

13.2.3 Result of the uncertainty calculation

Table 13.2 shows uncertainty values for activity and emission factors and combined and total uncertainties for the air pollutants.

The overall uncertainty calculation for agricultural greenhouse gases is calculated to ±25 %. Especially emission sources as N_2O from N-leaching, synthetic fertiliser, animal waste applied to soil and CH_4 from enteric fertiliser affects the total uncertainty. This is due to a combination of large contribution to total emissions and high uncertainty for the emission factor.

Table 13.4 Uncertainty values for agricultural greenhouse gases - N_2O and CH_4, 2011.

Pollutant	CRF category	Emission	Activity data,%	Emission factor, %	Combined Uncertainty, %	Total Uncertainty, %
Gg CO_2 eqv.	4. Agriculture total	9 672				25
CH_4, Gg CO_2 eqv.	4.A Enteric fermentation	2 840	5	20	20	14
	4.B Manure management	1 308	5	20	21	6
	4.F Field burning	2	25	50	56	<1
N_2O, Gg CO_2 eqv.	4.B Manure management	403	22	100	55	4
	4.D.1.1 Synthetic fertiliser	1180	25	100	103	22
	4.D.1.2 Animal waste applied to soils	1169	22	100	102	22
	4.D.1.3 N-fixing crops	259	20	100	102	5
	4.D.1.4 Crop residue	315	20	100	102	6
	4.D.1.5 Cultivation of histosols	205	20	100	102	4
	4.D.1.6 Sewage sludge/industrial waste	39	20	100	102	<1
	4.D.2 Animal production (grazing)	208	25	100	103	4
	4.D.3.1 Atmospheric deposition	286	19	100	102	5
	4.d.3.2 N-leaching and runoff	1456	20	100	102	27
	4.F Field burning	1	25	50	56	<1

14 Conclusion

In response to a number of international conventions, Denmark is committed to calculate the Danish emissions to the atmosphere of a range of different pollutants. For the agricultural sector, the emissions to be calculated are ammonia (NH_3), the greenhouse gases methane (CH_4) and nitrous oxide (N_2O), the indirect greenhouse gases non-methane volatile organic compounds (NMVOC), particulate matter (PM), a series of other pollutants related to the field burning of crop residues (NOx, CO, SO_2, heavy metals, PAHs, dioxins, HCB and PCBs) and HCB from use of pesticides.

Danish Centre for Environment and Energy (DCE) is responsible for preparing and reporting the annual emissions inventories. In addition to the emissions inventories themselves, requirements in the various conventions call for documentation of the calculation methodology. This report should be viewed in the light of the reporting requirements of these conventions. The report includes the emissions from the agricultural sector from 1985 to 2011, a description of the methodology used and a description of background data used in the emission calculations.

14.1 Agricultural emissions from 1985 to 2011

In 2012, the agricultural sector contributes 96 % of the total NH_3 emission, while the agricultural part of the greenhouse gases are estimated to 17 %.

The emission of NH_3 and greenhouse gases from the agricultural sector stems primarily from livestock production, while a smaller part of the emission is from the fertilisation and cultivation of crops.

The NH_3 emission has decreased from 96.2 Gg NH_3-N in 1985 to 58.7 Gg NH_3-N in 2011. By using the conversion factor 17/14, the emission in pure NH_3 corresponds to 116.8 Gg NH_3 in 1985 and 71.3 Gg NH_3 in 2011. In percentage terms the reduction is 39 %. Similarly, for the greenhouse gas emissions there has been a reduction from 13.4 million tonnes to 9.7 million tonnes CO_2 equivalents, which corresponds to a reduction of 28 %.

The significant decrease of emissions of both NH_3 and greenhouse gases is a consequence of an active national environmental policy over the last 20 years. A string of measures have been introduced by action plans to prevent loss of nitrogen from agriculture to the aquatic environment. The focus on improvement of nitrogen utilisation in manure has led to a decrease in consumption of synthetic fertiliser. The improvement in the utilisation of nitrogen has occurred via improvements in feed efficiency and stricter legal requirements especially concerning the handling of animal manure during storage and application. In addition, these environmental measures have a significant effect on the total greenhouse gas emission, which is due to the close correlation between nitrogen turnover and the emission of N_2O, which has a strong global warming potential.

14.2 Methodology and documentation

Preparation of the Danish emission inventories is based on the international guidelines EMEP/EEA air pollutant emission inventory guidebook

(EMEP/EEA, 2004; EMEP/EEA 2009), Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997) and Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000). In Denmark, a relatively large amount of data and information is available on agricultural production, including livestock populations, slaughter data, feed intake, N-excretion, etc. Where data relevant for Danish agricultural production are not available, standard values recommended in the international guidelines are used.

Data used to calculate the agricultural emissions are collected, assessed and discussed in cooperation with a range of different institutions involved in research or administration within the agricultural sector. Especially of relevance are Statistics Denmark, Danish Centre for Food and Agriculture at Aarhus University and the Danish Agricultural Advisory Service. Furthermore, the following institutions have been involved: the Danish Environmental Protection Agency, Danish AgriFish Agency and the Danish Energy Authority.

Calculation methodology and background data will be continually evaluated and, where necessary, adjusted as part of developments in research on a national scale, as well as on an international scale via changes in the guidelines.

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Appendixes

A) Ammonia emission from Danish agriculture 1985 – 2011.

NH_3-N	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
							Gg NH_3-N							
Agricultural sector - total	**96.17**	**97.39**	**95.40**	**93.38**	**93.68**	**93.43**	**90.25**	**89.11**	**87.38**	**84.99**	**80.00**	**77.30**	**76.27**	**76.69**
Manure management	76.67	77.13	74.83	74.37	73.38	72.21	70.53	70.53	69.09	66.45	62.96	62.28	62.11	63.09
Agricultural soils - total	7.90	7.60	7.24	7.36	7.19	7.83	7.64	7.31	7.13	7.30	7.07	6.32	5.84	5.93
-Synthetic fertiliser	5.32	5.07	4.82	4.97	4.80	5.43	5.18	4.85	4.63	4.85	4.57	3.81	3.39	3.49
-Pasture, range and paddock	2.58	2.52	2.42	2.39	2.38	2.40	2.46	2.46	2.50	2.45	2.49	2.51	2.45	2.44
Field burning of agricultural residue	1.26	1.08	1.03	0.77	0.81	0.06	0.07	0.06	0.07	0.07	0.08	0.07	0.08	0.10
Agriculture Other - total	10.34	11.58	12.30	10.88	12.30	13.33	12.02	11.21	11.08	11.17	9.90	8.63	8.24	7.57
-Sewage sludge used as fertiliser	0.04	0.04	0.04	0.04	0.05	0.06	0.06	0.07	0.09	0.08	0.09	0.09	0.07	0.07
-Growing crops	4.92	4.92	4.91	4.86	4.84	4.88	4.85	4.82	4.75	4.41	4.35	4.38	4.48	4.45
-NH_3 treated straw	5.39	6.62	7.35	5.97	7.41	8.39	7.12	6.32	6.24	6.67	5.46	4.17	3.69	3.05

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
							Gg NH_3-N						
Agricultural sector - total	**72.77**	**71.74**	**70.23**	**69.15**	**68.38**	**67.90**	**65.19**	**62.56**	**61.85**	**60.86**	**58.93**	**59.17**	**58.72**
Manure management	60.94	59.68	59.14	58.99	58.68	58.36	56.04	53.59	52.93	51.62	49.73	50.00	49.20
Agricultural soils - total	5.63	5.58	5.27	4.92	4.57	4.61	4.40	4.43	4.45	4.65	4.59	4.40	4.74
-Synthetic fertiliser	3.24	3.17	2.82	2.56	2.46	2.66	2.57	2.70	2.82	3.01	3.02	2.86	3.24
-Pasture, range and paddock	2.39	2.41	2.45	2.36	2.11	1.95	1.82	1.73	1.64	1.64	1.57	1.54	1.49
Field burning of agricultural residue	0.09	0.09	0.10	0.08	0.10	0.10	0.10	0.11	0.09	0.08	0.10	0.07	0.07
Agriculture Other - total	6.10	6.39	5.72	5.17	5.04	4.83	4.65	4.44	4.37	4.50	4.51	4.70	4.71
-Sewage sludge used as fertiliser	0.07	0.07	0.07	0.07	0.06	0.05	0.04	0.04	0.04	0.04	0.06	0.05	0.05
-Growing crops	4.33	4.29	4.33	4.33	4.32	4.34	4.40	4.40	4.33	4.46	4.46	4.45	4.46
-NH_3 treated straw	1.71	2.03	1.33	0.77	0.66	0.43	0.21	0.00	0.00	0.00	0.00	0.20	0.20

A) *Continued…*

NH_3	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
							Gg NH_3							
Agricultural sector - total	**116.78**	**118.25**	**115.84**	**113.38**	**113.75**	**113.45**	**109.59**	**108.21**	**106.10**	**103.20**	**97.14**	**93.86**	**92.61**	**93.13**
Manure management	93.09	93.65	90.86	90.31	89.10	87.68	85.64	85.64	83.90	80.69	76.45	75.62	75.42	76.61
Agricultural soils - total	9.59	9.22	8.79	8.93	8.73	9.51	9.27	8.88	8.66	8.87	8.58	7.67	7.09	7.20
-Synthetic fertiliser	6.46	6.16	5.86	6.03	5.83	6.59	6.29	5.89	5.62	5.89	5.55	4.63	4.12	4.24
-Pasture, range and paddock	3.13	3.06	2.94	2.90	2.90	2.92	2.99	2.99	3.04	2.97	3.03	3.05	2.98	2.96
Field burning of agricultural residue	1.53	1.32	1.25	0.93	0.98	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.10	0.12
Agriculture Other - total	12.56	14.06	14.93	13.21	14.94	16.18	14.60	13.61	13.46	13.56	12.02	10.48	10.00	9.19
-Sewage sludge used as fertiliser	0.05	0.05	0.05	0.05	0.06	0.07	0.07	0.09	0.11	0.10	0.11	0.10	0.09	0.09
-Growing crops	5.97	5.97	5.96	5.91	5.88	5.92	5.88	5.85	5.77	5.36	5.28	5.31	5.44	5.41
-NH_3 treated straw	6.54	8.04	8.92	7.25	9.00	10.19	8.64	7.67	7.58	8.10	6.63	5.06	4.48	3.70

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
							Gg NH_3						
Agricultural sector - total	**88.36**	**87.11**	**85.28**	**83.97**	**83.04**	**82.45**	**79.16**	**75.96**	**75.10**	**73.90**	**71.56**	**71.85**	**71.30**
Manure management	74.00	72.46	71.81	71.63	71.25	70.87	68.05	65.07	64.28	62.68	60.38	60.72	59.74
Agricultural soils - total	6.84	6.77	6.39	5.97	5.55	5.59	5.34	5.38	5.41	5.64	5.57	5.34	5.75
-Synthetic fertiliser	3.93	3.85	3.42	3.11	2.99	3.23	3.12	3.28	3.42	3.65	3.67	3.47	3.94
-Pasture, range and paddock	2.90	2.92	2.97	2.86	2.57	2.36	2.21	2.09	1.99	1.99	1.91	1.87	1.81
Field burning of agricultural residue	0.12	0.11	0.12	0.10	0.12	0.13	0.13	0.13	0.11	0.10	0.12	0.09	0.09
Agriculture Other - total	7.41	7.76	6.95	6.28	6.12	5.86	5.65	5.39	5.31	5.47	5.48	5.71	5.71
-Sewage sludge used as fertiliser	0.08	0.08	0.08	0.08	0.07	0.06	0.05	0.05	0.05	0.05	0.07	0.06	0.06
-Growing crops	5.25	5.21	5.25	5.26	5.24	5.27	5.34	5.34	5.26	5.41	5.41	5.41	5.42
-NH_3 treated straw	2.08	2.47	1.62	0.94	0.80	0.53	0.26	0.00	0.00	0.00	0.00	0.24	0.24

B) Development in the emission of greenhouse gases, 1985-2011, measured in Gg CO_2 equivalents.

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
CH_4	4 702	4 596	4 382	4 266	4 217	4 242	4 274	4 280	4 347	4 244	4 239	4 232	4 148	4 171
N_2O	8 718	8 548	8 390	8 223	8 227	8 303	8 111	7 881	7 721	7 713	7 353	6 814	6 789	7 012
Total	13 420	13 144	12 772	12 489	12 444	12 545	12 385	12 161	12 068	11 957	11 592	11 046	10 937	11 184

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
CH_4	4 038	4 048	4 142	4 136	4 108	4 055	4 043	4 021	4 100	4 106	4 095	4 165	4 151
N_2O	6 706	6 423	6 236	6 163	5 729	5 912	5 809	5 638	5 787	5 837	5 503	5 449	5 521
Total	10 744	10 471	10 378	10 299	9 837	9 966	9 852	9 659	9 888	9 943	9 598	9 614	9 672

C) Development in the emission of greenhouse gases, 1985-2011, measured in Gg CO_2 equivalents, distributed on main sources.

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
CH_4														
Enteric Fermentation	3 703	3 585	3 390	3 277	3 222	3 247	3 251	3 212	3 237	3 144	3 134	3 113	3 017	3 004
Manure Management	962	980	963	967	972	993	1 021	1 066	1 107	1 098	1 103	1 117	1 129	1 164
Field burning	36	31	30	22	23	2	2	2	2	2	2	2	2	3
N_2O														
Crop Residue	290	287	288	287	312	361	351	306	315	340	330	348	344	344
Atmospheric Deposition	468	474	465	455	456	455	440	434	426	414	390	377	372	374
N-fixing Crops	246	242	231	249	241	269	236	199	256	241	226	218	264	292
Grazing	359	351	337	333	332	334	342	343	348	341	347	349	341	340
Manure Management	609	614	602	607	612	600	596	601	598	582	566	565	572	580
Field burning	14	12	11	8	9	1	1	1	1	1	1	1	1	1
Synthetic fertiliser	2 392	2 296	2 292	2 205	2 266	2 405	2 373	2 220	1 999	1 957	1 896	1 748	1 731	1 703
Histosols	310	306	302	298	294	290	286	282	278	274	270	266	262	258
Manure on soil	1 177	1 182	1 146	1 135	1 125	1 112	1 108	1 117	1 133	1 094	1 064	1 066	1 061	1 084
Sewage sludge	21	21	22	23	26	28	36	41	57	54	55	55	51	54
Leaching and run-off	2 832	2 762	2 692	2 623	2 553	2 447	2 342	2 336	2 311	2 415	2 209	1 821	1 791	1 983
CO_2														
Field burning	967	830	789	590	621	49	51	48	53	51	58	57	61	77

C) *Continued…*

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
CH_4													
Enteric Fermentation	2 891	2 861	2 911	2 872	2 833	2 753	2 737	2 740	2 805	2 830	2 823	2 862	2 840
Manure Management	1 144	1 184	1 229	1 262	1 272	1 299	1 303	1 278	1 293	1 273	1 270	1 300	1 308
Field burning	3	3	3	2	3	3	3	3	3	2	3	2	2
N_2O													
Crop Residue	333	337	345	325	320	325	331	329	320	305	312	316	315
Atmospheric Deposition	354	349	342	337	333	331	318	305	301	296	287	288	286
N-fixing Crops	237	233	217	222	192	183	208	211	212	213	248	238	259
Grazing	333	335	341	328	294	271	254	240	228	229	218	215	208
Manure Management	568	537	539	537	521	533	512	478	479	457	423	423	403
Field burning	1	1	1	1	1	1	1	1	1	1	1	1	1
Synthetic fertiliser	1 580	1 512	1 406	1 268	1 210	1 243	1 240	1 151	1 168	1 324	1 201	1 139	1 180
Histosols	254	250	246	242	238	234	230	226	221	217	213	209	205
Manure on soil	1 080	1 061	1 100	1 136	1 141	1 177	1 189	1 151	1 213	1 191	1 156	1 164	1 169
Sewage sludge	48	53	65	63	58	52	47	44	41	40	42	40	39
Leaching and run-off	1 917	1 754	1 634	1 704	1 422	1 562	1 480	1 502	1 603	1 564	1 401	1 417	1 456
CO_2													
Field burning	73	72	75	63	75	79	80	81	70	65	77	56	55

D) Number of livestock.

1) Number of livestock given in AAP (average annual production), thousands.

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Dairy Cattle	896	864	811	774	759	753	742	712	714	700	702	701	670	669
Non-Dairy Cattle[1]	1 721	1 631	1 540	1 488	1 462	1 486	1 480	1 478	1 481	1 405	1 388	1 393	1 334	1 308
Pigs[2]	9 089	9 321	9 266	9 217	9 190	9 497	9 783	10 455	11 568	10 923	11 084	10 842	11 383	12 095
Poultry[3]	16 282	16 282	16 603	16 586	18 257	17 311	16 995	20 103	20 962	20 916	20 685	20 955	20 062	19 743
Horses	140	139	138	137	136	135	137	138	140	141	143	144	146	147
Sheep	40	52	59	73	83	92	107	102	88	80	81	94	96	101
Goats	8	8	8	8	8	7	7	7	7	7	7	7	7	8
Fur farming	1 906	2 194	2 402	2 877	3 055	2 264	2 112	2 283	1 537	1 828	1 850	1 918	2 212	2 345
Deer	9	10	10	10	10	10	10	10	10	10	10	10	10	10

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Dairy Cattle	640	636	623	610	596	563	564	550	545	558	563	568	565
Non-Dairy Cattle[1]	1 247	1 232	1 284	1 187	1 128	1 082	1 006	984	1 021	1 006	977	1 003	1 003
Pigs[2]	11 626	11 922	12 608	12 732	12 949	13 233	13 534	13 361	13 723	12 738	12 369	13 173	12 932
Poultry[3]	22 080	22 902	22 308	21 649	18 911	17 716	18 699	18 491	17 805	16 469	20 738	19 794	20 382
Horses	149	150	155	160	165	170	175	180	185	190	178	165	155
Sheep	106	112	119	117	121	124	126	128	124	117	116	111	94
Goats	8	8	9	9	10	11	11	12	13	14	16	16	13
Fur farming	2 089	2 199	2 304	2 422	2 361	2 471	2 552	2 708	2 837	2 810	2 721	2 699	2 757
Deer	10	10	11	10	10	10	10	10	10	10	9	10	8

[1]Non-Dairy Cattle includes: Calves, bulls, heifers and suckling cattle.

[2]Pigs includes: Sows, weaners and fattening pigs.

[3]Poultry includes: Hens, pullets, broilers, turkeys, ducks, geese, pheasants and ostrich.

D) *Continued…*

2) Number of livestock given in produced number of animals, thousands.

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Dairy Cattle	896	864	811	774	759	753	742	712	714	700	702	701	670	669
Non-Dairy Cattle[1]	3 314	3 182	2 993	2 890	2 807	2 856	2 862	2 893	2 849	2 737	2 712	2 704	2 623	2 532
Pigs[2]	30 420	32 145	32 222	32 770	32 648	33 803	35 532	38 640	42 535	43 039	42 394	42 732	43 964	47 570
Poultry[3]	95 264	94 625	93 892	100 677	107 846	109 782	114 815	124 651	130 655	140 804	137 057	130 461	133 554	140 350
Horses	140	139	138	137	136	135	137	138	140	141	143	144	146	147
Sheep	40	52	59	73	83	92	107	102	88	80	81	94	96	101
Goats	8	8	8	8	8	7	7	7	7	7	7	7	7	8
Fur farming	1 906	2 194	2 402	2 877	3 055	2 264	2 112	2 283	1 537	1 828	1 850	1 918	2 212	2 345
Deer	9	10	10	10	10	10	10	10	10	10	10	10	10	10

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Dairy Cattle	640	636	623	610	596	563	564	550	545	558	563	568	565
Non-Dairy Cattle[1]	2 400	2 345	2 325	2 264	1 406	1 385	1 264	1 238	1 284	1 283	1 234	1 244	1 294
Pigs[2]	48 087	47 382	49 478	51 148	51 278	53 080	51 853	51 428	51 788	51 079	49 364	51 619	52 967
Poultry[3]	151 376	147 971	150 217	149 882	144 373	145 129	136 340	119 006	119 042	120 342	120 220	129 723	129 046
Horses	149	150	155	160	165	170	175	180	185	190	178	165	155
Sheep	106	112	119	117	121	124	126	128	124	117	116	111	94
Goats	8	8	9	9	10	11	11	12	13	14	16	16	13
Fur farming	2 089	2 199	2 304	2 422	2 361	2 471	2 552	2 708	2 837	2 810	2 721	2 699	2 757
Deer	10	10	11	10	10	10	10	10	10	10	9	10	8

[1]Non-Dairy Cattle includes: Calves, bulls, heifers and suckling cattle.

[2]Pigs includes: Sows, weaners and fattening pigs.

[3]Poultry includes: Hens, pullets, broilers, turkeys, ducks, geese, pheasants and ostrich.

E) Housing type distribution in percent, 1985-2011.

<u>Cattle:</u>

Dairy cattle:

Livestock categories	Housing type	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Dairy cattle	Tethered with liquid and solid manure	40	39	38	37	36	35	35	34	33	32	31	30	30	30
	Tethered with slurry	45	45	44	44	44	44	43	43	43	43	42	42	36	30
	Loose-holding with beds, slatted floor	9	10	11	11	12	13	14	15	15	16	17	18	21	24
	Loose-holding with beds, slatted floor, scrapes	1	1	1	1	1	1	1	1	1	1	1	1	2	3
	Loose-holding with beds, solid floor	4	4	4	4	4	3	3	3	3	3	3	3	3	3
	Loose-holding with beds, drained floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Loose-holding with beds, solid floor with tilt	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Deep litter (all)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Deep litter, slatted floor	1	1	1	2	2	3	3	3	4	4	5	5	6	8
	Deep litter, slatted floor, scrapes	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Deep litter, solid floor, scrapes	0	0	1	1	1	1	1	1	1	1	1	1	2	1
	Deep litter, long eating space, solid floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Livestock categories	Housing type	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Dairy cattle	Tethered with liquid and solid manure	30	18	15	12	8	6	12	12	7	6	5	5	4
	Tethered with slurry	30	28	25	23	18	16	14	14	10	9	7	7	6
	Loose-holding with beds, slatted floor	24	34	36	39	42	44	44	44	42	44	45	45	46
	Loose-holding with beds, slatted floor, scrapes	3	3	4	4	5	6	11	11	20	20	21	21	21
	Loose-holding with beds, solid floor	3	6	9	11	16	17	11	11	13	14	14	14	15
	Loose-holding with beds, drained floor	0	0	0	0	0	0	0	0	0	0	0	0	0
	Loose-holding with beds, solid floor with tilt	0	0	0	0	0	0	0	0	1	1	2	2	3
	Deep litter (all)	0	0	0	0	0	0	2	2	2	2	2	2	2
	Deep litter, slatted floor	8	7	7	7	7	7	4	4	2	2	2	2	1
	Deep litter, slatted floor, scrapes	1	1	1	1	1	1	2	2	2	1	1	1	1
	Deep litter, solid floor, scrapes	1	3	3	3	3	3	0	0	0	0	0	0	0
	Deep litter, long eating space, solid floor	0	0	0	0	0	0	0	0	1	1	1	1	1

E) *Continued…*

Heifers:

Livestock categories	Housing type	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Heifer calves, 0-6 mth.	Deep litter (boxes)	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Deep litter, solid floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Heifer calves, 0-6 mth.	Deep litter (boxes)	100	100	100	89	84	83	80	93	93	96	96	96	96
	Deep litter, solid floor	0	0	0	11	16	17	20	7	7	4	4	4	4

Livestock categories	Housing type	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Heifer, 6 mth.-calving	Tethered with liquid and solid manure	25	24	23	22	20	19	18	17	16	14	14	12	11	10
	Tethered with slurry	25	24	23	22	20	19	18	17	16	14	14	12	11	10
	Slatted floor-boxes	45	44	43	42	41	40	39	38	37	36	35	34	33	33
	Loose-housing with beds, slatted floor	0	1	2	2	3	4	4	5	6	7	7	8	10	12
	Loose-holding with beds, slatted floor, scrapes	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Loose-holding with beds, solid floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Loose-holding with beds, solid floor with tilt	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Deep litter (all)	5	4	4	4	4	3	3	2	2	2	1	1	0	0
	Deep litter, solid floor	0	2	4	5	7	9	12	13	14	17	19	22	24	24
	Deep litter, slatted floor	0	1	1	2	3	4	4	5	6	7	7	7	7	6
	Deep litter, slatted floor, scrapes	0	0	0	0	1	1	1	1	1	1	1	1	1	2
	Deep litter, long eating space, solid floor	0	0	0	1	1	1	1	2	2	2	2	3	3	3

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Heifer, 6 mth.-calving	Tethered with liquid and solid manure	10	9	8	7	7	5	6	7	7	6	6	6	5
	Tethered with slurry	10	9	8	7	7	5	4	3	2	2	2	2	2
	Slatted floor-boxes	32	32	31	30	30	29	32	36	39	37	35	35	31
	Loose-housing with beds, slatted floor	13	14	17	20	21	23	19	16	12	14	16	16	19
	Loose-holding with beds, slatted floor, scrapes	0	0	0	0	0	0	2	3	5	6	6	6	7
	Loose-holding with beds, solid floor	0	0	0	0	0	0	2	3	5	6	6	6	7
	Loose-holding with beds, solid floor with tilt	0	0	0	0	0	0	0	0	0	0	0	0	1
	Deep litter (all)	0	0	0	0	0	0	8	15	23	22	22	22	21
	Deep litter, solid floor	24	25	26	26	26	28	19	10	1	1	1	1	1
	Deep litter, slatted floor	6	6	5	5	5	5	4	3	2	2	2	2	2
	Deep litter, slatted floor, scrapes	2	2	2	2	1	2	2	2	2	2	2	2	2
	Deep litter, long eating space, solid floor	3	3	3	3	3	3	2	2	2	2	2	2	2

E) *Continued…*

Bulls:

Livestock categories	Housing type	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Bull calves, 0-6 mth.	Deep litter (boxes)	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Deep litter, solid floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Bull calves, 0-6 mth.	Deep litter (boxes)	100	100	100	91	86	82	77	95	95	97	97	97	97
	Deep litter, solid floor	0	0	0	9	14	18	23	5	5	3	3	3	3

Livestock categories	Housing type	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Bull, 6 mth -440 kg	Tethered with liquid and solid manure	25	24	23	22	21	20	19	17	16	15	14	13	12	11
	Tethered with slurry	25	24	23	22	21	20	19	17	16	15	14	13	12	11
	Slatted floor-boxes	45	44	43	43	42	41	40	40	39	38	37	37	36	35
	Loose-holding with beds, slatted floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Loose-holding with beds, slatted floor, scrapes	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Deep litter (all)	5	5	4	4	3	3	2	2	2	2	1	1	0	0
	Deep litter, solid floor	0	2	4	6	8	10	12	15	17	19	21	22	25	27
	Deep litter, slatted floor	0	1	2	2	3	4	5	6	7	8	8	9	10	11
	Deep litter, slatted floor, scrapes	0	0	0	0	1	1	1	1	1	1	2	2	2	2
	Deep litter, solid floor, scrapes	0	0	1	1	1	1	2	2	2	2	3	3	3	3
	Deep litter, long eating space, solid floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Boxes with sloping bedded floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Bull, 6 mth -440 kg	Tethered with liquid and solid manure	11	10	9	8	8	7	9	9	4	4	3	3	2
	Tethered with slurry	11	10	9	8	8	7	2	2	1	1	1	1	1
	Slatted floor-boxes	34	33	32	31	30	28	31	31	30	30	27	27	25
	Loose-holding with beds, slatted floor	0	0	0	0	0	0	0	0	0	0	0	0	3
	Loose-holding with beds, slatted floor, scrapes	0	0	0	0	0	0	0	0	0	0	0	0	3
	Deep litter (all)	0	0	0	0	0	0	47	47	57	58	60	60	58
	Deep litter, solid floor	29	33	37	41	45	48	8	8	5	4	4	4	4
	Deep litter, slatted floor	10	9	8	7	5	6	1	1	1	1	2	2	1
	Deep litter, slatted floor, scrapes	2	2	2	2	1	1	0	0	1	1	2	2	2
	Deep litter, solid floor, scrapes	3	3	3	3	3	3	2	2	0	0	0	0	0
	Deep litter, long eating space, solid floor	0	0	0	0	0	0	0	0	1	1	1	1	1
	Boxes with sloping bedded floor	0	0	0	0	0	0	0	0	0	0	0	0	0

E) *Continued…*

Suckling cattle:

Livestock categories	Housing type	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Suckling cattle	Tethered with liquid and solid manure	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	Tethered with slurry	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Deep litter (all)	90	87	83	80	76	73	69	66	62	59	55	52	48	45
	Deep litter, solid floor	0	3	7	10	14	17	21	24	28	31	35	38	42	45
	Deep litter, long eating space, solid floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Deep litter, slatted floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Deep litter, slatted floor, scrapes	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Boxes with sloping bedded floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Suckling cattle	Tethered with liquid and solid manure	10	9	8	7	4	5	9	14	18	16	15	15	13
	Tethered with slurry	0	0	0	0	0	0	3	6	9	9	9	9	10
	Deep litter (all)	45	45	44	43	44	43	51	58	66	68	69	69	69
	Deep litter, solid floor	45	46	48	50	52	52	35	19	2	2	2	3	3
	Deep litter, long eating space, solid floor	0	0	0	0	0	0	0	1	1	1	1	1	1
	Deep litter, slatted floor	0	0	0	0	0	0	1	1	1	1	1	1	2
	Deep litter, slatted floor, scrapes	0	0	0	0	0	0	1	1	2	2	2	2	2
	Boxes with sloping bedded floor	0	0	0	0	0	0	0	0	1	1	1	0	0

E) *Continued…*

Swine:

Sows:

Livestock categories	Housing type	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Sows	Full slatted floor	3	5	7	8	10	11	13	13	14	14	15	16	16	16
	Partly slatted floor	50	51	52	54	55	56	57	58	58	59	59	59	60	60
	Solid floor	44	41	38	35	32	29	26	23	21	19	16	14	11	9
	Deep litter	3	3	3	3	3	4	4	4	4	4	5	5	6	6
	Deep litter + slatted floor	0	0	0	0	0	0	0	1	1	2	2	2	3	3
	Deep litter + solid floor	0	0	0	0	0	0	0	1	1	1	2	2	2	3
	Outdoor sows	0	0	0	0	0	0	0	0	1	1	1	2	2	3

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Sows	Full slatted floor	17	17	16	15	14	14	14	14	14	14	15	15	15
	Partly slatted floor	61	59	60	60	59	59	65	70	75	77	77	77	79
	Solid floor	6	6	5	5	5	5	4	3	2	1	1	1	0
	Deep litter	7	7	7	7	7	7	5	4	1	1	1	1	1
	Deep litter + slatted floor	3	4	5	6	7	7	6	5	5	5	4	4	4
	Deep litter + solid floor	3	4	4	5	6	6	4	2	1	1	1	1	1
	Outdoor sows	3	3	3	2	2	2	2	2	2	1	1	1	0

E) *Continued…*
Weaners:

Livestock categories	Housing type	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Weaners	Fully slatted floor	40	43	46	49	51	54	57	60	56	54	51	49	46	43
	Partly slatted floor	20	20	20	20	20	20	20	20	24	27	31	34	37	41
	Solid floor	35	32	29	26	24	21	18	15	14	13	11	9	8	7
	Deep litter (to-climate housings)	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	Deep litter + slatted floor	0	0	0	0	0	0	0	0	1	1	2	3	4	4
	Partly slatted and drained floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Weaners	Fully slatted floor	40	38	36	35	33	31	29	27	26	23	22	22	20
	Partly slatted floor	45	47	49	50	52	54	57	60	63	67	68	68	70
	Solid floor	5	5	5	5	5	5	4	3	1	1	0	0	1
	Deep litter (to-climate housings)	5	5	5	5	5	5	4	4	3	2	2	2	1
	Deep litter + slatted floor	5	5	5	5	5	5	0	0	0	0	0	0	0
	Partly slatted and drained floor	0	0	0	0	0	0	6	6	7	7	8	8	8

E) *Continued…*
Fattening pigs:

Livestock categories	Housing type	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Fattening pigs	Fully slatted floor	29	33	38	42	47	51	56	60	60	60	60	60	60	60
	Partly slatted floor	30	29	27	26	24	23	21	20	21	23	24	25	26	28
	Partly slatted floor (50-75 % solid floor)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Partly slatted floor (25-49 % solid floor)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Solid floor	40	36	33	29	26	22	19	15	14	12	11	9	8	6
	Deep litter	1	2	2	3	3	4	4	5	4	4	3	3	2	2
	Partly slatted floor and partly deep litter	0	0	0	0	0	0	0	0	1	1	2	3	4	4
	Partly slatted and drained floor	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Fattening pigs	Fully slatted floor	60	58	57	56	55	53	53	53	53	53	54	54	53
	Partly slatted floor	29	31	33	34	35	38	0	0	0	0	0	0	0
	Partly slatted floor (50-75 % solid floor)	0	0	0	0	0	0	6	6	6	7	7	7	7
	Partly slatted floor (25-49 % solid floor)	0	0	0	0	0	0	29	29	28	28	27	27	28
	Solid floor	5	5	4	4	4	3	3	4	3	2	2	2	1
	Deep litter	1	1	1	1	1	1	2	3	4	3	2	2	2
	Partly slatted floor and partly deep litter	5	5	5	5	5	5	4	1	1	1	1	1	1
	Partly slatted and drained floor	0	0	0	0	0	0	3	4	5	6	7	7	8

E) *Continued…*

Poultry:

Livestock categories	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Free-range hens	0	0	0	0	0	0	0	2	2	2	5	9	8	8
Organic hens	0	0	0	0	0	0	0	0	0	0	3	5	6	10
Barn hens	2	4	9	7	6	5	8	8	8	11	15	17	17	15
Battery hens, manure shed	20	21	20	22	23	24	25	26	27	28	26	25	26	26
Battery hens, manure tank	15	14	13	13	13	13	12	11	11	10	8	7	7	6
Battery hens, manure cellar	63	61	58	58	58	58	55	53	52	49	43	37	36	35
Hens for production of brood egg	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Pullet, consumption, net	22	21	20	19	18	17	16	15	14	13	12	11	10	8
Pullet, consumption, floor	52	53	54	55	56	57	58	59	60	61	62	63	64	66
Pullet, brood egg, floor	26	26	26	26	26	26	26	26	26	26	26	26	26	26
Broilers, (conv. 30 days)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Broilers, (conv. 32 days)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Broilers, (conv. 35 days)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Broilers, (conv. 40 days)	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Broilers, (conv. 45 days)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Broilers, barn (56 days)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Organic broilers (81 days)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Turkey, male	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Turkey, female	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Ducks	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Geese	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Pheasant	0	0	0	0	0	0	0	2	2	2	5	9	8	8

E) *Continued…*

Livestock categories	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Free-range hens	9	9	9	8	9	7	8	6	6	6	6	7	8
organic hens	12	13	13	14	14	13	14	14	15	16	15	15	16
Barn hens	17	17	17	18	20	23	25	24	20	19	19	17	17
Battery hens, manure shed	26	29	29	33	29	33	32	36	39	42	44	45	45
Battery hens, manure tank	5	5	5	4	5	4	5	6	8	8	7	7	8
Battery hens, manure cellar	31	27	27	23	23	20	16	14	12	9	9	9	6
Hens for production of brood egg	100	100	100	100	100	100	100	100	100	100	100	100	100
Pullet, consumption, net	7	8	7	6	7	5	5	5	7	7	7	7	19
Pullet, consumption, floor	67	69	68	69	68	69	69	69	73	84	78	78	76
Pullet, brood egg, floor	26	23	25	25	25	26	26	26	20	9	15	15	5
Broilers, (conv. 30 days)	0	0	0	0	0	0	0	0	1	0	0	0	0
Broilers, (conv. 32 days)	0	0	0	0	0	0	4	5	1	2	7	3	11
Broilers, (conv. 35 days)	0	0	0	0	0	0	45	41	45	49	57	76	86
Broilers, (conv. 40 days)	100	100	100	100	100	100	49	54	53	49	36	21	3
Broilers, (conv. 45 days)	0	0	0	0	0	0	2	0	0	0	0	0	0
Broilers, barn (56 days)	0	0	0	0	0	0	0	0	0	0	0	0	0
Organic broilers (81 days)	0	0	0	0	0	0	0	0	0	0	0	0	0
Turkey, male	50	50	50	50	50	50	50	50	50	50	50	50	50
Turkey, female	50	50	50	50	50	50	50	50	50	50	50	50	50
Ducks	100	100	100	100	100	100	100	100	100	100	100	100	100
Geese	100	100	100	100	100	100	100	100	100	100	100	100	100
Pheasant	9	9	9	8	9	7	8	6	6	6	6	7	8

E) *Continued…*

Fur farming:

Livestock categories	Housing type	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Mink	Slurry system	10	12	13	15	17	18	20	20	22	23	25	26	27	29
	Solid manure	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Solid manure and urine	90	88	87	85	83	82	80	80	78	77	75	74	73	71
Foxes	Slurry system	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Solid manure and urine	100	100	100	100	100	100	100	100	100	100	100	100	100	100
		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	
Mink	Slurry system	30	42	50	55	60	65	73	80	88	92	95	97	96	
	Solid manure	0	0	0	0	0	0	1	2	3	3	3	3	4	
	Solid manure and urine	70	58	50	45	40	35	26	18	9	5	2	0	0	
Foxes	Slurry system	0	2	5	10	15	30	0	0	0	0	0	0	0	
	Solid manure and urine	100	98	95	90	85	70	100	100	100	100	100	100	100	

Horses, sheep, goats, deer and ostrich:

Horses, sheep, goats and ostrich are all housed in deep litter housings all years 1985-2011.

Deer are on pasture all years 1985-2011

F) Number of grazing days corresponding to the proportion of N in manure deposited on the field during grazing. Days per year

	1985-1990	1991-2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Cattle:											
Dairy Cattle	55	55	46	39	32	25	18	18	18	18	18
Calves and bulls	0	0	0	0	0	0	0	0	0	0	0
Heifers	165	171	180	168	156	144	132	132	132	132	132
-actual days on grass	165	165	152	141	131	121	111	111	111	111	111
Suckling Cattle	184	192	224	224	224	224	224	224	224	224	224

F) *Continued…*

	1985-2011
Swine:	
Sows, weaners and fattening pigs	0
Sows, outdoor	365
Poultry:	
Hens, pullets, Broilers, Turkeys and Ducks	0
Geese, Pheasant and Ostrich	365
Other:	
Horses	183
Sheep and Goats	265
Deer	365
Fur animals	0

G) Nitrogen excretion and ammonia emission according to livestock category 1985 – 2011.

1) Nitrogen excretion distributed on livestock groups.

N-excretion	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
							tonnes N							
Cattle	168 660	164 160	156 186	151 781	150 532	150 413	148 763	145 119	144 330	139 016	138 294	137 784	132 563	130 543
Swine	117 025	120 565	117 899	116 654	113 536	112 451	112 539	116 642	120 872	114 432	107 500	107 494	110 132	116 459
Poultry	7 472	7 820	8 092	9 111	10 211	10 329	10 335	10 949	11 718	13 043	12 271	12 034	11 958	11 798
Horses	6 309	6 264	6 219	6 174	6 129	5 960	5 901	5 839	5 775	5 707	5 637	5 696	5 756	5 815
Sheep	835	1 100	1 248	1 533	1 749	1 947	2 272	2 199	1 907	1 740	1 767	1 891	1 758	1 668
Goats	168	166	164	162	160	159	158	157	156	154	153	139	124	128
Fur animals	10 071	11 397	12 268	14 481	15 066	11 089	10 189	10 952	7 295	8 588	8 608	8 935	10 294	10 893
Deer	144	152	160	160	160	160	160	160	160	160	160	160	160	160
N-excretion total	**310 685**	**311 625**	**302 237**	**300 055**	**297 544**	**292 508**	**290 316**	**292 018**	**292 213**	**282 841**	**274 391**	**274 134**	**272 745**	**277 465**

Continued…

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
							tonnes N						
Cattle	125 194	124 483	124 135	121 951	119 440	116 181	116 328	116 757	120 759	122 811	121 566	122 038	122 490
Swine	116 018	114 607	120 139	126 171	123 142	128 267	124 446	113 785	117 215	109 958	103 016	102 825	103 158
Poultry	12 231	12 171	12 346	12 308	12 506	13 266	12 986	11 469	11 231	11 510	10 934	11 288	10 763
Horses	5 874	5 934	6 131	6 329	6 527	6 725	6 923	7 121	7 319	7 516	7 022	6 527	6 132
Sheep	1 559	1 892	2 010	1 991	2 051	2 105	2 140	2 165	2 098	1 991	1 958	1 881	1 585
Goats	119	143	160	151	164	176	181	191	198	231	257	262	206
Fur animals	9 676	10 169	10 639	11 172	10 886	12 585	13 718	14 026	14 698	14 860	15 005	15 697	15 566
Deer	160	160	170	158	155	155	154	154	155	153	152	152	129
N-excretion total	**270 833**	**269 559**	**275 731**	**280 232**	**274 873**	**279 460**	**276 875**	**265 667**	**273 674**	**269 031**	**259 909**	**260 671**	**260 029**

G) *Continued…*

2) Ammonia emission from animal manure (incl. pasture) distributed on livestock groups.

Ammonia emission	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
	tonnes NH_3-N													
Cattle	35 230	34 152	32 326	31 218	30 803	31 385	30 485	29 240	28 534	27 106	26 468	26 089	24 973	24 384
Swine	36 137	36 969	35 914	35 294	34 094	33 971	33 530	34 253	34 885	32 718	30 051	29 712	30 028	31 401
Poultry	2 510	2 594	2 718	3 034	3 395	3 411	3 462	3 702	3 936	4 334	4 187	4 087	4 105	4 050
Horses	1 099	1 081	1 063	1 046	1 028	998	988	976	964	952	939	947	954	962
Sheep	106	138	156	190	215	239	278	269	233	212	215	230	214	204
Goats	21	21	20	20	20	19	19	19	19	19	19	17	15	16
Fur animals	4 132	4 681	5 041	5 952	6 199	4 578	4 212	4 519	3 013	3 550	3 558	3 694	4 258	4 505
Deer	10	11	11	11	11	11	11	11	11	11	11	11	11	11
Emission total	**79 245**	**79 648**	**77 249**	**76 765**	**75 764**	**74 613**	**72 985**	**72 989**	**71 595**	**68 902**	**65 448**	**64 787**	**64 558**	**65 533**

Continued…

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	tonnes NH_3-N												
Cattle	23 247	23 237	22 307	21 362	21 001	18 712	17 298	17 676	18 005	18 235	17 922	18 083	17 819
Swine	30 661	29 132	29 260	29 722	29 421	30 485	28 998	26 421	25 624	23 841	22 208	22 030	21 826
Poultry	4 212	4 217	4 279	4 270	4 356	4 545	4 456	3 904	3 477	3 560	3 375	3 477	3 354
Horses	989	982	1 016	1 054	1 083	1 113	1 140	1 169	1 126	1 156	1 080	1 004	951
Sheep	192	229	244	242	249	255	258	261	241	229	225	216	183
Goats	15	17	19	18	20	21	22	23	23	27	30	30	24
Fur animals	4 002	4 257	4 451	4 663	4 647	5 167	5 679	5 846	6 065	6 205	6 447	6 695	6 528
Deer	11	11	12	11	11	11	11	11	11	11	11	11	9
Emission total	**63 329**	**62 083**	**61 589**	**61 343**	**60 788**	**60 310**	**57 863**	**55 311**	**54 571**	**53 264**	**51 297**	**51 546**	**50 694**

G) *Continued…*

3) Ammonia emission from manure (incl. pasture) distributed on the different parts of the production.

Ammonia emission	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
							tonnes NH_3-N							
Housing	30 017	30 908	30 589	31 192	31 082	29 504	29 118	29 930	29 203	28 599	27 320	27 278	27 929	28 948
Storage	13 909	13 914	13 380	13 143	12 840	12 464	12 213	12 255	12 289	11 755	11 203	11 042	11 041	11 234
Spreading	32 741	32 306	30 860	30 039	29 458	30 243	29 196	28 343	27 600	26 098	24 433	23 958	23 138	22 911
Pasture	2 579	2 521	2 419	2 390	2 384	2 403	2 459	2 461	2 503	2 449	2 493	2 510	2 451	2 440
Emission total	**79 245**	**79 648**	**77 249**	**76 765**	**75 764**	**74 613**	**72 985**	**72 989**	**71 595**	**68 902**	**65 448**	**64 787**	**64 558**	**65 533**

Continued…

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
							tonnes NH_3-N						
Housing	28 163	28 442	29 498	30 657	30 521	31 934	31 878	30 244	30 559	29 959	28 645	28 818	28 809
Storage	10 812	10 146	10 144	9 764	9 282	9 402	6 961	6 534	4 421	4 324	4 121	4 141	4 109
Spreading	21 963	21 088	19 499	18 565	18 872	17 028	17 201	16 807	17 954	17 338	16 962	17 045	16 283
Pasture	2 391	2 407	2 447	2 357	2 112	1 946	1 823	1 725	1 638	1 643	1 569	1 542	1 493
Emission total	**63 329**	**62 083**	**61 589**	**61 343**	**60 788**	**60 310**	**57 863**	**55 311**	**54 571**	**53 264**	**51 297**	**51 546**	**50 694**

H) N ex animal.

A) Cattle, large breed		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Dairy cows	Total N	125.0	127.3	129.5	131.8	134.0	133.0	132.0	131.0	130.0	129.0	128.0	127.8	127.7	127.5
Bulls[a]	Total N	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3
Heifers[b]	Total N	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2	39.2
Continued		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	
Dairy cows	Total N	127.3	128.0	128.0	130.0	132.8	134.5	136.3	137.4	140.2	140.6	140.9	141.4	141.4	
Bulls[a]	Total N	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3	
Heifers[b]	Total N	39.2	39.2	39.2	39.2	39.2	39.2	43.7	48.1	52.6	52.6	52.6	50.0	50.4	

[a] 6 month to slaughter. Kg N per produced animal.

[b] 6 month to calving.

Continued…

B) Swine		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Sows	Total N	31.9	31.2	30.6	29.9	29.3	28.7	28.1	27.5	26.9	26.3	25.7	26.0	26.2	26.5
Fattening pigs[c]	Total N	5.1	5.0	4.9	4.9	4.8	4.5	4.3	4.0	3.8	3.5	3.3	3.3	3.2	3.2
Weaners[c]	Total N	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Continued		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	
Sows (incl. piglets)	Total N	26.6	26.6	27.2	27.2	27.2	27.2	26.5	26.0	26.4	25.8	26.0	25.1	25.1	
Fattening pigs[c]	Total N	3.2	3.1	3.1	3.3	3.2	3.2	3.2	3.0	3.1	3.0	2.9	2.8	2.8	
Weaners[c]	Total N	0.6	0.6	0.6	0.7	0.6	0.6	0.7	0.5	0.5	0.6	0.5	0.5	0.5	

[c] per. produced animal.

Continued…

C) Poultry		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Battery hens[d]	Total N	61.1	64.6	68.0	71.4	74.9	75.2	75.6	75.9	76.3	76.6	77.0	77.0	77.0	77.0
Broilers[e]	Total N	40.7	40.7	48.3	52.2	56.0	55.2	54.4	53.7	52.9	52.1	51.3	51.3	51.3	51.3
Continued		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	
Battery hens[d]	Total N	76.9	67.1	67.1	67.9	72.5	73.2	77.9	77.9	68.4	69.5	69.5	69.5	69.3	
Broilers[e]	Total N	51.3	53.3	53.3	53.6	53.6	58.1	64.3	64.2	65.5	65.5	65.5	65.0	64.8	

[d] pr. 100 animal. Change in methodology has taken place from N ex per produced hens to N ex per AAP (annual average population – see definition in section 4.1). In this table all years covers N ex per AAP.

[e] pr. 1000 produced animal.

H) *Continued…*

D) Fur animals		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Mink (incl. cubs)	Total N	5.2	5.1	5.0	5.0	4.9	4.8	4.8	4.7	4.7	4.6	4.6	4.6	4.6	4.6
Continued		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	
Mink (incl. cubs)	Total N	4.6	4.6	4.6	4.6	4.6	5.1	5.4	5.2	5.2	5.3	5.5	5.8	5.6	

Sources: Laursen (1994), Poulsen & Kristensen (1997), Poulsen et al. (2001), Poulsen (2012).

l) TAN ex animal.

kg per animal		2007	2008	2009	2010	2011
Cattle						
Dairy cows	TAN	66.67	67.00	65.70	65.69	67.20
Bulls[a]	TAN	16.11	16.11	16.11	16.11	16.11
Heifers[b]	TAN	35.86	35.86	35.86	33.49	33.85
Swine						
Sows	TAN	19.77	19.20	19.34	18.67	18.66
Fattening pigs[c]	TAN	2.04	2.03	1.96	1.87	1.86
Weaners[c]	TAN	0.31	0.33	0.31	0.29	0.29
Fur animals						
Mink	TAN	3.85	3.93	4.11	4.34	4.20

[a] 6 month to slaughter. Per produced animal.

[b] 6 month to calving.

[c] per produced animal.

Source: Poulsen (2012).

J) Ammonia emission factors for housing units.

Swine			Urine TAN	Slurry TAN	Solid manure Total N	Deep litter Total N
	Housing type	Floor or manure type	Pct. loss of TAN ex animal		pct. loss of N ex animal	
Sows	Individual, mating and gestation	Partly slatted floor	-	13	-	-
		Full slatted floor	-	19	-	-
		Solid floor	21	-	16	-
	Group, mating and gestation	Deep litter	-	-	-	15
		Deep litter + slatted floor	-	16	-	15
		Deep litter + solid floor	-	19	-	15
		Partly slatted floor	-	16	-	-
	Farrowing crate	Full slatted floor	-	13	-	-
		Partly slatted floor	-	26	-	-
	Farrowing pen	Solid floor	20	-	15	-
		Partly slatted floor	-	22	15	-
Weaners		Full slatted floor	-	24	-	-
		Drained + Partly slatted floor	-	21	-	-
		Deep litter (two-climate housing)	-	10	-	15
		Solid floor	37	-	25	-
		Deep litter	-	-	-	15
Fattening pigs		Partly slatted floor (50-75 % solid)	-	13	-	-
		Partly slatted floor (25-49% solid)	-	17	-	-
		Drained + Partly slatted floor	-	21	-	-
		Full slatted floor	-	24	-	-
		Solid floor	27	-	18	-
		Deep litter, divided	-	18	-	15
		Deep litter	-	-	-	15

J) *Continued…*

Poultry			Solid manure	Deep litter
			Total N	Total N
	Housing type	Floor or manure type	pct. loss of N ex animal	
Hens and pullets	Free-range, organic and barn	Deep pit	40	25
		Deep litter	-	28
		Manure belt	10	25
	Battery	Deep pit	12	-
		Manure belt	10	-
Broilers	Conventional	Deep litter	-	20
	Organic and barn	Deep litter	-	25
Turkeys, ducks and geese		Deep litter	-	20

J) Continued…

Other	Urine	Slurry	Solid manure	Deep litter
	TAN	TAN	Total N	Total N
	Pct. loss of TAN ex animal		pct. loss of N ex animal	
Fur animals	35	47	35	-
Horses, sheep and goats	-	-	-	15

K) Correction for lack of floating / fixed cover on slurry tanks.

	Emission factor[1] NH_3-N in % of N ex housing-total	Emissions faktor[5] NH3-N in % of TAN ex housing-total	1985-1999[2]	2000-2001[3]	2002[4]	2003-2006[4]	2007-2011[4] TAN
Swine							
No cover	9%	11.4%	40%	20%	10%	5%	5%
Full cover	2%	2.5%	60%	80%	90%	95%	95%
Emission under storage			**4.8%**	**3.4%**	**2.7%**	**2.4%**	**2.9%**
Cattle							
No cover	6%	10.3%	20%	5%	5%	2%	2%
Full cover	2%	3.4%	80%	95%	95%	98%	98%
Emission under storage			**2.8%**	**2.2%**	**2.2%**	**2.1%**	**3.5%**
Fur animals							
No cover		12.9%	20%	5%	5%	2%	2%
Full cover		2.9%	80%	95%	95%	98%	98%
Emission under storage			**4.9%**	**3.4%**	**3.4%**	**3.1%**	**3.1%**

[1] Poulsen et al., 2001.
[2] COWI 1999.
[3] COWI 2000.
[4] Estimate – DCA.
[5] Hansen et al., 2008.

L) Correction for lack of cover on manure heaps.

	Emission factor NH_3-N in % of N ex housing-total	Solid manure 2007-2011
Cattle		
No cover	5%	50%
Full cover	3%	50%
Emission under storage		**4%**
Swine		
No cover	25%	50%
Full cover	13%	50%
Emission under storage		**19%**
Hens		
No cover	10%	50%
Full cover	5%	50%
Emission under storage		**7.5%**
Broilers		
No cover	15%	50%
Full cover	8%	50%
Emission under storage		**11,5%**
Fur animals		
No cover	15%	50%
Full cover	8%	50%
Emission under storage		**11.5%**
Horses, sheep and goats		
No cover	5%	50%
Full cover	3%	50%
Emission under storage		**4%**

M) Estimate of how liquid and solid manure has been handled in practice, 1985-2011.

<u>Cattle and other livestock except from swine:</u>

Liquid manure:

Crop stage	Application time	Lying time	Percent of N ex storage per manure type													
			1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
	<u>Injection</u>	<u>Hours</u>														
-	March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-	April	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
+	March	< week	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+	April	< week	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+	Summer, grass injection	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2
-	Summer, before winter rape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+	Autumn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Autumn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	<u>Hose application</u>															
-	March	4	0	0	0	0	0	0	1	2	3	4	5	7	8	9
-	April	4	0	0	0	0	0	0	1	1	2	2	3	3	4	5
+	March	< week	0	0	0	0	0	0	1	1	2	3	3	4	5	5
+	April	< week	0	0	0	0	0	0	2	3	3	5	6	8	9	11
+	May	< week	0	0	0	0	0	0	1	3	3	5	7	8	10	11
+	Summer	< week	0	0	0	0	0	0	1	2	3	3	4	5	5	4
-	Summer	4	0	0	0	0	0	0	1	1	2	2	3	3	3	2
+	Autumn	< week	0	0	0	0	0	0	0	1	2	3	3	4	4	4
-	Autumn	4	0	0	0	0	0	0	0	1	1	1	2	2	1	1
	<u>Broad spreading</u>															
-	Winter-spring	< 12	26	27	28	29	30	26	25	24	23	22	21	20	18	17
-	Winter-spring	> 12	5	5	5	5	5	5	5	5	5	5	5	5	5	5
-	Winter-spring	< week	15	15	15	15	15	20	20	20	20	20	20	20	18	17
+	Spring-summer	< week	8	8	8	8	8	8	7	6	5	4	3	2	2	2
+	Late summer-autumn	< week	7	7	7	7	7	7	6	5	4	4	3	2	2	1
-	Late summer-autumn	< 12	2	3	3	4	4	4	4	4	4	4	3	3	3	2
-	Late summer-autumn	> 12	8	7	7	6	6	6	5	5	4	3	3	2	1	1
-	Late summer-autumn	< week	29	28	27	26	25	24	20	16	12	8	4	0	0	0
		Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100

- indicate bare soil+ indicate growth.

M) *Continued…*

Crop stage	Application time	Lying time	Percent of N ex storage per manure type												
			1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	Injection	Hours													
-	March	0	1	2	5	8	11	21	20	20	20	21	21	21	25
-	April	0	1	3	5	8	12	21	21	20	20	21	21	21	30
+	March	< week	0	0	0	0	0	0	1	2	3	3	3	3	8
+	April	< week	0	0	0	0	0	0	2	3	4	4	4	4	0
+	Summer, grass injection	0	2	2	3	4	4	5	5	6	6	7	7	7	10
-	Summer, before winter rape	0	0	0	0	0	1	6	6	7	7	7	7	7	3
+	Autumn	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Autumn	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hose application														
-	March	4	10	9	10	10	14	8	8	6	5	3	3	3	0
-	April	4	5	4	5	5	4	2	2	1	1	1	1	1	0
+	March	< week	6	6	7	7	7	5	5	5	4	4	4	4	5
+	April	< week	12	13	18	17	15	10	9	9	9	9	9	9	8
+	May	< week	12	13	18	17	15	10	9	9	9	9	9	9	7
+	Summer	< week	4	4	4	3	3	3	3	3	3	2	2	2	2
-	Summer	4	2	2	3	3	5	5	5	5	5	5	5	5	0
+	Autumn	< week	4	4	5	5	5	4	4	4	4	4	4	4	2
-	Autumn	4	0	0	0	0	0	0	0	0	0	0	0	0	0
	Broad spreading														
-	Winter-spring	< 12	15	14	6	5	2	0	0	0	0	0	0	0	0
-	Winter-spring	> 12	5	4	2	1	0	0	0	0	0	0	0	0	0
-	Winter-spring	< week	15	14	6	4	2	0	0	0	0	0	0	0	0
+	Spring-summer	< week	2	2	1	1	0	0	0	0	0	0	0	0	0
+	Late summer-autumn	< week	1	1	0	0	0	0	0	0	0	0	0	0	0
-	Late summer-autumn	< 12	2	2	1	2	0	0	0	0	0	0	0	0	0
-	Late summer-autumn	> 12	1	1	1	0	0	0	0	0	0	0	0	0	0
-	Late summer-autumn	< week	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total	100	100	100	100	100	100	100	100	100	100	100	100	100

- indicate bare soil+ indicate growth.

M) *Continued…*

Solid manure:

Crop stage	Application time	Lying time	Percent of N ex storage per manure type													
			1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
	Broad spreading															
-	Winter-spring	4	13	16	19	22	25	26	26	27	28	29	29	30	32	33
-	Winter-spring	6	18	16	14	12	10	11	11	12	13	14	14	15	15	15
-	Winter-spring	< week	19	18	17	16	15	14	14	13	12	11	11	10	10	10
+	Spring-summer	< week	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+	Late summer-autumn	< week	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Late summer-autumn	4	13	16	19	22	25	25	25	25	25	25	25	25	25	25
-	Late summer-autumn	6	13	11	9	7	5	5	5	5	5	5	5	5	5	5
-	Late summer-autumn	< week	24	23	22	21	20	19	19	18	17	16	16	15	13	12
		Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Continued…			1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	Broad spreading														
-	Winter-spring	4	35	38	49	54	54	56	57	59	60	60	60	60	70
-	Winter-spring	6	15	14	14	15	15	14	14	13	12	12	12	12	20
-	Winter-spring	< week	10	9	10	11	11	11	10	9	9	9	9	9	0
+	Spring-summer	< week	0	0	0	0	0	0	0	0	0	0	0	0	5
+	Late summer-autumn	< week	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Late summer-autumn	4	25	26	18	13	15	15	16	16	17	17	17	17	5
-	Late summer-autumn	6	5	5	3	2	1	0	0	0	0	0	0	0	0
-	Late summer-autumn	< week	10	9	6	5	4	4	3	3	2	2	2	2	0
		Total	100	100	100	100	100	100	100	100	100	100	100	100	100

- indicate bare soil+ indicate growth.

M) *Continued…*

Swine:

Liquid manure:

Crop status	Application time	Lying time	Percent of N ex storage per manure type													
			1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
	Injection	Hours														
-	March	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
-	April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
+	March	< week	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+	April	< week	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+	Summer, grass injection	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Summer, before winter rape	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2
+	Autumn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Autumn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hose application															
-	March	4	0	0	0	0	0	0	1	1	2	3	4	5	6	6
-	April	4	0	0	0	0	0	0	1	2	3	3	5	5	6	7
+	March	< week	0	0	0	0	0	0	1	1	2	3	4	4	5	5
+	April	< week	0	0	0	0	0	0	1	3	3	6	6	9	10	12
+	May	< week	0	0	0	0	0	0	1	4	4	6	6	9	10	12
+	Summer	< week	0	0	0	0	0	0	1	1	2	3	3	4	4	4
-	Summer	4	0	0	0	0	0	0	1	1	2	2	3	3	3	2
+	Autumn	< week	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Autumn	4	0	0	0	0	0	0	1	2	3	3	5	5	4	3
	Broad spreading															
-	Winter-spring	< 12	26	27	28	29	30	26	25	24	23	22	21	20	18	17
-	Winter-spring	> 12	5	5	5	5	5	5	5	5	5	5	5	5	5	5
-	Winter-spring	< week	15	15	15	15	15	20	20	20	20	20	20	20	18	17
+	Spring-summer	< week	8	8	8	8	8	8	7	6	5	4	3	2	2	2
+	Late summer-autumn	< week	7	7	7	7	7	7	6	5	4	4	3	2	2	1
-	Late summer-autumn	< 12	2	3	3	4	4	4	4	4	4	3	3	3	3	2
-	Late summer-autumn	> 12	8	7	7	6	6	6	5	5	4	3	3	2	2	1
-	Late summer-autumn	< week	29	28	27	26	25	24	20	16	12	8	4	0	0	0
		Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100

- indicate bare soil+ indicate growth.

M) *Continued…*

Crop status	Application time	Lying time	Percent of N ex storage per manure type												
			1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	Injection	Hours													
-	March	0	1	2	5	8	6	6	7	7	8	10	10	10	14
-	April	0	1	3	6	8	7	7	7	8	8	9	9	9	11
+	March	< week	0	0	0	0	0	0	0	1	2	2	2	2	2
+	April	< week	0	0	0	0	0	0	0	2	3	3	3	3	3
+	Summer, grass injection	0	0	0	1	2	1	1	1	1	1	2	2	2	2
-	Summer, before winter rape	0	2	2	2	2	1	1	2	2	2	2	2	2	5
+	Autumn	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Autumn	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hose application														
-	March	4	10	7	7	7	9	8	7	6	4	2	2	2	0
-	April	4	5	7	8	8	9	8	7	6	4	3	3	3	0
+	March	< week	6	6	11	11	13	14	14	14	14	14	14	14	14
+	April	< week	13	14	16	15	20	23	28	30	32	32	32	32	33
+	May	< week	13	14	16	15	21	23	18	14	13	13	13	13	13
+	Summer	< week	4	4	5	5	3	3	3	3	3	2	2	2	1
-	Summer	4	2	2	3	3	3	3	3	3	3	3	3	3	0
+	Autumn	< week	0	0	0	0	0	0	0	0	0	0	0	0	2
-	Autumn	4	2	2	3	3	3	3	3	3	3	3	3	3	0
	Broad spreading														
-	Winter-spring	< 12	15	14	6	5	2	0	0	0	0	0	0	0	0
-	Winter-spring	> 12	5	4	2	1	0	0	0	0	0	0	0	0	0
-	Winter-spring	< week	15	13	6	4	2	0	0	0	0	0	0	0	0
+	Spring-summer	< week	2	2	1	1	0	0	0	0	0	0	0	0	0
+	Late summer-autumn	< week	1	1	1	0	0	0	0	0	0	0	0	0	0
-	Late summer-autumn	< 12	2	2	1	2	0	0	0	0	0	0	0	0	0
-	Late summer-autumn	> 12	1	1	0	0	0	0	0	0	0	0	0	0	0
-	Late summer-autumn	< week	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total	100	100	100	100	100	100	100	100	100	100	100	100	100

- indicate bare soil+ indicate growth.

M) *Continued…*

Solid manure:

Crop stage	Application time	Lying time	Percent of N ex storage per manure type													
			1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
	Broad spreading		13	16	19	22	25	26	26	27	28	29	29	30	32	33
-	Winter-spring	4	18	16	14	12	10	11	11	12	13	14	14	15	15	15
-	Winter-spring	6	19	18	17	16	15	14	14	13	12	11	11	10	10	10
-	Winter-spring	< week	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+	Spring-summer	< week	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+	Late summer-autumn	< week	13	16	19	22	25	25	25	25	25	25	25	25	25	25
-	Late summer-autumn	4	13	11	9	7	5	5	5	5	5	5	5	5	5	5
-	Late summer-autumn	6	24	23	22	21	20	19	19	18	17	16	16	15	13	12
-	Late summer-autumn	< week	13	16	19	22	25	26	26	27	28	29	29	30	32	33
		Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Continued…			1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	Broad spreading		35	38	49	54	54	56	57	59	60	60	60	60	60
-	Winter-spring	4	15	14	14	15	15	14	14	13	12	12	12	12	16
-	Winter-spring	6	10	9	10	11	11	11	10	9	9	9	9	9	0
-	Winter-spring	< week	0	0	0	0	0	0	0	0	0	0	0	0	5
+	Spring-summer	< week	0	0	0	0	0	0	0	0	0	0	0	0	0
+	Late summer-autumn	< week	25	26	18	13	15	15	16	16	17	17	17	17	19
-	Late summer-autumn	4	5	4	3	2	1	0	0	0	0	0	0	0	0
-	Late summer-autumn	6	10	9	6	5	4	4	3	3	2	2	2	2	0
-	Late summer-autumn	< week	35	38	49	54	54	56	57	59	60	60	60	60	60
		Total	100	100	100	100	100	100	100	100	100	100	100	100	100

- indicate bare soil+ indicate growth.

N) Emission of particular matter, 1985-2011.

TSP

Gg TSP	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Animal Category														
Dairy cattle	0.93	0.90	0.85	0.81	0.80	0.80	0.79	0.76	0.76	0.75	0.76	0.76	0.72	0.71
Non-dairy cattle	1.20	1.14	1.07	1.03	1.00	1.01	0.99	0.97	0.95	0.90	0.87	0.87	0.84	0.83
Sheep	0.001	0.002	0.002	0.003	0.003	0.003	0.004	0.004	0.003	0.003	0.003	0.003	0.003	0.004
Goats	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002	0.0003
Horses	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Swine	6.40	6.52	6.46	6.41	6.38	6.58	6.77	7.22	8.07	7.52	7.60	7.40	7.74	8.65
Laying hens	0.31	0.29	0.27	0.30	0.30	0.30	0.28	0.35	0.31	0.40	0.39	0.40	0.37	0.32
Broilers	0.44	0.44	0.50	0.49	0.56	0.51	0.52	0.66	0.70	0.63	0.65	0.67	0.65	0.68
Turkeys	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.02
Other poultry	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TSP total	9.33	9.34	9.20	9.09	9.10	9.25	9.39	10.01	10.85	10.25	10.33	10.16	10.38	11.24

Continued…	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Animal Category													
Dairy cattle	0.68	0.72	0.72	0.72	0.74	0.72	0.73	0.73	0.74	0.76	0.77	0.78	0.78
Non-dairy cattle	0.78	0.76	0.77	0.73	0.45	0.44	0.42	0.43	0.46	0.45	0.44	0.45	0.45
Sheep	0.004	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.003
Goats	0.0003	0.0003	0.0003	0.0003	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0006	0.0006	0.0005
Horses	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03
Swine	8.26	8.47	8.93	9.00	9.13	9.34	9.53	9.37	9.64	8.88	8.52	9.13	8.95
Laying hens	0.37	0.33	0.31	0.30	0.34	0.32	0.38	0.26	0.28	0.35	0.29	0.36	0.40
Broilers	0.78	0.83	0.81	0.79	0.63	0.59	0.62	0.67	0.61	0.51	0.77	0.67	0.65
Turkeys	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.01
Other poultry	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.004	0.004	0.004
Other	0	0	0	0	0	0	0	0	0	0	0	0	0
TSP total	10.92	11.18	11.61	11.60	11.35	11.47	11.74	11.52	11.78	11.01	10.86	11.43	11.29

N) *Continued…*

PM$_{10}$.

Gg PM_{10}	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Animal Category														
Dairy cattle	0.43	0.41	0.39	0.37	0.37	0.37	0.36	0.35	0.35	0.35	0.35	0.35	0.33	0.33
Non-dairy cattle	0.55	0.52	0.49	0.47	0.46	0.47	0.45	0.45	0.44	0.41	0.40	0.40	0.39	0.38
Sheep	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.001	0.001	0.001	0.002	0.002	0.002
Goats	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Horses	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Swine	2.88	2.93	2.91	2.88	2.87	2.96	3.05	3.25	3.63	3.38	3.42	3.33	3.48	3.89
Laying hens	0.31	0.29	0.27	0.30	0.30	0.30	0.28	0.35	0.31	0.40	0.39	0.40	0.37	0.32
Broilers	0.44	0.44	0.50	0.49	0.56	0.51	0.52	0.66	0.70	0.63	0.65	0.67	0.65	0.68
Turkeys	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.02
Other poultry	0.012	0.011	0.010	0.010	0.012	0.010	0.011	0.010	0.010	0.012	0.013	0.009	0.008	0.009
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PM_{10} total	4.64	4.64	4.59	4.55	4.60	4.64	4.70	5.08	5.47	5.20	5.26	5.19	5.27	5.64

Continued…	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Animal Category													
Dairy cattle	0.31	0.33	0.33	0.33	0.34	0.33	0.34	0.34	0.34	0.35	0.36	0.36	0.36
Non-dairy cattle	0.36	0.35	0.36	0.33	0.21	0.20	0.19	0.20	0.21	0.21	0.20	0.20	0.21
Sheep	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Goats	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003	0.0002
Horses	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01
Swine	3.72	3.81	4.02	4.05	4.11	4.20	4.29	4.22	4.34	4.00	3.84	4.11	4.03
Laying hens	0.37	0.33	0.31	0.30	0.34	0.32	0.38	0.26	0.28	0.35	0.29	0.36	0.40
Broilers	0.78	0.83	0.81	0.79	0.63	0.59	0.62	0.67	0.61	0.51	0.77	0.67	0.65
Turkeys	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.01
Other poultry	0.010	0.008	0.009	0.010	0.009	0.009	0.008	0.009	0.005	0.005	0.004	0.004	0.004
Other	0	0	0	0	0	0	0	0	0	0	0	0	0
PM_{10} total	5.57	5.70	5.87	5.84	5.66	5.69	5.86	5.72	5.81	5.44	5.50	5.73	5.68

N) *Continued…*

$PM_{2.5.}$

Gg $PM_{2,5}$	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Animal Category														
Dairy cattle	0.27	0.27	0.25	0.24	0.24	0.24	0.23	0.22	0.23	0.22	0.22	0.22	0.21	0.21
Non-dairy cattle	0.35	0.33	0.31	0.30	0.29	0.30	0.29	0.29	0.28	0.26	0.26	0.26	0.25	0.24
Sheep	0.0002	0.0003	0.0003	0.0004	0.0004	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005	0.0005	0.0005
Goats	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.00003	0.00003	0.00003	0.00003	0.00004
Horses	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Swine	0.47	0.48	0.47	0.47	0.47	0.48	0.50	0.53	0.59	0.55	0.56	0.54	0.57	0.63
Laying hens	0.06	0.05	0.05	0.06	0.05	0.06	0.05	0.06	0.06	0.07	0.07	0.08	0.07	0.06
Broilers	0.06	0.06	0.07	0.06	0.07	0.07	0.07	0.09	0.09	0.08	0.09	0.09	0.09	0.09
Turkeys	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002
Other poultry	0.002	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$PM_{2,5}$ total	1.22	1.20	1.16	1.14	1.14	1.15	1.15	1.20	1.26	1.20	1.21	1.20	1.19	1.25

Continued…	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Animal Category													
Dairy cattle	0.20	0.21	0.21	0.21	0.22	0.21	0.22	0.22	0.22	0.22	0.23	0.23	0.23
Non-dairy cattle	0.23	0.22	0.23	0.21	0.13	0.13	0.12	0.13	0.14	0.13	0.13	0.13	0.13
Sheep	0.0005	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005
Goats	0.00004	0.00004	0.00005	0.00005	0.00005	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Horses	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Swine	0.61	0.62	0.66	0.66	0.67	0.69	0.70	0.69	0.71	0.65	0.63	0.67	0.66
Laying hens	0.07	0.06	0.06	0.06	0.06	0.06	0.07	0.05	0.05	0.07	0.06	0.07	0.08
Broilers	0.10	0.11	0.11	0.10	0.08	0.08	0.08	0.09	0.08	0.07	0.10	0.09	0.09
Turkeys	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002
Other poultry	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.0005
Other	0	0	0	0	0	0	0	0	0	0	0	0	0
$PM_{2,5}$ total	1.22	1.24	1.27	1.26	1.18	1.18	1.21	1.18	1.21	1.16	1.16	1.20	1.20

O) Feeding plans - average feeding level.

Winter feeding plans		Feeding code	Pct. dm	Pct. Crude protein	Pct. Raw fat	Pct. Raw ashes	Pct. Carbon-hydrates	FU per kg dm	kg feed per day	MJ per day	MJ per FU
		AgriFish (2002)									
Heifers:	Straw	781	85.0	4.0	1.9	4.5	89.6	0.2	33.4	571.8	
	Maize silage	593	31.0	8.7	2.2	4.2	84.9	0.9	57.5	1 009.0	
	Toasted soya	155	87.5	49.1	3.2	7.4	40.3	1.4	8.1	161.7	
	Total	-	-	-	-	-	-	-	99.0	1 742.4	**25.8**
Suckling cattle:	Straw	781	85.0	4.0	1.9	4.5	89.6	0.2	1.6	119.1	
Period 1 (2 mth)	Toasted soya	155	87.5	49.1	3.2	7.4	40.3	1.4	3.4	49.6	
	Barley	201	85.0	11.2	2.9	2.2	83.7	1.1	1.8	29.2	
Period 2 (4 mth)	Straw	781	85.0	4.0	1.9	4.5	89.6	0.2	3.2	238.2	
	Toasted soya	155	87.5	49.1	3.2	7.4	40.3	1.4	3.0	29.1	
	Barley	202	85.0	11.2	2.9	2.2	83.7	1.1	3.2	52.0	
	Total	-	-	-	-	-	-	-	15.2	517.1	**34.0**
Horses:	Straw	781	85.0	4.0	1.9	4.5	89.6	0.2	4.0	58.2	
	Hay	665	85.0	12.1	2.6	7.7	77.6	0.6	3.0	44.0	
	Oat	202	86.0	12.1	5.7	2.7	79.5	0.9	2.5	40.1	
	Supplemental		86.4	15.4	4.3	6.6	73.7	1.0	1.0	15.5	
	Total	-	-	-	-	-	-	-	-	157.7	**29.8**
Sheep and Goats:	Straw	781	85.0	4.0	1.9	4.5	89.6	0.2	1.0	14.6	
	Toasted soya	155	87.5	49.1	3.2	7.4	40.3	1.4	0.1	1.8	
	Barley	202	85.0	11.2	2.9	2.2	83.7	1.1	0.4	6.2	
	Grass pills (dried)	707	92.0	17.0	3.1	11.0	68.9	0.6	1.0	15.7	
	Total	-	-	-	-	-	-	-	-	38.2	**30.0**
Summer grazing[1]											
Grazing	Clover grass, 2 weeks old	422	18.0	22.0	4.1	9.4	64.5	1.0	1.0	18.8	
	Total	-	-	-	-	-	-	-	1.0	18.8	**18.8**
Swine:	Full feeding										
	Sows	-	87.1	16.1	5.2	5.5	73.2	1.2	-	64.2	**17.5**
	Weaners	-	87.4	18.8	5.7	5.5	70.0	1.3	-	2.1	**16.5**
	Fattening pigs	-	86.9	17.0	4.7	5.1	73.3	1.2	-	9.6	**17.3**

P)

1) Area grown with sugar beet and maize for feeding, ha.

Area, ha	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Sugar beet for feeding	102 347	93 170	80 979	70 993	60 380	52 927	41 347	37 414	32 188	22 917	17 577
Maize for feeding	18 735	19 164	20 245	26 187	31 269	36 583	41 652	42 701	46 992	48 452	61 493

Continued…	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Sugar beet for feeding	13 302	9 953	7 991	6 233	4 974	4 035	3 819	5 206	5 257	4 118	3 985
Maize for feeding	78 814	95 741	118 267	129 317	131 027	135 245	144 869	159 030	168 917	172 168	173 693

2) Average CH_4 conversion rate (Y_m) – national factor used for dairy cattle and heifer > ½ year 1990 – 2011, %.

Dairy cattle + Heifer > ½ year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Y_m - average	6.78	6.70	6.60	6.51	6.42	6.36	6.26	6.23	6.19	6.11	6.06

Continued…	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Y_m - average	6.03	6.00	5.98	5.97	5.96	5.95	5.95	5.96	5.96	5.95	5.95

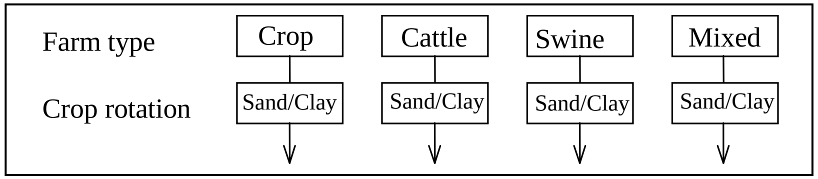
Q) Area for N-fixing crops.

Area, ha	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Legumes to maturity	126 836	144 595	203 604	146 927	122 572	114 354	98 876	118 123	120 295	100 883	74 178	69 158	95 256	106 051
Lucerne	4 189	4 742	4 555	4 608	6 373	8 494	10 810	10 838	11 650	10 629	10 099	11 145	7 342	6 850
Crops for silage	50 629	55 220	47 416	52 819	50 104	47 772	53 621	63 761	68 015	77 696	87 893	58 997	101 124	115 657
Legumes/marrow-stem kale	243 473	177 131	181 671	212 662	154 420	186 217	199 957	116 007	94 678	138 940	154 963	54 449	16 602	28 019
Peas for conservation	11 194	11 716	7 456	7 949	8 992	8 791	8 716	8 723	8 977	6 103	5 529	3 758	3 124	3 962
Seeds of leguminous grass crops	3 138	3 535	3 932	3 835	3 735	2 334	2 017	2 047	2 975	3 555	3 835	2 977	2 848	3 890
Grass and clover in rotation	277 857	263 719	247 327	256 032	252 453	248 815	250 129	255 069	287 109	330 370	238 384	257 398	235 285	249 128
Grass not in rotation	220 564	214 446	210 480	216 775	219 085	217 235	212 030	207 932	197 229	316 668	207 122	192 851	167 600	156 260
Fields with catch crop	NO	NO	NO	NO	NO	232 000	180 000	228 000	231 000	241 000	236 000	258 000	270 000	274 000

Continued…	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Legumes to maturity	65 762	35 590	31 964	40 184	31 356	26 593	15 819	11 353	5 639	4 910	6 332	10 349	7 109
Lucerne	5 514	5 245	3 451	3 566	3 946	4 147	4 575	3 982	3 682	3 756	5 366	6 405	6 926
Crops for silage	117 782	118 763	113 504	112 469	110 089	102 041	75 512	63 998	60 348	52 251	55 851	62 845	56 672
Legumes/marrow-stem kale	25 000	23 000	34 000	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Peas for conservation	4 172	4 149	3 441	2 689	3 386	2 979	2 999	2 841	2 741	3 592	3 737	2 677	2 935
Seeds of leguminous grass crops	4 385	4 603	4 157	3 812	4 271	4 386	5 258	6 274	5 454	4 457	4 542	4 483	3 742
Grass and clover in rotation	238 107	246 656	240 320	218 000	211 950	196 375	253 007	270 840	262 429	300 251	305 889	320 914	329 135
Grass not in rotation	159 530	166 261	173 702	177 546	177 635	172 536	192 968	189 384	196 630	189 962	192 433	199 859	186 652
Fields with catch crop	325 800	309 100	297 200	282 400	190 200	152 700	121 800	115 400	126 000	113 900	115 200	116 600	116 700

R) Model calculation of nitrogen leaching nationwide by SKEP/DAISY and N-LES.

Basic DAISY calculations of N-leaching



<u>Each crop rotation calculates for:</u>
6 climate regions
30 fertilizer plan
4 soil type (here 2 w/w.out water)

} 38.000 combinations

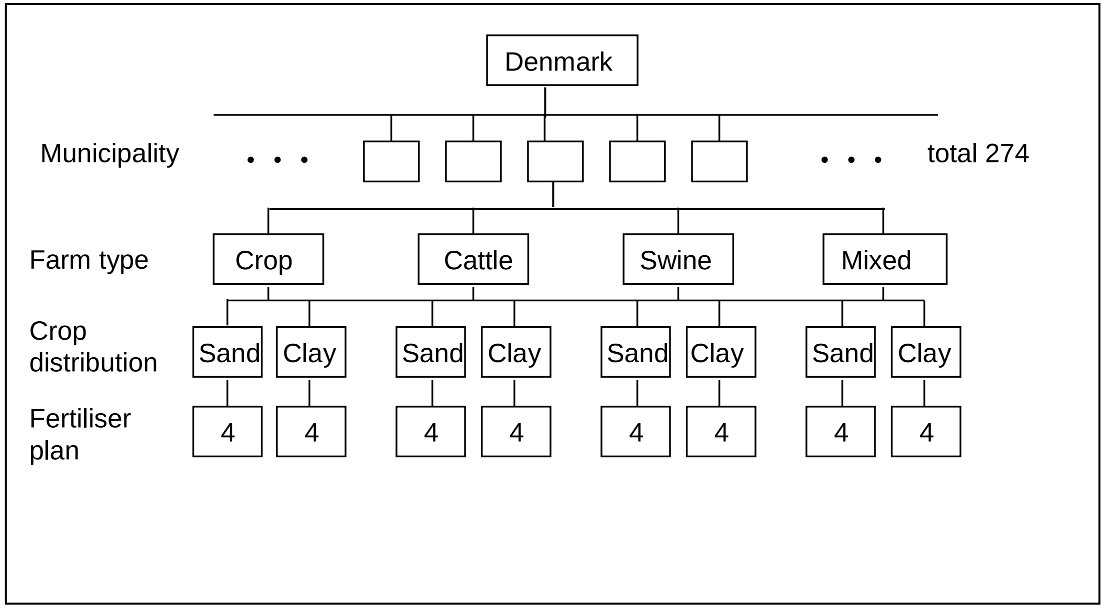
<u>Data base</u>
Calculation for all combinations for each of 4 climate year
Calculation for 12 combinations for each year in an 11 years period (1989-2001).

N-LES calculations

Model calculations for the crop rotations and fertiliser planes in SKEP plus appurtenant percolations from the DAISY calculations. Model calculations for each of the 11 years in the period 1989-2001, mean of the 11 years is up scaled nationwide by SKEP

Up scaling by the SKEP model

In the up scaling of DAISY calculations a climate normalisation and yield correction is made



S) Biogas production.

Production of biogas 1990-2011, and the amount of slurry used.

	Energy production			Estimated M tonnes slurry used in biogas production		Reduction		
	Communal plants T Joule	Farm plants T Joule	Total T Joule	Cattle slurry, 1000 Gg	Pig slurry, 1000 Gg	Gg CH_4	Gg N_2O	CO_2-eq. 1000 Gg CO_2
1990	211	19	230	0.09	0.10	0.088	0.005	0.003
1991	369	19	388	0.14	0.18	0.149	0.008	0.006
1992	449	24	473	0.18	0.21	0.181	0.010	0.007
1993	529	27	556	0.21	0.25	0.214	0.012	0.008
1994	632	26	658	0.24	0.30	0.251	0.014	0.010
1995	745	27	772	0.29	0.35	0.298	0.017	0.011
1996	803	27	830	0.31	0.38	0.321	0.018	0.012
1997	973	32	1005	0.37	0.46	0.386	0.022	0.015
1998	1166	56	1222	0.45	0.56	0.470	0.026	0.018
1999	1183	70	1253	0.47	0.57	0.483	0.027	0.019
2000	1279	129	1408	0.52	0.64	0.539	0.030	0.021
2001	1345	179	1524	0.57	0.69	0.586	0.033	0.023
2002	1403	344	1747	0.65	0.79	0.669	0.038	0.026
2003	1508	625	2133	0.79	0.97	0.818	0.046	0.031
2004	1531	745	2276	0.85	1.03	0.874	0.049	0.034
2005	1593	745	2338	0.87	1.06	0.897	0.051	0.035
2006	1678	907	2585	0.96	1.18	0.995	0.056	0.038
2007	1699	904	2603	0.97	1.18	1.000	0.056	0.038
2008	1739	907	2646	0.99	1.20	1.018	0.057	0.039
2009	1839	1046	2885	1.08	1.31	1.111	0.063	0.043
2010	1839	1046	2885	1.08	1.31	1.111	0.063	0.043
2011	1839	1046	2885	1.08	1.31	1.111	0.063	0.043

Source: Pers. comm.. Søren Tafdrup (The Danish Energy Authority) and own calculations.

T) Emission of different pollutants from field burning of agricultural residue.

Pollutants	Unit	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
NH_3	Gg	1.53	1.32	1.25	0.93	0.98	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.10	0.12
CH_4	Gg	1.72	1.48	1.41	1.05	1.11	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.11	0.14
N_2O	Gg	0.045	0.038	0.036	0.027	0.029	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.004
NO_x	Gg	1.53	1.32	1.25	0.93	0.98	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.10	0.12
CO	Gg	37.58	32.29	30.67	22.93	24.13	1.89	1.97	1.88	2.06	1.98	2.24	2.23	2.37	2.98
CO_2	Gg	966.54	830.46	788.90	589.70	620.62	48.73	50.66	48.44	52.89	51.00	57.72	57.40	60.85	76.60
SO_2	Gg	0.19	0.16	0.16	0.12	0.12	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
NMVOC	Gg	4.02	3.45	3.28	2.45	2.58	0.20	0.21	0.20	0.22	0.21	0.24	0.24	0.25	0.32
PM															
TSP	Gg	3.70	3.18	3.02	2.26	2.38	0.19	0.19	0.19	0.20	0.20	0.22	0.22	0.23	0.29
PM_{10}	Gg	3.70	3.18	3.02	2.26	2.38	0.19	0.19	0.19	0.20	0.20	0.22	0.22	0.23	0.29
$PM_{2.5}$	Gg	3.51	3.01	2.86	2.14	2.25	0.18	0.18	0.18	0.19	0.19	0.21	0.21	0.22	0.28
Metals															
Pb	Tonnes	0.55	0.47	0.45	0.34	0.35	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04
Cd	Tonnes	0.031	0.027	0.026	0.019	0.020	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Hg	Tonnes	0.0051	0.0044	0.0042	0.0031	0.0033	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0004
As	Tonnes	0.037	0.032	0.030	0.023	0.024	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003
Cr	Tonnes	0.140	0.121	0.115	0.086	0.090	0.007	0.007	0.007	0.008	0.007	0.008	0.008	0.009	0.011
Ni	Tonnes	0.113	0.097	0.092	0.069	0.073	0.006	0.006	0.006	0.006	0.006	0.007	0.007	0.007	0.009
Se	Tonnes	0.023	0.020	0.019	0.014	0.015	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002
Zn	Tonnes	0.018	0.015	0.015	0.011	0.011	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Cu	Tonnes	0.0002	0.0002	0.0002	0.0001	0.0001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00002
Dioxin	g I-TEQ	0.38	0.32	0.31	0.23	0.24	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
PAH															
Benzo(a)pyrene	Tonnes	1.78	1.53	1.45	1.08	1.14	0.09	0.09	0.09	0.10	0.09	0.11	0.11	0.11	0.14
Benzo(b)fluoranthene	Tonnes	1.74	1.50	1.42	1.06	1.12	0.09	0.09	0.09	0.10	0.09	0.10	0.10	0.11	0.14
Benzo(k)fluoranthene	Tonnes	0.68	0.59	0.56	0.42	0.44	0.03	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.05
Indeno(1,2,3-cd)pyrene	Tonnes	0.65	0.56	0.53	0.40	0.42	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.04	0.05
HCB	kg	2.22	1.90	1.80	1.33	1.40	0.08	0.08	0.08	0.09	0.08	0.10	0.09	0.10	0.12
PCB	kg	0.002	0.002	0.002	0.001	0.001	0.00002	0.00002	0.00001	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002

T) *Continued…*

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
NH_3	Gg	0.12	0.11	0.12	0.10	0.12	0.13	0.13	0.13	0.11	0.10	0.12	0.09	0.09
CH_4	Gg	0.13	0.13	0.13	0.11	0.13	0.14	0.14	0.14	0.13	0.12	0.14	0.10	0.10
N_2O	Gg	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.004	0.003	0.003	0.004	0.003	0.003
NO_x	Gg	0.12	0.11	0.12	0.10	0.12	0.13	0.13	0.13	0.11	0.10	0.12	0.09	0.09
CO	Gg	2.83	2.79	2.93	2.44	2.93	3.07	3.12	3.16	2.73	2.53	2.98	2.17	2.15
CO_2	Gg	72.77	71.68	75.33	62.66	75.33	78.98	80.14	81.30	70.35	65.15	76.64	55.89	55.32
SO_2	Gg	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.01
NMVOC	Gg	0.30	0.30	0.31	0.26	0.31	0.33	0.33	0.34	0.29	0.27	0.32	0.23	0.23
PM														
TSP	Gg	0.28	0.27	0.29	0.24	0.29	0.30	0.31	0.31	0.27	0.25	0.29	0.21	0.21
PM_{10}	Gg	0.28	0.27	0.29	0.24	0.29	0.30	0.31	0.31	0.27	0.25	0.29	0.21	0.21
$PM_{2.5}$	Gg	0.26	0.26	0.27	0.23	0.27	0.29	0.29	0.30	0.26	0.24	0.28	0.20	0.20
Metals														
Pb	Tonnes	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03
Cd	Tonnes	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002
Hg	Tonnes	0.0004	0.0004	0.0004	0.0003	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003	0.0004	0.0003	0.0003
As	Tonnes	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.002	0.002
Cr	Tonnes	0.011	0.010	0.011	0.009	0.011	0.011	0.012	0.012	0.010	0.009	0.011	0.008	0.008
Ni	Tonnes	0.009	0.008	0.009	0.007	0.009	0.009	0.009	0.009	0.008	0.008	0.009	0.007	0.006
Se	Tonnes	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001
Zn	Tonnes	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001
Cu	Tonnes	0.00001	0.00001	0.00001	0.00001	0.00001	0.00002	0.00002	0.00002	0.00001	0.00001	0.00002	0.00001	0.00001
Dioxin	g I-TEQ	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02
PAH														
Benzo(a)pyrene	Tonnes	0.13	0.13	0.14	0.12	0.14	0.15	0.15	0.15	0.13	0.12	0.14	0.10	0.10
Benzo(b)fluoranthene	Tonnes	0.13	0.13	0.14	0.11	0.14	0.14	0.14	0.15	0.13	0.12	0.14	0.10	0.10
Benzo(k)fluoranthene	Tonnes	0.05	0.05	0.05	0.04	0.05	0.06	0.06	0.06	0.05	0.05	0.05	0.04	0.04
Indeno(1,2,3-cd)pyrene	Tonnes	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.04	0.04
HCB	kg	0.12	0.12	0.12	0.10	0.12	0.13	0.13	0.13	0.11	0.11	0.12	0.09	0.09
PCB	kg	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002

U) QA/QC procedure, stage I – III.

Stage I: Check of input data	**Variable**	**Reference**
Livestock production	- number of animal	DSt
	- slaughter data	
Normative figures	- N-excretion	DCA
	- use of straw	
	- amount of manure	
	- feed intake	
	- milk yield	
Housing types	- distribution	DAAS + DAFA
Grazing days		DAAS
Crops	- land use	DSt
	- crop yield	
	- crop production	
Synthetic fertiliser	- N-content	DAFA
	- fertiliser types	
N-leaching	- amount of nitrogen leached	DCE
Atmospheric deposition	- all NH_3 emission sources	DCE – NH_3 inventory
Sewage sludge and industrial waste	- Amount of sludge applied to soils	EPA + DAFA
Stage II: Check of IDA data – overall	**Emission source**	**Variable**
Recalculation	- CO_2 eqv. total emission	- compared with latest submission
	- CH_4, N_2O, NMVOC	
	- emission from field burning	
Time series	- CO_2 eqv. total emission	- trends
	- CH_4, N_2O, NMVOC	- jumps and dips
	- emission from field burning	
Stage III: Check of IDA data – specific	**Emission source**	**Variable**
CH_4	- enteric fermentation	- IEF (jumps and dips)
		- Ym (dairy cattle + heifer)
		- GE
CH_4	- manure management	- IEF (jumps and dips)
		- VS
		- biogas
N_2O	- manure management	- trends (jumps and dips)
		- IEF
		- biogas
N_2O	- synthetic fertiliser	- trends (jumps and dips)
		- IEF
N_2O	- animal waste applied to soil	- trends (jumps and dips)
		- IEF
N_2O	- N-fixing crops	- trends (jumps and dips)
		- IEF
N_2O	- crop residue	- trends (jumps and dips)
		- IEF
N_2O	- pasture, range and paddock	- trends (jumps and dips)
		- IEF
N_2O	- atmospheric deposition	- trends (jumps and dips)
		- IEF
N_2O	- N-leaching and run-off	- trends (jumps and dips)
		- IEF
N_2O	- sewage sludge + industrial waste	- trends (jumps and dips)
		- IEF
NMVOC	- crops	- trends (jumps and dips)

DANISH EMISSION INVENTORIES FOR AGRICULTURE

Inventories 1985 – 2011

Regulations in international conventions obligate Denmark to prepare annual emission inventories and document the methodologies used to calculate emissions. The responsibility for preparing the emissions inventory for agriculture is undertaken by the Danish Centre for Environment and Energy (DCE), Aarhus University, Denmark.

This report contains a description of the emissions from the agricultural sector from 1985 to 2011 and includes a detailed description of methods and data used to calculate the emissions, which is based on international guidelines as well as national methodologies. The emission is calculated by using an Integrated Database model for Agricultural emissions (IDA), which covers all aspects of the agricultural inputs and estimates both greenhouse gases and air pollutants; methane (CH_4), nitrous oxide (N_2O), ammonia (NH_3), particulate matter (PM), non-methane volatile organic compounds (NMVOC) and other pollutants, which mainly are related to the field burning of agricultural residue such as NO_x, CO_2, CO, SO_2, heavy metals, dioxins, PAHs, HCB and PCBs. The largest contribution to agricultural emissions originates from livestock production, which is dominated by production of cattle and swine. The agricultural NH_3 emission from 1985 to 2011 has decreased from 116 800 tonnes NH_3 to 71 300 tonnes NH_3, corresponding to a reduction of approximately 39 %. The emission of greenhouse gases in 2011 is estimated at 9.7 million tonnes CO_2 equivalents and reduced from 13.4 million tonnes CO_2 equivalents in 1985. Since 1990, which is the base year of the Kyoto protocol a reduction of 23 % is obtained. Improvements in feed efficiency, the utilisation of nitrogen in livestock manure and a significant decrease in the consumption of synthetic fertiliser are the most important explanations for the reduction of NH_3. This has furthermore resulted in a significant reduction of N_2O emission, which is the main reason for a considerable fall in the total greenhouse gas.

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