National Environmental Research Institute
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Emission of ammonia, nitrous oxide and methane from Danish Agriculture 1985-2002

Methodology and Estimates

Research Notes from NERI, no. 231

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2006

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Data sheet

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Abstract: The National Environmental Research Institute in Denmark, NERI, has the responsibility of estimating and reporting the annual Danish air emissions. This report describes the methodology for the Danish emission inventories for ammonia, methane and nitrous oxide from Danish agriculture and the estimated emissions from 1985-2002. The methodology and estimates are used to meet the Danish obligations and reporting under the Gotheborg protocol, the EU National Emission Ceiling directive and to the UN Framework on Climate Change Convention, UNFCCC. The estimation is based on national methodologies as well as international guidelines. The Danish ammonia emission from agriculture has been reduced from 138,400 tonnes ammonia in 1985 to 98,300 tonnes in 2002, corresponding to a reduction of 29%. At the same time there has been a reduction in green house gases from 13.79 M tonnes CO_2-eq./year to 10.15 M CO_2-eq./year The most important factors for the reductions are implementation of turf legislations, which obligate the farmers to utilize nutrients in manure and decrease the consumption of mineral fertilisers.

Keywords: Agriculture, emission, ammonia, methane, nitrous oxide, model, inventory, Denmark

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Preface

The Danish National Environmental Research Institute (NERI) prepares the Danish atmospheric emission inventories and reports the results on an annual basis to the Climate Convention and to the UNECE Convention on Long-Range Transboundary Air Pollution. This report forms part of the documentation for the inventories and covers emissions of ammonia and green house gases from the agricultural sector. The results of inventories up to 2002 are included in this report. It is a translation into English of the Danish version 'Opgørelse og beregningsmetode for landbrugets emissioner af ammoniak og drivhusgasser' Research notes no. 204 from NERI.

Besides the annual reporting this report include the methodology used. The methodology is especially important in cases where national values are used instead of the standard values as given in the guidelines based on EMEP/CORINAIR Emission Inventory Guidebook (EEA 2004), IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual (IPCC 1996) and IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000)). National data are used whenever possible but only in cases where the national data are found to be more precise and can be documented. This is especially valid for nitrogen excretion levels for animals, feed consumption, nitrogen content in crops and nitrogen leaching.

This report has been sent for comments at the Danish Agricultural Advisory Service, The Danish Environmental Protection Agency, Danish Forest and Nature Agency and The Ministry of Food, Agriculture and Fisheries which all has given valuable contributions. Special thanks given to persons within Danish Institute of Agricultural Sciences and National Environmental Research Institute which has been very helpful with knowledge and data in connection to this report. This is particularly Torben Hvelplund, Arne Kyllingsbæk, Jørgen Djurhuus, Ib Sillebak Kristensen and Christian Duus Børgesen from DIAS and Ruth Grant and Gitte Blicher-Mathiasen from NERI.

Summary

By regulations given in international conventions Denmark is obliged to work out an annual emission inventory and document the methodology used in the inventory. The National Environmental Research Institute (NERI) in Denmark is responsible for preparing the emission inventory. The first section of this report contains a description of the emission from the agricultural sector from 1985 to 2002. The second part of the report includes a detailed description of methods and data used to calculate the emissions.

The emission from the agricultural sector includes emission of ammonia (NH_3) and the greenhouse gases methane (CH_4) and nitrous oxide (N_2O).

The emission inventory in this report differs from previous emission inventories. The calculated emission is based on an integrated model with an improved methodology. The model covers all aspects of the agricultural inputs and estimates both the emissions of ammonia and greenhouse gases. The input data related to the livestock population and land use is based on data from Statistics Denmark, Danish standards for livestock production and fodder consumption from the Danish Institute of Agricultural Science, nitrogen content in crops from animal feed Figures and the amount of nitrogen runoff and leaching from estimations developed in preparing for the Danish Water Action Plan III. The emission inventory is adjusted to reflect the Danish agricultural production. In cases where no Danish data is available default values recommended by the Climate Panel (IPCC)[1] are used.

The ammonia emission from 1985 to 2002 has decreased from 138.400 tonnes of NH_3 to 98.300 tonnes NH_3, corresponding an approximately 30% reduction. The main part of the ammonia emission is related to the livestock manure. In 2002 the emission from swine and cattle contributed to the total ammonia emission with 53% and 33% respectively.

The emission of greenhouse gases in 2002 is estimated to 10.15 M tonnes CO_2-equivalents. From 1985 the emission has decreased from 13.79 M tonnes CO_2-equivalents, which corresponds to a 26% reduction. From 1990, which is the base year of the Kyoto protocol, the emission from the agricultural sector has decreased by 21%.

The emission of methane is primarily related to the cattle and swine production, which contribute to the total GHG emission with 70% and 26% respectively. The methane emission in 2002 is estimated to 180.3 Gigagram (Gg) or given in CO_2- equivalents 3.79 M tonnes.

The emission of nitrous oxide originates from the nitrogen turnover in the agricultural fields. The main sources are related to the use of livestock manure, synthetic fertiliser and the nitrogen run-off and leaching.

[1] Intergovernmental Panel on Climate Change

The emission of N_2O in 2002 is estimated to 20.53 Gg N_2O corresponding to 6.36 M tonnes CO_2- equivalents.

Biogas plants using animal slurry reduce the emission of methane and nitrous oxide. The methods to estimate the reduced emission are not yet described in the IPCC guidelines. The calculation is based on the amount of treated slurry and the content of volatile solid and nitrogen. In 2002 the emission reduction due to biogas production is estimated to 0.03 M tonnes CO_2- equivalents.

Improvements in utilisation of nitrogen in livestock manure and the following lower consumption of synthetic fertiliser are the most important reasons for the reduction of both the ammonia and greenhouse gas emission. From 1990 there are almost no changes in the emission of methane. A decrease in the cattle production caused a decrease in the emission. But, on the other hand, the emission has increased due to changes in stabling systems towards more slurry. By coincidence the decrease and the increase balance so the emission trend is about zero.

The CO_2 emission from land use, land use changes and liming of agricultural soils are not included in the emissions inventory from the agricultural sector. According to the IPCC guidelines this emission should be included in the LULUCF sector (Land-Use, Land-Use Change and Forestry). This CO_2 emission is included in the inventories from year 2005 (submission 2003) under the LULUCF sector reported to Climate Convention. The emissions are based on results from a project worked out in co-operation between NERI, the Danish Institute of Agricultural Science and the Danish Centre for Forest, Landscape and Planning (Gylden-kærne et al., 2005).

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 omfatter derfor dels en opgørelse, og dels en beskrivelse af metoden for beregning af landbrugets emissioner af ammoniak (NH_3) samt drivhusgasserne metan (CH_4) og lattergas (N_2O). Opgørelsen omfatter perioden fra 1985 til 2002.

Denne opgørelse adskiller sig fra tidligere opgørelser, ved at emissionerne for de forskellige stoffer er indarbejdet i et samlet modelkompleks, med forbedrede opgørelsesmetoder, og derfor afviger opgørelserne fra det som tidligere er afrapporteret. Modellen er baseret på data for husdyrproduktion og areal-anvendelse fra Danmarks Statistik, danske normtal for husdyrproduktionen angivet af Danmarks JordbrugsForskning, afgrødernes kvælstofindhold fra fodermiddeltabellen og udvaskningsberegningerne foretaget i forbindelse med VMP III. Emissionsopgørelsen er således tilpasset de forhold der gør sig gældende for den danske landbrugsproduktion. For de områder hvor der ikke forefindes nationale data anvendes Klimapanelets (IPCC)[2] anbefalede værdier.

Ammoniakemissionen sker i forbindelse med omsætningen af kvælstof. Størstedelen af emissionen kommer fra husdyrgødning, hvor svin og kvæg i 2002 bidrager med henholdsvis 53% og 33%. Den samlede emission er opgjort til 80.800 tons kvælstof (NH_3-N) i 2002, hvilket svarer til 98.300 tons ren ammoniak (NH_3).

Emissionen af metan stammer primært fra kvæg (70%) og svin (26%). Den samlede emission af metan er opgjort til 180,3 gigagram (Gg) i 2002 svarende til 3,79 mio. tons CO_2-ækvivalenter.

Emissionen af lattergas er relateret til de steder hvor der sker en omsætning af kvælstof. Heraf bidrager handels- og husdyrgødning samt udvaskningen med størstedelen af emissionen. Den samlede emission i 2002 er opgjort til 20,53 Gg N_2O, svarende til 6,36 mio. tons CO_2-ækvivalenter.

Anvendelse af husdyrgødning i biogasanlæg reducerer emissionen af metan og lattergas. Metoden for hvordan dette skal opgøres, er ikke beskrevet i guidelines - udarbejdet af IPCC - hvorfor den reducerede emission er opgjort på baggrund af danske antagelser. Anvendelse af gylle i biogasanlæg er i 2002 beregnet til at reducere udslippet af drivhusgasser med 0,03 mio. tons CO_2-ækvivalenter.

2 Intergovernmental Panel on Climate Change

Den samlede emission af drivhusgasser fra landbruget, opgjort i CO_2-ækvivalenter, er fra 1985 til 2002 faldet fra 13,79 mio. tons til 10,15 mio. tons, hvilket svarer til en samlet reduktion på 26%.

Lavere forbrug af handelsgødning og en bedre udnyttelse af kvælstofindholdet i husdyrgødningen er de væsentligste forklaringer på reduktionen af såvel ammoniak- som drivhusgasemissionen. Der er ikke sket en væsentlig ændring i emissionen af CH_4 siden 1990. Faldet i antallet af kvæg har medvirket til en reduktion i CH_4-udledningen, mens ændringer i staldtypefordelingen i retning af flere dybstrøelsessystemer har haft en modsatrettet virkning.

I emissionsopgørelsen fra landbrugsektoren indgår ikke emissionen af CO_2 fra dyrkning af landbrugsjord. Ifølge IPCC guidelines skal emissionen herfra angives som kilde under sektor for skov og ændringer i arealanvendelse (LUCF – Land-Use Change and Forestry). CO_2-emissionen er indarbejdet i LUCF i indrapportering til Klimakonventionen fra år 2005 (opgørelse af emission for år 2003). Metoden for opgørelse af CO_2-emissionen er baseret på samarbejde mellem Danmarks Miljøundersøgelser, Danmarks JordbrugsForskning og Skov & Landskab, KVL (Gyldenkærne et al., 2005).

1 Introduction

Denmark, as signatory to international conventions, is under an obligation to prepare annual emission inventories for a range of polluting substances. As far as agriculture is concerned, the emissions to be calculated are ammonia (NH_3) and the greenhouse gases, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Denmark's National Environmental Research Institute (NERI) is responsible for preparation and reporting of the annual emission inventory. The largest part of the calculations is based on data collected from Statistics Denmark, the Danish Institute of Agricultural Sciences (DIAS) and the Danish Agricultural Advisory Service (DAAS). In addition to the reporting itself, Denmark is obliged by the conventions to document the calculation methodology. This report, therefore, includes both a review of the emissions in the period 1990 – 2002 and a description of the methodology on which calculation of the emissions is based.

The 1999 Gothenburg Protocol, under the UNECE Long-range Transboundary Air Pollution Convention, and the EU's NEC Directive on national emission ceilings commit Denmark to reduce ammonia emissions to 69,000 tonnes NH_3 by 2010 at the latest. The emission ceiling does not relate to the emission of ammonia from crops, themselves, or ammonia-treated straw. In 2002, 97 percent of the total ammonia emission in Denmark came from the agricultural sector. The remainder came from traffic and industrial processes. The report, here, represents a revised version of an earlier report on the subject of ammonia emissions (Andersen et al., 2001a) and a description of the basis for the calculations.

Denmark has ratified the Kyoto Protocol under the Climate Convention and is committed to reduce the emission of greenhouse gases, measured in CO_2-equivalents, by 21 percent from the level in the base year of 1990 to the first commitment period 2008-2012. In 2002, 16 percent of the total emission of greenhouse gases in Denmark, measured in CO_2-equivalents, came from the agricultural sector. The relatively large contribution is due to the emission of methane and nitrous oxides from the sector. These gases have a significantly more powerful global warming effect than CO_2. Measured in GWUs (Global Warming Unit), the effect from CH_4 and N_2O is 21 and 310 times stronger than that from CO_2, respectively.

The UN's climate panel (IPCC) has issued protocols on how the emission of greenhouse gases should be calculated (IPCC 1996, 2000). The protocols contain guidelines for use in all countries based on a division of different climatic regions in different geographic locations. The guidelines, however, do not always represent the best method at the level of the individual country due to the range of specific local conditions found at this level. The IPCC, therefore, advocates the use, as far as possible, of national Figures for the areas where data is available.

A good basis for calculation of the emissions from the agricultural sector for Denmark is provided by making use of Danish statistics and a comprehensive task of calculation of normative values for fodder consumption and nitrogen separation in relation to livestock husbandry (Poulsen et al. 2001, Poulsen & Kristensen 1997, Laursen 1994), the nitrogen content in crops (Kristensen, 2003; Kyllingsbæk, 2000; Høgh-Jensen et al., 1998), as well as calculation of the effect of the national plans for the water environment (Børgesen & Grant, 2003).

Generally, the IPCC's guidelines are based on livestock numbers to be in accordance with international statistics. For livestock from which meat is produced, the Danish normative calculations are based on the number of livestock produced. The Danish normative values are used to calculate an emission which is based on actual levels of production in the Danish agricultural sector.

Agricultural emissions are calculated in an overall national model complex (DIEMA)[3] as recommended in the IPCC guidelines. This means that the calculation of ammonia and greenhouse gas emissions share the same base, i.e. the number of livestock, the distribution of types of livestock housing, fertiliser type, etc. Changes in the emission of ammonia will, therefore, have knock-on effects with regard to changes in the level of nitrous oxide.

The emission inventory has been improved continuously with the arrival of new knowledge. This means that over time adjustments will be made with regard to both emission factors and methodology in IPCC guidelines as well as in the national inventories. In the emissions inventory, the aim is to use national data as far as possible. This sets high requirements for the documentation of data, especially in areas where the method used and the national data differ widely from the IPCC's recommended standard values.

The report starts with an introductory overview of emissions in the period from 1985 to 2002, describing the changes in agricultural activities which have influenced emissions. Thereafter, the DIEMA model used to calculate the emissions is described and a detailed review of how the emissions for the individual sources are calculated is provided.

3 Danish Integrated Emission Model for Agriculture

2 Agricultural emissions 1985-2002

2.1 Ammonia

The emission of ammonia from agricultural activities was calculated at 113,800 tonnes ammoniacal nitrogen (NH_3-N) in 1985, which is equivalent to approximately 138,400 tonnes of pure ammonia (NH_3) (DMU 2004a). Since 1985, the emission of ammonia has fallen and, for 2002, is calculated at a level of 80,800 tonnes NH_3-N and 98,300 tonnes NH_3. Therefore, the emission of ammonia has decreased by 29 percent over the period. A large part of the reduction can be attributed to the increasing focus on raising livestock's utilisation of the nitrogen present in feedstuffs as well as the increasing integration of nature and environmental protection in agricultural production. This sharpened focus has expressed itself via a range of measures, for example, the NPO Action Plan (1996), Plans for the Water Environment (1987 and 1988) and the Action Plan for Sustainable Agriculture (1991). These measures have included, among other things, requirements for more rapid breakdown of animal manure and reduced applications of fertilisers to crops.

Figure 1 shows the development in the ammonia distribution according to the various sources. It can be seen that the reduction in the emission of ammonia can chiefly be attributed to a decrease in the emission from livestock production, while the emission from commercial fertilisers and crops contributes with a lower share of the reduction. The emission in connection with ammonia treatment of straw has reduced considerably and, from 1 August 2004 – as a result of livestock regulations (BEK no. 604 of 15/7-2002), this activity is no longer permitted. The emission from slurry (semi-liquid manure) and the burning of surplus straw (banned since 1990) represents less than 1 percent of the total ammonia emission.

In Appendix B, ammonia emission levels for the various sources are listed for the period 1985 to 2002. The emission is calculated for both ammoniacal nitrogen and pure nitrogen.

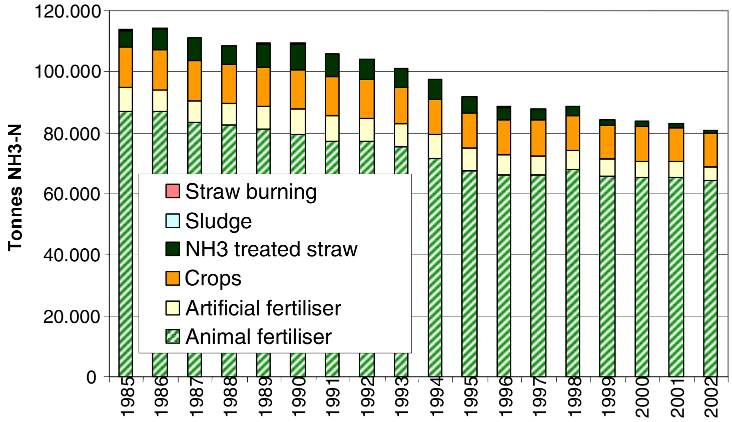

Figure 1 Ammonia emissions in the agricultural sector, 1985 to 2002

2.1.1 Ammonia emission from animal manure

As the ammonia emission from animal manure constitutes the largest source, the emission reductions are largely solely dependent upon developments in livestock production and the relevant conditions surrounding the handling of fertiliser. Appendix B shows N-separation for livestock production in the period from 1985 to 2002 as well as the ammonia emission distributed according to the different categories of livestock.

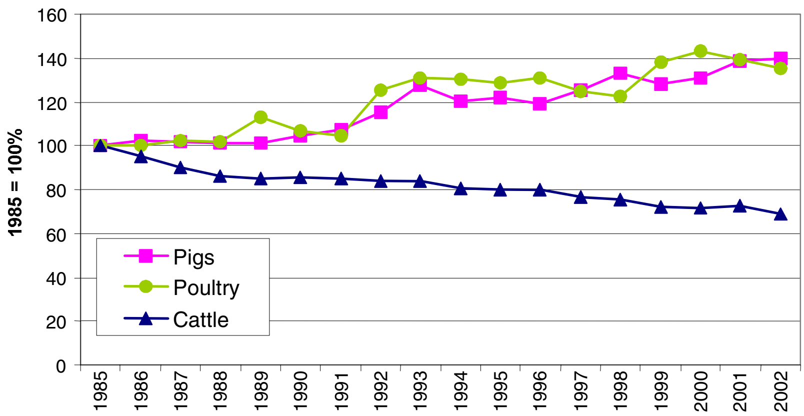

Figure 2 Development in livestock production of cattle, pigs and poultry 1985 – 2002 (Statistics Denmark)

In Figure 2 the relative development in livestock production in the period 1985 to 2002 is presented for cattle, pigs and poultry production. The development is based on calculation from Statistics Denmark, where production in 1985 is set at 100 percent. The population of dairy cattle has fallen as a result of the rise in milk yield. On the other hand, poultry and pig production has increased considerably. Since 1985, pork production has increased from 15.1 million to 23.7 million animals in 2002.

The ammonia emission from pig production contributes to around half the overall ammonia emission from animal manure. Despite the relatively high increase in pig production, the emission from the production of pigs has reduced over the same period. One of the most important reasons for this is the concomitant marked improvement in feed efficiency. In Table 1, it can be seen that N-separation per pig produced in the period from 1985 to 2002 has been reduced by approximately 35 percent.

Table 1 N-separation for slaughter pigs – N ex animal (kg N per pig produced)

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
	N ex Animal																	
Slaughter pigs	5.09	5.01	4.94	4.86	4.78	4.53	4.28	4.03	3.78	3.53	3.28	3.25	3.21	3.18	3.15	3.12	3.12	3.25

Furthermore, a change in the distribution of livestock housing types has also contributed significantly to the reduction in ammonia emissions. An increasing number of pigs are housed on full slatted flooring, where the emission is lower in comparison to housing systems with solid flooring.

Figure 3 shows the distribution of the ammonia emission from fertilisers in the housing unit, in storage, under field application and during grazing.

The level of emissions from livestock housing units and storage has been relatively constant over the period from 1985 to 2002, although a slight decrease can be seen over the period from the mid-1980s to the beginning of the 1990s. The emissions here are dependent on factors such as the scale of production and degree of N-separation, hereunder feed efficiency, housing-type distribution and type of cover on slurry tanks. As mentioned above, developments in the distribution of housing types for pigs has led to a decrease in ammonia emissions. On the contrary, changes in the types of housing for cattle have led to increases in emissions as a result of the increased use of deep litter systems, where the emission is higher than with older tethering stalls.

The fall in ammonia emissions should also be examined in the context of the application of animal manure. Changes in practices here have resulted in a significant contribution to the fall witnessed in the overall ammonia emission. From the beginning of the 1990s a continuously rising proportion of slurry has been spread with drag hoses and from the late 1990s the proportion of slurry injected or mechanically incorporated into the soil under application has increased. For 2002 it is estimated that up to 21 percent is applied using injection/incorporation techniques (Dansk Agriculture (Dansk Landbrug), 2002), giving rise to a significant reduction in ammonia emissions.

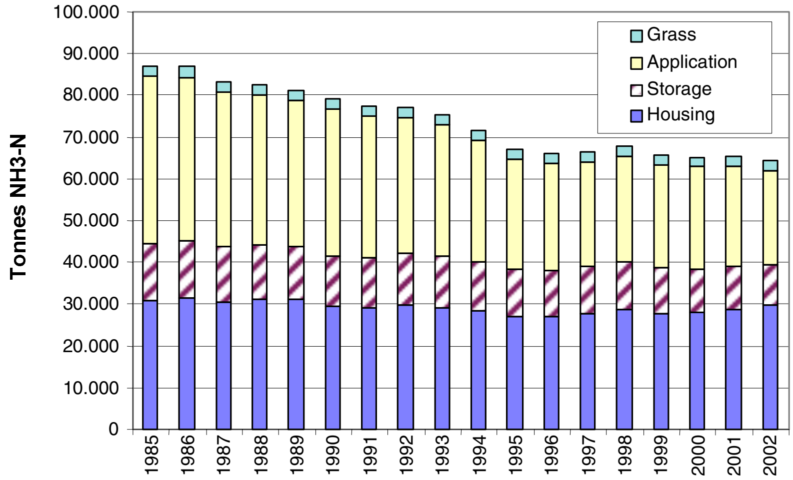

Figure 3 Ammonia emission from animal manure 1995 to 2002

In order to achieve further reductions in the evaporation of ammonia it must be expected that greater attention has to be focused on technological options to reduce the ammonia emission associated with management of animal manure in the housing unit and in storage.

2.1.2 Ammonia emissions from the field

In relation to the ammonia emission from the cultivation of agricultural land, application of mineral fertilisers and the growing crops, themselves, represent the largest contributors.

Studies have demonstrated that ammonia can be emitted from crops, themselves (Schjoerring & Mattsson 2001), and this emission is therefore included in the Danish emission inventory in a worst-case scenario situation. Some uncertainty exists with regard to the assessment of how much ammonia is emitted from crops under different geographic and climatic conditions. This is evidently likely to be the reason that the emission from crops are not included in the emissions ceiling, whether in the Gothenburg Protocol or in the NEC Directive. The emission is following a downward trend due to the fall in agricultural area.

As a result of the increasing requirements with regard to the utilisation of nitrogen in animal manure, the use of mineral fertilisers has decreased significantly. The amount of nitrogen applied in mineral fertilisers in 2002 was halved compared with the situation in 1985.

2.2 Greenhouse gases

Table 2 shows the development in the emission of greenhouse gases measured in CO_2-equivalents. The overall emission calculated in CO_2-equivalents has been calculated at 13.79 million tonnes, falling to 10.15 million tonnes in 2002, corresponding to a 26 percent reduction (DMU 2004b). Since 1990, the Kyoto Protocol's base year, the emission has been reduced by 21 percent. Nitrous oxide has the most powerful global warning effect and represents the largest contribution to the overall emission of greenhouse gases.

Table 2 Development in the emission of greenhouse gases 1985-2002 measured in M tonnes CO_2-equivalents

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Red.
CH_4	4.31	4.17	4.00	3.89	3.87	3.85	3.88	3.89	3.98	3.94	3.94	3.96	3.88	3.92	3.80	3.82	3.86	3.79	12%
N_2O	9.48	9.27	9.08	8.89	8.89	8.98	8.83	8.53	8.31	8.10	7.90	7.56	7.48	7.45	7.01	6.76	6.62	6.36	33%
Total	**13.79**	**13.44**	**13.07**	**12.78**	**12.76**	**12.83**	**12.71**	**12.42**	**12.29**	**12.04**	**11.84**	**11.52**	**11.35**	**11.37**	**10.81**	**10.58**	**10.48**	**10.15**	**26%**

2.2.1 Methane emissions

The largest part of the methane emission comes from livestock's digestion processes and a lesser contribution comes from handling animal manure. From 1985 to 1989 a further contribution came from the burning of surplus straw on fields. In Table 3 the development in methane emissions between 1985 and 2002 is presented. It can be seen that from 1990 to 2002 there has largely been no change in the emission from livestock production.

Table 3 CH_4 emission 1985-2002, Gg CH_4 per year

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Digestive processes	168.4	162.2	153.8	148.7	146.6	147.6	147.4	145.4	146.9	146.3	146.3	146.7	141.9	142.3	137.1	136.5	137.6	133.2
Animal manure	34.1	33.7	34.2	34.5	34.9	35.8	37.5	40.0	42.4	41.4	41.4	42.0	42.6	44.4	43.7	45.4	46.4	47.1
-effect of biogas plants	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.8
Straw burning	2.9	2.5	2.4	1.9	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Gg CH_4	205.4	198.4	190.3	185.1	184.3	183.4	184.9	185.4	189.3	187.7	187.6	188.7	184.5	186.6	180.9	181.9	184.0	180.3
Total CO_2-equiv. M tonnes*	**4.31**	**4.17**	**4.00**	**3.89**	**3.87**	**3.85**	**3.88**	**3.89**	**3.98**	**3.94**	**3.94**	**3.96**	**3.88**	**3.92**	**3.80**	**3.82**	**3.86**	**3.79**

* This CH_4 calculation includes animals bred for their fur. Due to the phrasing of the reporting requirements in relation to the Climate Convention, the emission from these animals is not included in the national inventory. New reporting requirements will be taken into use in the next reporting phase, where the opportunity will be present to include this category of animal.

In the period 1985 to 2002 the emission of methane from digestion processes in livestock reduced by 32.5 Gg CH_4 due to smaller cattle numbers. On the other hand, the emission from animal manure has increased 12.1 Gg CH_4 due to an increase in pig production and changes in housing type. Structural change in the industry and increased focus on animal welfare has led to a greater number of cows being housed in loose-housing and pigs on slatted flooring, where a greater proportion of the slurry is used as fertiliser. This has led to an increase in the emission of methane as liquid manure has an emission factor 10 times higher than solid manure. This development has meant that, despite a decrease in the number of cattle, the CH_4 emission has only reduced by 2 percent.

The burning of surplus straw was banned by legislation in 1990. Exception can be made in the case of grass seed production and dispensation can be given in years characterised by high rainfall. The extent of the practice is no longer considered to be of a size which affects the overall methane emission and, therefore, has not been included in the emissions inventory since 1990.

Reductions in the emission of methane resulting from the biogas treatment of slurry are taken into account in the calculations. Approximately 4 percent of slurry was treated in this way in 2002.

2.2.2 Nitrous oxide emissions

The emission of N_2O occurs in the chemical transformation of nitrogen and, therefore, is closely linked with the handling of animal manure and the ammonia emission. Data used in the calculation of ammonia emissions relates to that used in the calculation of N_2O emissions.

In Table 4 the development in the emissions of nitrous oxide in the period 1985 to 2002 is presented. Between 1990 and 2002 the emission of nitrous oxide has decreased from 29.0 Gg N_2O to 20.5 Gg N_2O, which corresponds to a 29 percent reduction.

The emission of nitrous oxide comes from a range of different sources – see Table 4. The largest part of the emission occurs in connection with handling of animal manure and mineral fertilisers being applied in the field and from the leaching of nitrogen. Since 1985 a marked decrease in the emission from these sources has occurred due to reductions in use of mineral fertilisers and the associated reduction in the leaching of nitrogen. Furthermore, a strengthening of the rules for the utilisation and management of animal manure has taken place.

The emission from the way in which animal manure is handled in the housing units and in storage has decreased due to the fall in N-separation and changes in the type of housing used. In contrast to the situation with methane emissions, changes in housing system types whereby more of the livestock are housed on slurry collection-based systems, has led to a lower N_2O emission as the emission for liquid manure is lower than that for solid manure.

The emission associated with atmospheric deposition represented 6 percent of the overall N_2O emission in 2002. The reduction in the emission of ammonia has been instrumental in the fall in the emission of N_2O.

The emission from the remaining sources has largely remained unchanged in the period 1985 to 2002. The emission from crops left on the field after harvest has increased slightly as a result of the 1990 ban on the burning of surplus straw. A slight reduction is seen in the emission of N_2O from nitrogen-fixing crops since 1999 as a consequence of the lower area with grass and clover under cultivation as well as the reduction in the cultivation of legumes to maturity.

Tabel 4 Emission of N_2O according to source 1985-2002, Gg N_2O per year

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Handling of animal manure	2.29	2.28	2.22	2.23	2.25	2.21	2.20	2.22	2.21	2.15	2.09	2.09	2.10	2.14	2.07	1.98	1.91	1.95
Grazing	1.08	1.06	1.01	1.00	1.00	1.01	1.03	1.03	1.05	1.03	1.04	1.05	1.02	1.01	0.99	0.99	1.01	0.96
Mineral fertiliser	7.67	7.36	7.35	7.07	7.26	7.69	7.59	7.10	6.39	6.25	6.06	5.58	5.53	5.44	5.05	4.83	4.49	4.05
Application of animal manure	3.76	3.75	3.62	3.58	3.57	3.51	3.52	3.56	3.62	3.50	3.41	3.45	3.42	3.50	3.43	3.40	3.48	3.58
Application of sludge	0.07	0.07	0.07	0.07	0.08	0.09	0.11	0.13	0.18	0.17	0.18	0.18	0.16	0.17	0.15	0.17	0.21	0.22
Atmospheric deposition	1.79	1.79	1.75	1.71	1.72	1.72	1.66	1.64	1.59	1.53	1.45	1.39	1.38	1.40	1.33	1.32	1.31	1.27
N-leaching	11.92	11.63	11.34	11.04	10.75	10.50	10.24	9.99	9.74	9.49	9.23	8.62	8.35	8.13	7.56	7.05	6.84	6.59
N-fixation	0.80	0.79	0.75	0.81	0.79	0.88	0.77	0.65	0.83	0.79	0.73	0.71	0.86	0.95	0.77	0.76	0.71	0.66
Crop residues	0.90	0.89	0.88	0.89	0.97	1.13	1.10	0.95	0.98	0.99	1.08	1.10	1.08	1.08	1.05	1.08	1.11	1.03
Organogenic soils	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Straw burning	0.07	0.06	0.06	0.05	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reduction due to biogas production	n.c.	n.c.	n.c.	n.c.	n.c.	-0.00	-0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.02
Total Gg N_2O	30.58	29.92	29.28	28.69	28.68	28.98	28.47	27.50	26.82	26.13	25.49	24.38	24.13	24.03	22.61	21.79	21.35	20.53
Total CO_2-equiv. M tonnes CO_2*	**9.48**	**9.27**	**9.08**	**8.59**	**8.89**	**8.98**	**8.83**	**8.53**	**8.31**	**8.10**	**7.90**	**7.56**	**7.48**	**7.45**	**7.01**	**6.76**	**6.62**	**6.36**

* In the N2O emission reported to the Climate Convention, the reduction resulting from biogas treatment of slurry is not included. The reduction represents less that 1 percent of the overall emission and will be included in the emissions inventory for 2003.

2.2.3 Emission of NMVOC

Non-methane Volatile Organic Compounds (NMVOC) do not constitute actual greenhouse gases, however, are included in the UNECE's reporting requirements for emissions inventories. The emission of NMVOC has an indirect effect on greenhouse processes. An estimate of the emission from crops and grass is included in the emission inventory. Emission factors are based on assessments carried out in the beginning of the 1990s (Fenhann & Kilde 1994, Priemé & Christensen 1991). There is a need for review of the emission factors used and adjustments, as necessary.

Agriculture contributed with 1.21 Gg NMVOC in 2002, corresponding to 1 percent of the overall national NMVOC emission. From 1985 the emission has reduced due to a decrease in the land area used for agricultural purposes.

3 Review of agricultural emissions

Calculations of agricultural emissions are continuously revised in the light of new knowledge and information concerning the data upon which the calculations are based. This means that inventories published earlier do not always agree with the values given in this report. In the following text, a short description of the most important changes occurring in recent years is provided and the implications for the calculation of the overall emission of ammonia and greenhouse gases from the agricultural sector.

3.1 Ammonia

In the autumn of 2002, amendments were made which resulted in increases in the emission in the years 1985-1999 (Illerup et al. 2002) in relation to previously published results (Andersen et al. 2001a). The most important change arose as a result of revision of the estimates relating to manure spreading practices (DMU 2003, DJF 2002). Due to the greater area with winter crops, it is estimated that a higher proportion of slurry is applied to crops which are in growth without the fertiliser not being subsequently incorporated in the soil. This has led to an increase in the overall ammonia emission of between 2 percent and 9 percent dependent on the individual year in question (Table 5).

Table 5 Changes in the calculation of the ammonia emission 1985-1999 in relation the previous inventory calculations

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	1,000 tonnes NH^3-N														
Latest inventory[2]	113.8	114.2	111.4	108.8	109.3	109.3	105.9	104.2	101.1	97.6	92.0	88.6	88.1	88.9	84.5
Earlier inventory[1]	110.8	110.9	108.0	105.0	105.4	105.0	101.3	98.9	95.6	91.5	85.6	81.6	80.9	81.4	77.2
Difference	2.9	3.2	3.4	3.8	3.9	4.4	4.5	5.3	5.6	6.1	6.5	7.0	7.2	7.5	7.3
Difference (pct.)	**3**	**3**	**3**	**4**	**4**	**4**	**4**	**5**	**6**	**7**	**8**	**9**	**9**	**9**	**9**

[1] Andersen et al. 2001a. Ammonia emission from agriculture since the middle of the 1980s – NERI Technical Report nr. 353
[2] Inventory for the ammonia emission - reported to the UNECE, Jan. 2004 (http://www2.dmu.dk/1_Viden/2_miljoe-tilstand/3_luft/4_adaei/Tables/NH3.html)

3.2 Greenhouse gases

In connection with the reporting of greenhouse gas emissions to the UNFCCC in April 2004, a reassessment of the calculation method made in collaboration with the Danish Institute of Agricultural Sciences (DIAS) was undertaken which resulted in an improvement of the model calculations for the greenhouse gases emission in the agricultural sector. This work has resulted in recalculation of the emissions for the years 1985 to 2001, where the level of agricultural emissions is lower than stated in previous inventories. In any case, emissions have fallen from 1990, which is the Kyoto Protocol's base year, to 2001 by approximately 20 percent, which corresponds with the reduction in earlier calculations.

The most important changes in the calculations for methane emissions are that account is taken of changes in fodder intake and house-type distribution based on Danish normative Figures (Laursen 1994, Poulsen & Kristensen 1994, Poulsen et al. 2001). In the future, the emission will similarly be calculated from the updated normative values. This means that the emission factor will vary from year to year depending on changes in fodder intake and housing-type distribution.

In the case of nitrous oxide emissions, the method for calculating the emission from residual crop material on the field and the data for the emission from nitrogen-fixing crops and nitrogen leaching have been amended based on the latest calculations in connection with the final evaluation of the Action Plan for the Aquatic Environment II (VMP II).

In Table 6 the recalculated emissions are compared with those from earlier inventories. Here, it is seen that the fall in the emission of CH_4 evident in the earlier Figures, from 1990 to 2001, is not evident in the recalculated Figures. The emission declined due to the reduction in the population of dairy cattle, however, this reduction is countered by the increase in the emission associated with the handling of animal manure following the change to slurry collection-based housing systems where the emission of CH_4 is higher.

The reduction in the N_2O emission remains largely the same as in the earlier calculations, however, the level of the total emission is stated at a somewhat lower level, which is chiefly a result of changes in the calculation of the emission from residual crop material. In the recalculations, national data for the nitrogen content of crop residues is used.

Table 6 Changes in the calculation of greenhouse gas emissions 1990-2001 in relation to earlier inventory Figures

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Reduction 1990-2001	
	M tonnes CO_2-equiv.													
Recalculation[1]														pct.
Total emission	**12.8**	**12.7**	**12.4**	**12.3**	**12.0**	**11.8**	**11.5**	**11.3**	**11.4**	**10.8**	**10.6**	**10.5**	**2.4**	**18**
CH_4	3.8	3.9	3.9	4.0	3.9	3.9	4.0	3.9	3.9	3.8	3.8	3.8	0.0	0
N_2O	9.0	8.8	8.5	8.3	8.1	7.9	7.6	7.5	7.4	7.0	6.8	6.6	2.4	26
Earlier calculation[2]														
Total emission	**14.3**	**14.1**	**13.4**	**13.6**	**13.2**	**13.1**	**12.8**	**12.4**	**12.5**	**12.1**	**11.9**	**11.6**	**2.8**	**19**
CH_4	4.1	4.1	4.0	4.1	4.0	4.0	4.0	3.9	3.9	3.6	3.6	3.6	0.5	11
N_2O	10.3	10.0	9.4	9.5	9.2	9.1	8.8	8.5	8.6	8.5	8.3	7.9	2.3	23
Difference	-1.5	-1.4	-1.0	-1.3	-1.1	-1.3	-1.3	-1.0	-1.1	-1.3	-1.3	-1.1		
	Percent													
Difference	**11**	**10**	**8**	**10**	**9**	**10**	**10**	**8**	**9**	**11**	**11**	**9**		

[1] Reported to UNFCCC in April 2004
[2] Reported to UNFCCC in April 2003

4 Methodology for calculating emissions from the agricultural sector

4.1 Data references

Emissions inventories are prepared by Denmark's National Environmental Research Institute (NERI). Data used in the inventories is collected, assessed and discussed in collaboration with a range of different institutions involved in agricultural research or administration. For example, organisations include Statistics Denmark, the Danish Agricultural Advisory Service, the Danish Environmental Protection Agency and the Danish Plant Directorate.

Table 7 provides an overview of the various institutions and organisations who contribute with data in connection with preparation of the emissions inventory for the agricultural sector.

Table 7 Parties involved in the preparation of the emissions inventory

National Environmental Research Institute (Danmarks Miljøundersøgelser)	NERI (DMU)	- reporting - data collection
Statistics Denmark Danmarks Statistik	(DSt)	- number of livestock - milk production - data re. slaughtered livestock - land-use - crop yield
Danish Institute of Agricultural Sciences Dansk JordbrugsForskning	DIAS (DJF)	- N-separation - feed intake - growth - N-fixing crops - crop residues - N-leaching - emission factors for NH_3
Danish Agricultural Advisory Service, National Centre (Dansk Landbrugsrådgivning, Landscentret)	DAAS (DLR)	- housing types - grazing - application of animal manure
Danish Environmental Protection Agency Miljøstyrelsen	DEPA (MST)	- sewage or industrial sludges applied to agricultural land
Danish Plant Directorate Plantedirektoratet	(PD)	- organically cultivated land area - consumption of mineral fertileisers - feedstuff analyses
Other: Danish Association of Agricultural Contractors (Danske Maskinstationer) Danish Energy Agency (Energistyrelsen)		- amount of injected-/mechanically incorporated slurry - amount of biogas-treated slurry

4.2 Methodology

Preparation of the emissions inventory is, in the case of ammonia, based on the guidelines prescribed in the "EMEP/CORINAIR Emission Inventory Guidebook" (EEA 2004). In the case of greenhouse gases, the basis for inventory preparation is the guidelines described by the Climate Panel, "IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual" (IPCC 1996) and "IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories" (IPCC 2000).

The overall emission is calculated as the sum of a number of activities (a) multiplied by an average emission factor for each activity (emf).

$$E_{total} = \sum a_i \bullet emf_i$$

A model complex called DIEMA (Danish Integrated Emission Model for Agriculture) is used to calculate the emissions of ammonia and greenhouse gases. An overview of the model complex is illustrated in Figure 4.

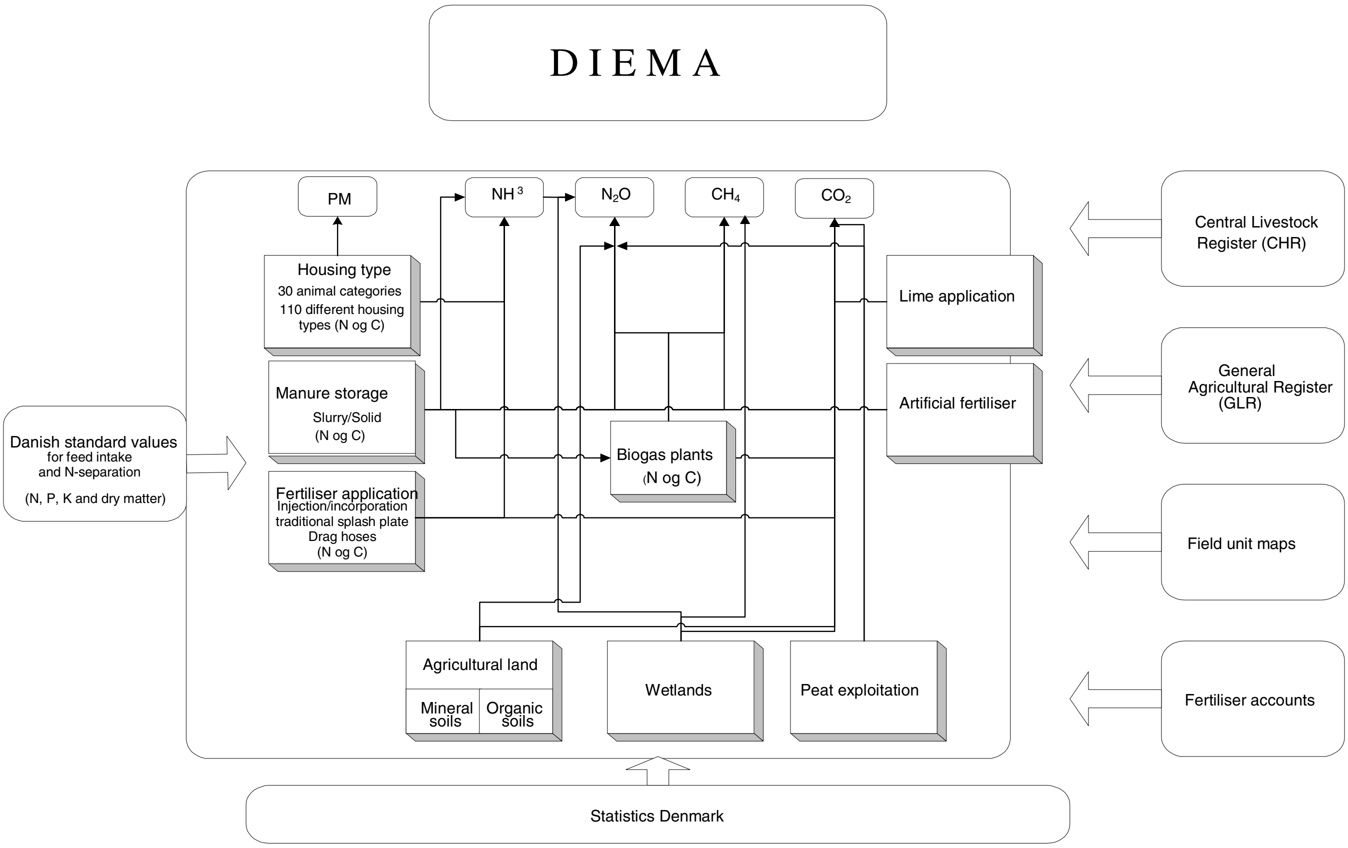

Figure 4 DIEMA – model for calculating the emissions from the agricultural sector (Danish Integrated Emission Model for Agriculture)

The largest part of the emissions is related to livestock production. In DIEMA, distinction is made between approximately 30 livestock categories according to breed and weight class divisions. Each category is further divided according to housing-type and this subcategory is determinant for the way in which the manure is handled. The result is 110 different sub-categories. For each of the livestock categories, the emission is calculated on the basis of information on livestock numbers from Statistics Denmark and feed consumption normatives prepared by the Danish Institute of Agricultural Sciences.

Livestock production is the most important parameter for the emission of both ammonia and greenhouse gases. In the text to follow, a description of the way in which the scale of livestock production is calculated is provided as well as a description of housing-type distribution.

4.3 Livestock production

Livestock production is based on data from Statistics Denmark. Livestock numbers are either calculated as the number of years' livestock units[1] or the number of animals produced in a particular year. For pigs and poultry bred for meat, production is based on the number of animals slaughtered and mortality during the breeding process and export are taken into account.

4.3.1 Cattle

Cattle are divided into 6 main categories in which distinction is made between large breed and Jersey cattle (Table 8). Each of the categories is further divided according to 11 different housing systems.

Data according to the distinction between large breed and Jersey cattle has, until 2000, been collected via special calculations from Statistics Denmark. From 2001, however, the percentage of Jersey cattle has come from the Danish Cattle Federation (Dansk Kvæg, 2003), based on registrations from yield control exercises which cover approximately 85 percent of dairy cattle.

Table 8 Categories of cattle

	Proportion of Jersey cattle (%) in the total dairy cattle population 2002 [1]
Bull calves, 0-6 months	4.2
Bulls, 6 months to slaughter age	6.6
Breeding calves, 0 - 6 months	9.4
Breeding calves, 6 months to calving	8.5
Dairy cows	12.2
Sucklers	

[1] Source: Danish Agriculture (Danish Agricultural Advisory Service -DAAS)

Dairy cattle

The number of dairy cattle is based on the number of year's livestock units which equates to the number of dairy cattle listed by Statistics Denmark.

The normative values for bulls and breeding animals distinguish between calves less than 6 months, bull calves over 6 months for slaughter

1 Year's livestock unit. A livestock animal present on the farm establishment for 365 feed days - e.g. year's sow.

and heifers over 6 months to be used for breeding purposes. In order to be able to calculate the emission, the number of animals has to be quantified for each of the respective subcategories.

Bulls

Data from Statistics Denmark is used to quantify the number of bulls produced each year, including calves both from dairy and beef cattle. This assumes that the distribution of cattle between dairy cows and suckler cows is approximately the same as that within calves, which was 16.5 percent in 2002. The number of bull calves from sucklers is counted under the category of calves, large breed.

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

The number of bulls produced per year is calculated in the following way:

Number of bulls from sucklers:

$$no._{bulls from sucklers} = \text{bull calves}_{DSt} * \text{sucklers}_{DSt} / (\text{sucklers}_{DSt} + \text{dairy cows}_{DSt})$$

Example from 2002 for bull calves < ½ year:

$$23{,}041 = 139{,}755 * 0.165$$

Number of calves

$$\text{no.}_{\text{bulls,lge breed}} = (\text{bull calves}_{DSt} - \text{no.}_{\text{bulls from suckler}}) * (1 - \text{Jersey}_{\text{pct}})) + \text{no.}_{\text{bulls from suckler}}$$

$$\text{no.}_{\text{bulls,Jersey}} = (\text{bull calves}_{DSt} - \text{no.}_{\text{bulls from suckler}}) * \text{Jersey}$$

Example for 2002 for the number of bull calves, big breed < ½ year:

$$134{,}453 = ((139{,}755 - 23{,}041) * (1 - 0.0042)) + 23{,}041$$

Bulls are slaughtered, on average, after 382 days which means that the overall production time is comprised of ½ year + 200 days. In calculation of the annual production of bulls < ½ year, the population from Statistics Denmark is multiplied by 365/182.5 and for bulls > ½ year the sum is multiplied by 365/200.

Number of bull calves produced per year:

$$no._{\text{bulls,<½ year}} = \text{no.}_{\text{bulls,<½ year}} * \frac{365}{182.5}$$

$$\text{no.}_{\text{bulls,>½ year}} = \text{no.}_{\text{bulls,>½ year}} * \frac{365}{200}$$

Heifer calves

The number of heifers produced annually is calculated on the basis of the proportion of total number of breeding heifers. The number is calculated as the population of heifers stated in Statistics Denmark multiplied by the reciprocal value of the share of the production time (Poulsen et al. 2001). This special methodology is due to that the normative Figures from Poulsen et al. (2001) for feed indtake and N excretion are based on an average share of the heifer calves into two groups (< ½ year and > ½ year). This methodology is used in Denmark to make it easier for the farmers to calculate the total farm N excretion rate. In future the normative Figures will be changed so the represent the actual number of the heifers as given in Statistics Denmark. This change will not affect the emission estimates.

Heifers (large breed) calve, on average, after 28 months and the share of production time where cows are < ½ year equates, therefore, to 0.2148 (approx. 6/28). The share of production time where heifers, large breed, are < ½ year is 0.7852 (approx. 22/28). Jersey heifers calve, on average, after 25 months and the proportions for < ½ year and > ½ year are 0.2405 and 0.7595, respectively.

Example for the number of heifer calves < ½ year produced:

$$\text{no.}_{\text{heifers,large breed<½year}} = (\text{heifers} < \text{½ year}_{DSt\,*}(1 - \text{Jersey}_{\text{pct}})) * (1/0.2148)$$

$$\text{no.}_{\text{heifers,Jersy<½year}} = (\text{heifers} < \text{½year}_{DSt} * (\text{Jersey}_{\text{pct}})) * (1/0.2148)$$

Example from 2002 for the number of heifer calves (large breed) < ½ year produced:

$$712{,}100 = ((168{,}819 * (1 - 0.094)) * 1/0.2148$$

4.3.2 Pigs

In the case of pigs, three different main categories are distinguished between; year's sows (including young pigs up to 7.2 kg), weaners pigs (7.2 to 30 kg) and slaughter pigs.

Sows

The normative feed intake and excretion values for year's sows include suckling pigs, breeding boars and mated young pigs (from average slaughter weight). The number of year's sows is calculated as the population of gestating, lactating and dry sows included in the agricultural statistics compiled by Statistics Denmark. It is assumed that the number of new young boars and female pigs equates to the number that are delivered to the slaughter house. The increase in the number of these pigs is included in the calculation of meat production.

Number of year's sows:

$$\text{no.}_{\text{sows}} = \text{pregnant}_{DSt} + \text{suckling}_{DSt} + \text{dry sows}_{DSt}$$

Example from 2002 for the number of year's sows:

1,128,100 = 856,079 + 221,476 + 41,500

Weaners pigs and slaughter pigs

The production of weaners and slaughter pigs is calculated on the basis of slaughter data from the agricultural statistics from Statistics Denmark. In addition to the number of animals delivered to the slaughterhouse, slaughter undertaken for the farmer, home-slaughter, population shifts, deaths occurring in the production process and, as mentioned above, additions of young boars and sows are all taken into account.

The normative feed intake and excretion values for slaughter pigs are based on a 100 kg live weight, equivalent to 76.3 kg slaughter weight. The number of meat producing livestock units per year is calculated as the total amount of meat produced divided by 76.3 kg. In order to calculate the number of slaughter pigs produced which corresponds to N-separation from the normative Figures, in 2002, 23.7 million slaughter pigs are produced in 2002 (see Table 9). The situation with regard to the number dying during production is incorporated in the normative values.

On the basis of slaughter data from Statistics Denmark's agricultural statistics, it has been calculated that, in 2002, 24,187 thousand young pigs were included in the production (Table 9). In calculation of the number of young pigs, an average death rate of 3.6 percent during the production process itself is taken into account (Poulsen et al., 2001). Division by 2 takes place to take into account that mortality, on average, takes place half-way through the production period.

Number of meat-producing units:

$$\text{no. meat producing units}_{\text{slaughter pigs}} = \frac{\text{amount of meat produced}}{76.3\,\text{kg}}$$

Example from 2002 – slaughter pigs produced (corresponding to normative values):

$$23.7\ \text{mill.}_{\text{slaughter pigs}} = \frac{1{,}808\ \text{mill. kg meat}}{76.3\,\text{kg}}$$

Number of young pigs produced:

$$\text{no. produced}_{\text{young pigs,7-30kg}} = \frac{\text{no. animals produced}}{1 - (\text{dead}_{\text{pct}}/2)}$$

Example from 2002 – young pigs produced:

$$24.6\ \text{mill.}_{\text{young pigs,7-30kg}} = \frac{24{,}187}{1 - (0.036/2)}$$

Table 9 Calculation of the number of young and slaughter pigs produced

Calculation of annual production of year's sows, young pigs and slaughter pigs	2002 no. animals [units - 1,000]	Slaughter weight pr. animal [kg]	Meat produced [M kg]
Delivered to slaughterhouse	21,637.00	78.10	1,689.85
Slaughtered for the producer at slaughterhouse	10.20	87.80	0.90
Slaughtered at home	220.00	78.18	17.20
Young sows to slaughter	22.80	42.00	0.96
Export of pigs for slaughter	1,833.80	29.82	54.69
Transfer to sow unit (at 100 kg)			
Boars to slaughter	23.60	76.30	1.80
Dry sows [1]	447.14	76.30	34.12
Export of live animals for breeding	14.10	76.30	0.68
Population additions, young pigs < 35 kg (average of 20-50 kg)	-196.00	25.90	-5.08
Population additions, slaughter pigs >75 kg (average of 50-100 kg)	32.00	55.50	1.78
Discarded	141.90	78.10	11.08
Sum – number of animals produced	24,187		
Sum – amount of meat produced			1,808
Slaughter pigs: No. of meat-producing units with a slaughter weigth of 76.3 kg as stated in the normative values	23,702		
Small pigs (7-30 kg): No. of units produced	24,630		

[1] Calculated as the population of sows pregnant for the first time as stated in DSt Figures multiplied by 2.25 corresponding to the number of litters per year

4.3.3 Poultry

For poultry, three main categories are distinguished between – hens, pullets, broilers and other poultry, which includes geese, ducks and turkeys.

Hens and pullets

The normative values for hens are based on year's hens (units of 100).

The calculation of the annual production for hens is based, as a point of departure, on the population Figures from Statistics Denmark. Certain farming units will be registered with zero hens on the day of registration due to their particular production cycle with regard to zero days. Allowances are made for this by multiplying the number with (production time + zero days)/production time. Production time and zero days vary according to the different housing types (Poulsen et al., 2001).

Five main production forms are distinguished between – free-range, organic, barn and battery as well as production of brood eggs. The percentage distribution between the different housing types is estimated on the basis of the number of eggs weighed as part of the efficiency control, which includes approx. 1/3 of eggs produced (Henrik Bang Jensen, pers. comm.).

The population of hens for 2002, according to Statistics Denmark, is 3.65 million, of which the number of year's brood hens is approx. 1.09 million (Henrik Bang Jensen, pers. comm.). With production time and zero days taken into consideration, this corresponds to a population of approx. 0.96 million brood hens.

The remaining hens which are not brood hens – i.e. 2.69 million in 2002, are distributed across the different categories according to the form of production. The number of year's hens within each category is calculated as follows:

Calculation of the number of hens produced:

$$\text{no. of year's hens} = (\text{hens}_{DSt} - \text{brood egg hens}_{DSt}) * \text{housing type distribution} * \frac{\text{production time} + \text{zero days}}{\text{production time}}$$

Example from 2002 for the number of free-range hens produced (100 units):

$$2{,}400 = (36{,}533 - 9{,}618) * 0.084 * \frac{324 + 14}{324}$$

The normative value for pullets is based on 100 birds produced. Production time for pullets is 119 days (Poulsen et al., 2001) corresponding to a potential production during the course of a year of 3 pullets (365/119 = 3.067). Annual production is determined as the population as stated by Statistics Denmark (chicks for breeding) multiplied by 3.067. The multiplication factor relating to the frequency of the particular housing type is based on information from the Danish Poultry Meat Association (Det Danske Fjerkræråd, Henrik Bang Jensen, pers. comm.)

Calculation of the total number of pullets produced:

$$\text{no. of pullets}_{\text{category}} = \text{pullets}_{DSt} * \text{housing type distribution} * \frac{365}{\text{production time}}$$

Example from 2002 for the number of pullets produced – consumption, net production (units - 100):

$$2{,}113 = 9{,}185 * 0.075 * \frac{365}{119}$$

Table 10 Calculation of the number of hens and pullets produced in 2002

Year 2002			Housing-type distribution[1]	Production time	Zero days	Rotation length	Number of produced hens pr. year
	100 units	100 units	%	days	days	days	100 units
Hens - total (population DSt)	36,533						
- of which brood egg layere		9,618		315	42	357	10,900[1]
- of which egg layers		26,915	100				
Free-range			8.4	324	14	338	2,359
Organic			16.3	330	14	344	4,573
Barn			17.7	351	14	365	4,954
Battery, manure shed			25.9	376	14	390	7,236
Battery, slurry tank			4.6	376	14	390	1,286
Battery, manure cellar			27.1	376	14	390	7,558
Total number of hens produced							**38,866**
Year 2002			Housing-type distribution[1]	Production time		Production runs per year	Number of pullets produced per year
	100 units		%	days			100 units
Pullets - total (population DSt)	9,185		100				
Consumption, net			7.5	119		3.067	2,113
Consumption , floor			67.5	119		3.067	19,016
Brood egg, floor			25.0	119		3.067	7,043
Number of pullets produced							**28,173**

[1] Henrik Bang Jensen – Det Danske Fjerkræråd (Danish Poultry Meat Association)

Broilers, ducks, geese and turkeys

Numbers of broilers and other poultry such as ducks, geese and turkeys are based on the number of birds produced. Production is calculated on the basis of slaughter data from Statistics Denmark's agricultural statistics. The calculations take into account export, own consumption and the number who die during the production process, itself.

It is assumed that the mortality for broilers, ducks and turkeys is 2 percent, 2.5 percent and 2 percent, respectively (Dansk Fjerkræråd – Danish Poultry Meat Association). Data on the export of live birds and private consumption is obtained from Statistics Denmark.

"Stable-door" sales of geese are estimated to constitute a large part of the overall production. Therefore, the production of geese is assessed to be double that described by Statistics Denmark, corresponding to 2 sets of geese per year.

Calculation method to estimate produced poultry:

$$no._{poultry,category} = no._{deleviverd\ to\ slaughter} + no._{eown\ consumption} + no._{export\ of\ live\ birds} + no._{deaths}$$

Example from 2002 for the number broilers produced (units, 1,000):

$$141,600 = 136,350 + 2,402 + 0 + 2,832$$

4.3.4 Horses

The normative values for horses are based on the number of year's horses. Three different weight classes are distinguished between; lighter breeds – up to 400 kg, medium-weight breeds – from 400 – 800 kg and large breeds – over 800 kg. DAAS estimates that the distribution between the lighter, medium and large breeds is 59 percent, 38 percent and 3 percent, respectively.

The number of horses included in statistics from Statistics Denmark includes horses on agricultural units larger than 5 ha. A study of pets undertaken by Statistics Denmark has, however, shown that the actual number of horses is considerably higher than the Figure produced here as a significant number of horses are found on smaller hobby farms and riding schools, with under 5 ha. In the inventory, therefore, the numbers from DAAS, Danish Agricultural Advisory Service, based on their breeding register, are used instead and adding a number for unregistered horses. In 2002, 38,100 horses were listed by Statistics Denmark, as opposed to 110,000 according to DAAS Figures. Table 11 shows the stated number of horses in Statistics Denmark compared with the number of horses estimated on DAAS information from the breeding register.

Table 11 Number of horses 1985 to 2002 (thousands)

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Statistics Denmark[1]	31.9	30.5	32.8	34.3	35.4	38.2	32.0	28.0	20.4	18.5	17.7	20.2	38.9	38.2	40.5	39.7	43.1	38.1
DAAS, National Centre[2]	140.0	139.0	138.0	137.0	136.0	135.0	136.5	138.0	139.5	141.0	142.5	144.0	145.5	147.0	148.5	150.0	151.5	153.0

[1] agricultural units > 5 ha

[2] inc. horses on smaller agricultural units and riding schools

4.3.5 Sheep and goats

The normative values for sheep are based on years' breeding ewes including lambs. It is expected that a number of sheep are to be found on farms of less than 5 ha and that the actual number is, therefore, higher than that stated in the agricultural statistics compiled by Statistics Denmark. Annual production, therefore, is calculated as the population of ewes stated in Statistics Denmark plus 20 percent.

$$no._{sheep} = \text{breeding ewe}_{DSt} * 1.2$$

Example from 2002 for the number of year's breeding ewes:

73,800 = 61,502 * 1.2

The latest publicised normative feed intake and excretion values from 2001 (Poulsen et al.) also include normative values for goats. The values are based on year's goats including kids. As the number of goats is not calculated in Statistics Denmark's agricultural statistics, the information is based on the Central Livestock Register (CHR Register) obtained from DAAS (Table 12).

Table 12 Number of goats 1985 to 2002

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
DAAS, National Centre	8,000	8,000	8,000	8,400	8,400	8,400	8,800	8,800	8,800	9,200	9,200	9,200	9,600	9,600	9,600	10,000	10,500	11,000

The emission from goats represents less than 0.5 percent of the total emission from animal manure. This means that the inclusion of goats in the calculation does not contribute to major disparities between the present and earlier inventories, either for ammonia or greenhouse gases.

4.3.6 Animals bred for their skins.

The normative values for animals bred for their skins are based on a year's breeding animal. The annual production of this category of livestock is calculated as the population of mink and foxes as stated by Statistics Denmark.

4.4 Type of housing system

A range of different housing types is distinguished between within each livestock category. The type of management is a determinant factor for how fertiliser is handled in the individual housing type.

A systematic account of the distribution of the different housing types does not exist and, therefore, the distribution in the inventories is based on an estimate. For cattle and pigs, the distribution is based on information from Jan Brøgger Rasmussen and Niels H Lundgaard (pers.comm.) from the department for Building and Technology, DAAS, National Centre. The distribution of housing systems for animals bred for their skins is obtained from Hans Jørgen Risager (pers. comm.) from DAAS, Department for Fur Animals. The housing distribution for poultry is determined on the basis of efficiency controls of Dansk Fjerkræråd (Danish Poultry meat Association) (Henrik Bang Jensen, pers. comm.) – see Table 10.

Tables 13 and 14 show the estimated housing distribution for dairy cows and slaughter pigs from 1985 to 2002. For cattle, since 1985, traditional tethering stalls have been replaced to a large extent by housing systems with bed stalls and deep litter. In the case of pig housing, a large part of the solid flooring has been replaced by full slatted flooring. This means that, today, a larger part of the animal manure can be handled as slurry.

Table 13 Housing type distribution for dairy cattle 1985 to 2002 (DAAS – estimate)

Dairy cows – housing type	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
									Percent									
Tethering stalls – total:	85	84	82	81	80	79	78	77	76	75	73	72	66	60	60	46	40	35
with mucking out	40	39	38	37	36	35	35	34	33	32	31	30	30	30	30	18	15	12
with grates	45	45	44	44	44	44	43	43	43	43	42	42	36	30	30	28	25	23
Bed pens - total	14	15	16	16	17	18	18	19	19	20	21	22	26	30	30	43	49	54
Slats, back flush/ring channel	9	10	11	11	12	13	13	15	15	16	17	18	21	24	24	34	36	39
Slats, scraper system	1	1	1	1	1	1	1	1	1	1	1	1	2	3	3	3	4	4
Solid floor, scraper system	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	6	9	11
Deep litter - total	1	1	2	3	3	3	4	4	5	5	6	6	8	10	10	11	11	11
Slats, back flush/ring channel	½	1	1	2	2	2	3	3	4	4	5	5	6	7½	7½	7	7	7
Slats, scraper system	0	0	0	0	0	0	0	0	0	0	0	0	0	½	½	1	1	1
Solid floor, scraper system	½	0	1	1	1	1	1	1	1	1	1	1	2	2	2	3	3	3

Table 14 Housing type distribution for slaughter pigs 1985 to 2002 (DAAS - estimate)

Slaughter pigs – housing types	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
									Percent									
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Full slatted flooring	29	33	38	42	47	51	56	60	60	60	60	60	60	60	60	58	57	56
Part slatted flooring	30	29	27	26	24	23	21	20	21	23	24	25	26	28	29	31	33	34
Solid flooring	40	36	33	29	26	22	19	15	14	12	11	9	8	6	5	5	4	4
Deep litter	1	2	2	3	3	4	4	5	4	4	3	3	2	2	1	1	1	1
Divided bedding area	0	0	0	0	0	0	0	0	1	1	2	3	4	4	5	5	5	5

5 Ammonia emission

Figure 5 shows the distribution of the ammonia emission from different sources in 2002. The emission from handling animal manure represents almost 80 percent of the total ammonia emission. The emission from crops is calculated to be 14 percent and mineral fertilisers contribute with 6 percent of the emission. The remainder of the emission stems from ammonia-treated straw as well as the portion of sewage and industrial sludge which is applied to agricultural land.

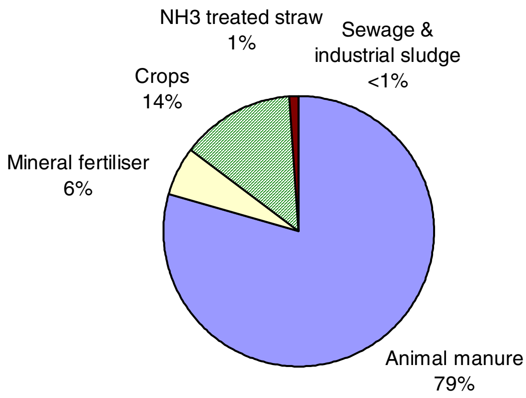

Figure 5 Ammonia emissions from agriculture distributed according to source, 2001

Figure 6 shows the distribution of the emission from animal manure from 1985 to 2002 according to different livestock categories. It is apparent that by far the largest part of the emission stems from pig and cattle production. The increase in the pig production has not given rise to higher emissions from this sector as a whole; however, the emission from pig breeding units represents a progressively higher proportion of the total animal manure emission. In 2002, approximately half the total ammonia emission was related to the production of pigs.

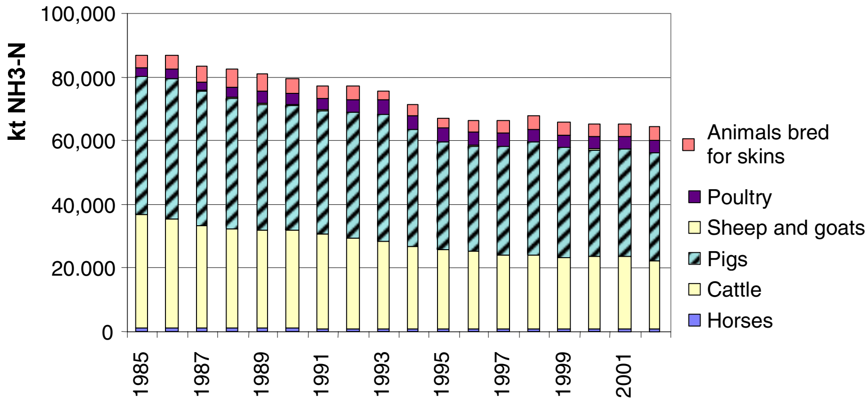

Figure 6 Ammonia emission from animal manure distributed according to different livestock categories

5.1 NH_3 emission from animal manure

The ammonia emission from animal manure is calculated as the sum of the emission from the housing unit, from storage, from its application on the field and the emission which taken place under grazing.

$NH_{3\ emission} = NH_{3\ housing\ unit} + NH_{3\ storage} + NH_{3\ application} + NH_{3\ grazing}$

For each of the elements above, ammonia losses are calculated for each individual combination of livestock category and housing type. How much time the livestock spend in the stable and on grass, respectively, is taken account in the calculations. This is stated as the share of feed consumed inside ($days_{housing\ unit}$) and on grass ($days_{grass}$).

$NH_{3\ housing\ unit}$ = number * N ex animals * $days_{housing\ unit}$ * $EF_{housing\ unit}$

$NH_{3\ storage}$ = number * N ex housing unit * $days_{housing\ unit}$ * $EF_{storage}$

$NH_{3\ application}$ = number * N ex storage * $days_{housing\ unit}$ * $EF_{application}$

$NH_{3\ grass}$ = number * N ex animals * $days_{grass}$ * EF_{grass}

An example of the emission calculation is shown below in relation to the inventory calculation for slaughter pigs housed on full slatted flooring in 2002, based on normative values and emission factors stated in Table 15.

In 2002, pig production represents 23.7 million finished pigs (see 4.3.2.2). Of these, 26 percent are housed for 365 days a year in housing systems with full slatted flooring.

Table 15 Normative values and emission factors for slaughter pigs in 2002

Normative values (kg N/prod. unit/year)			Emission factors *EF* (pct NH_3-N of total N)		
N ex anmal	N ex hosing	N ex storage	housing unit	storage	Application
3.25	2.73	2.67	16	2.7	12.43 (slurry)

Calculation of the emission from slaughter pigs housed on full slatted flooring:

$NH_{3\ housing\ unit}$ = (23,701,663 * 0.56) * (3.25/1000) * (1 – 0/365) * 0.16 = 6,902 tonnes NH_3 – N

$NH_{3\ storage}$ = (23,701,663 * 0.56) * (2.73/1000) * (1 – 0/365) * 0.027 = 978 tonnes NH_3 – N

$NH_{3\ grass}$ = (23,701,663 * 0.56) * (3.25/1000) * (1 – 365/365) * 0.07 = 0

$NH_{3\ application}$ = (23,701,663 * 0.56) * (2.67/1000) * (1 – 0/365) * 0.1243 = 4,405 tonnes NH_3 – N

Total $NH_{3\ slaughter\ pigs\ on\ full\ slatted\ flooring}$ = 6,902 + 978 + 4,405 = 12,300 tonnes NH_3 – N

5.1.1 Normative values for nitrogen in animal manure

The normative values for nitrogen separation – N ex animals, N ex housing unit and N ex storage are obtained from DIAS and are based on Efficiency Control reports, analyses of The Danish Plant Directorate as well as research results (Laursen, 1994; Poulsen & Kristensen, 1997; Poulsen et al., 2001). The normative values are continually adjusted in order to take the changes in efficiency with regard to used feedstuffs and feed composition into consideration. In the future, it the normative values will be updated every year.

N ex animal is provided in Table 16 for the most relevant livestock categories.

Increased attention focused on optimising the composition of fodder has led to increased feed efficiency. The rise in N-separation per animal in the period from 1985 to 2002 is an expression of the increase in weight per unit produced and the increase in egg production per hen.

Table 16 Changes in N ex animal for the period 1985 to 2002

N ex animal	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Cattle (large breed)																		
Dairy cows	125.00	127.25	129.50	131.75	134.00	133.00	132.00	131.00	130.00	129.00	128.00	127.83	127.66	127.49	127.32	128.02	128.02	129.95
Bulls, six MO slaughter	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30
Breeding stock, six MO calving	30.80	30.80	30.80	30.80	30.80	30.80	30.80	30.80	30.80	30.80	30.80	30.80	30.80	30.80	30.80	30.80	30.80	30.80
Pigs																		
Year's sows	31.88	31.23	30.59	29.94	29.29	28.69	28.09	27.50	26.90	26.30	25.70	25.97	26.23	26.50	26.76	26.39	26.39	27.17
Slaughter pigs	5.09	5.01	4.94	4.86	4.78	4.53	4.28	4.03	3.78	3.53	3.28	3.25	3.21	3.18	3.15	3.12	3.12	3.25
Poultry																		
Batterychickens	58.92	62.24	65.56	68.88	72.20	72.53	72.87	73.20	73.53	73.87	74.20	74.20	74.20	74.20	74.18	64.68	64.68	65.50
Broilers	40.66	40.66	48.33	52.17	56.00	55.22	54.43	53.65	52.87	52.08	51.30	51.30	51.30	51.30	51.29	53.34	53.34	53.62
Animals for skins																		
Mink	5.17	5.10	5.03	4.95	4.88	4.83	4.78	4.73	4.69	4.64	4.59	4.59	4.59	4.59	4.59	4.59	4.59	4.59

Source: Laursen (1994), Poulsen og Kristensen (1997), Poulsen et al. (2001), Hanne Damgaard Poulsen (pers. comm., 2003).

5.1.2 Emission factors

The evaporation of ammonia in the housing unit depends on the housing type. The emissions factors employed in the emissions inventories are based on the normative values from DIAS (Poulsen et al. 2001). In these emission factors is assumed a fixed relationship between ammonium (NH_4) and the total nitrogen content. However, the distribution of NH_4 and total-N will not remain constant over time due to changes in feed composition and efficiency.

Housing unit

In Table 17 the emissions factors for the ammonia emission from housing units are provided and are based on values stated in the report on normative standards (Poulsen et al. 2001). The emission factors vary according to housing-type.

For fur-bearing animals, the emission factors from Søren Pedersen of DIAS (Andersen et al. 2001b) are used. In animal waste systems with drains (with weekly emptying), it is estimated that ammonia evaporation represents 20 – 30 percent of total-N ex animals. Systems with these drains will result in a significantly higher emission, equivalent to 20 – 50 percent of total-N. In the emissions inventory, an average value is used – i.e. 25 percent for systems with drains and 35 percent for systems without drains.

Denitrification of the N in animal manure, where the ammonium nitrogen undergoes nitrification to N_2, N_2O and NO_X, can occur to a large degree with use of deep-straw bedding. The loss as a result of this process is subtracted from storage. The loss of N_2O is included in the calculation of the emission inventory for greenhouse gases.

Table 17 NH_3 emission from housing units (Source: Poulsen et al. 2001, Andersen et al. 2001b)

		Urine	Slurry (semi-liquid manure)	Solid manure	Deep litter manure
		NH3-N loss in percent of total N ex animal			
Cattle		5		16	15
Pigs	Year's sows	16	10,12,14,20(1)	16	45
	Young pigs	25	10,16(1)	25	15
	Slaughter pigs	18	12,16(1)	18	15
Poultry	Hens and pullets	-	10,40(1)	10,12,40(1)	25
	Broilers	-	-	-	20,25(1)
	Turkeys, ducks and geese	-	-	-	20
Animals bred for skins		0	2	15	-
Sheep/goats		-	-	-	5
Horses		-	-	-	5

(1) Dependent on housing type

Storage

The emission factors employed for storage are listed in Table 18 and are based on normative values (Poulsen et al. 2001 – Table 9.2 and 9.3).

In the case of slurry, that not all slurry tanks are covered has been taken into account.

Table 18 NH_3 emissions from storage (source: Poulsen et al. 2001).

		Urine	Slurry[1]	Solid manure	Deep litter	Perct. of manure stored in manure heap on field
		NH3-N i pct. af total N ex dyr				
Cattle		2	2.2	5	25	35
Pigs	Year's sows	2	2.7	25	25	50
	Young pigs	2	2.7	25	25	-
	Slaughter pigs	2	2.7	25	25	75
Poultry	Hens and pullets	-	2	5	10	95
	Broilers	-	-	-	15	85
	Turkeys, ducks and geese	-	-	-	15	-
Animals bred for skins		0	2	15	-	-
Sheep/goats		-	-	-	5	-
Horses		-	-	-	5	-

[1] It is assumed that 10 percent of slurry tanks in pig breeding and 5 percent in beef production are not covered or having a lack in the floating cover. The emission factors were higher in the previous years (see Table 19).

Urine - Liquid manure

The emission form liquid manure is, according to the normative values, estimated to be 2 percent of total-N ex housing unit from closed liquid manure containers.

Slurry

As all slurry tanks do not 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 capacity covered has increased in recent years as a result of the strengthened requirements with regard to the management of slurry tanks. For 2002, it is assumed that floating/fixed covers are absent on 10 percent of slurry tanks in pig production and on 5 percent in cattle production.

The correction for the lack of floating/fixed cover is calculated on the basis of normative values (Poulsen et al. 2001, Table 9.2). The emission factor for pig slurry with and without a floating/fixed cover is 2 percent and 9 percent, respectively, of total-N ex housing unit. For cattle slurry, the factor is determined as approximately 2 percent with floating/fixed cover and 6 percent without.

$$\text{Emission}_{\text{pig slurry}} = (0.1 * 9\%) + (0.9 * 2\%) = 2.7\%$$

$$\text{Emission}_{\text{cattle slurry}} = (0.05 * 6\%) + (0.95 * 2\%) = 2.2\%$$

Table 19 Correction for lack of floating/fixed cover on slurry tanks

	Emission factor[1] NH_3-N in % of N ex housing-total	1985-1999[2]	2000-2001[3]	2002[4]
Pigs				
No cover	9%	40%	20%	10%
Full cover	2%	60%	80%	90%
Emission under storage		**4.8%**	**3.4%**	**2.7%**
Cattle				
No cover	6%	20%	5%	5%
Full cover	2%	80%	95%	95%
Emission under storage		**2.8%**	**2.2%**	**2.2%**

[1] Poulsen et al. 2001

[2] COWI 1999

[3] COWI 2000

[4] Estimate - DMU

The ammonia emission from storage of slurry from hens, chickens, mink and foxes is estimated at 2 percent (Poulsen et al. 2001).

Solid manure

The evaporation from solid manure is based on normative values (Poulsen et al. 2001 – Table 9.3).

Deep litter

The emission from deep litter bedding is based on the emission factor stated in the normative values (Poulsen et al. 2001 – Table 9.3). In the calculation of the emission from cattle, year's sows, slaughter pigs, hens, chickens and broilers, it is taken 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 values states the size of the percentage of manure estimated to be stored in the field manure heap (Poulsen et al. 2001 – Table 9.1).

Denitrification

Table 20 lists the emission factors for denitrification of solid manure and deep litter, respectively, based on normative values (Poulsen et al. 2001). The emission factors are estimated on the basis of measurements undertaken for Danish pig and cattle housing units. The factors for the remaining livestock categories are not measured directly, however, they are estimated in relation to denitrification with regard to pig and cattle units. That a certain proportion of the manure is stored in the field manure heap is taken into account (Poulsen et al. 2001).

Table 20 Denitrification associated with storage of solid manure and deep llitter in the field manure heap (Source: Poulsen et al. 2001)

	Denitrification in percent of total N ex housing unit	
	Solid manure	Deep litter
Cattle	10	5
Year's sows	15	15
Young pigs	15	15
Slaughter pigs	15	15
Broilers	10	10
Hens	10	0
Other poultry	10	0

Field application

In the emission inventory the spreading of liquid and solid manure is distinguished from each other.

$NH_{3\ spreading} = NH_{3\ liquid\ spreading} + NH_{3\ solid\ spreading}$

A weighted emission factor is used for liquid and solid mnaure, respectively. This reflects the emission arising from the average national application practice. The weighted emission factor will, therefore, vary from year to year according to changes in application practice.

$NH_{3\ liquid\ spreading} = NH_{3\ ex\ storage\ liquid} * \text{Weighted emf}_{liquid}$

$NH_{3\ solid\ spreading} = NH_{3\ ex\ storage\ solid} * \text{Weighted emf}_{solid}$

Calculation of the weighted emission factor

The weighted emission factor for each year is calculated 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 (*emf*).

$$\text{Weighted emf} = \sum \text{application practice}_i * \text{emf}_i$$

An example of the calculation of the weighted emission factor for liquid manure under a national application practice which corresponds to:

25% applied with direct injection/incorporation: emf = 2%

45% applied with drag hoses, winter/spring – in the beginning of the growing season: emf = 20.5%

20% applied with hoses, winter/spring on bare earth – incorporated within 6 hours: emf = 5.2%

10% applied with hoses, late summer/autumn on growing crops: emf = 6.5%

Given this assumed national application practice, a weighted emission factor of 11.4 percent is obtained. This means that the NH_3 emission for liquid manure represents 11.4 percent of N ex storage.

$$\text{Weighted emf}_{liquid.} = 0.25 * 0.02 + 0.45 * 0.205 + 0.20 * 0.052 + 0.10 * 0.065 = \underline{\underline{11.4\%}}$$

It is apparent from Table 21 that the weighted emission factor for liquid and solid manure has fallen significantly in the period from 1985 to 2002. The Action Plan for the Aquatic Environment has contributed to changes in application practice. The requirement for fields which are green in winter has led to increased fertiliser being applied to winter crops as well as an almost complete ban of autumn application The strengthened requirement with regard to N-utilisation in fertilisers has also led to a greater proportion of slurry being applied with drag hoses or injected/incorporated directly into the soil. From 1 August 2003, according to Danish livestock regulation, a ban on traditional broad spreading has been enforced in law, which will further reduce the emission.

Changes in application practices have led to the emission from application of animal manure being reduced by 30 percent in the period 1985 to 2002.

Table 21 Calculated percentage loss of ammonia from application of liquid and solid animal manure

Weighted EF	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
									NH_3-N i percent of total N-content									
Liquid manure	19.8	19.6	19.4	19.2	19.0	19.4	18.6	17.8	16.9	16.1	15.3	14.5	14.4	14.4	14.3	14.1	13.7	12.4
Solid manure	9.2	8.9	8.7	8.4	8.1	8.0	7.9	7.8	7.7	7.6	7.5	7.4	7.3	7.1	7.0	6.8	6.4	6.0

Application practice

The weighted emission factor is dependent on application practice which, in turn, relates to factors such as:

Timing:	· spring-winter (bare earth, crops, grass) · spring-summer (grass) · late summer-autumn (rape, seed grass)
Method:	· injection/direct incorporation · drag hose application · conventional broad spreading
Time before incorporation:	· < 12 (6) hours · > 12 (6) hours · more than 1 week
Stage of crop growth:	· bare earth · growth

No statistical information is available at the present with regard to how animal manure is handled in practice. Therefore, an estimate for application practice is used in the emissions inventory, based on study of a limited number of farms, sales Figures for application machinery as well as development trends in LOOP areas (national surveillance plans) (Andersen et al. 2001a).

The estimate for application practice in 2001 and 2002 is, in addition to data from LOOP (Grant et al. 2002, Grant et al. 2003), based on information from the organisation for agricultural contractors (Danske Maskinestationer) (Mogens Kjeldal, pers. comm. 2002) and questionnaire studies of application practice covering 1,600 farmers implemented by Danish Agriculture (Dansk Landbrug, 2002).

Table 22 provides an estimate of how liquid and solid manure has been handled in practice for the period 1985 to 2002. The distribution according to different combinations of practice types is stated in percent.

Table 22 Average national application practice

Crop Status	Timing for application of fertiliser	Lying time	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
		Hours								Percentage distribution										
	Liquid manure																			
	Injection																			
-/+	Winter-spring	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	5	10	16
-/+	Summer-autumn	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2	3	4
	Hose application																			
-	Winter-spring	< 12 (6)	0	0	0	0	0	0	1	2	3	4	6	7	8	9	10	9	10	10
-	Winter-spring	> 12 (6)	0	0	0	0	0	0	1	1	2	2	3	3	4	4	5	5	5	5
-/+	Winter-spring	not	0	0	0	0	0	0	3	7	10	13	17	20	23	27	30	32	43	41
+	Spring-summer	not	0	0	0	0	0	0	1	2	3	3	4	5	5	4	4	4	4	3
+	Late summer-autumn	not	0	0	0	0	0	0	1	1	2	3	3	4	4	4	4	4	5	5
-	Late summer-autumn	< 12 (6)	0	0	0	0	0	0	1	1	2	2	3	3	3	2	2	2	3	3
-	Late summer-autumn	> 12 (6)	0	0	0	0	0	0	0	1	1	1	2	2	1	1	0	0	0	0
-	Late summer-autumn	not	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Broad spreading																			
-	Winter-spring	< 12 (6)	26	27	28	29	30	26	25	24	23	22	21	20	18	17	15	14	6	5
-	Winter-spring	> 12 (6)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	2	1
-/+	Winter-spring	not	15	15	15	15	15	20	20	20	20	20	20	20	18	17	15	14	6	4
+	Spring-summer	not	8	8	8	8	8	8	7	6	5	4	3	2	2	2	2	2	1	1
+	Late summer-autumn	not	7	7	7	7	7	7	6	5	5	4	3	2	2	1	1	1	0.5	0
-	Late summer-autumn	< 12 (6)	2	3	3	4	4	4	4	4	4	3	3	3	3	2	2	2	1	2
-	Late summer-autumn	> 12 (6)	8	7	7	6	6	6	5	4	4	3	3	2	2	1	1	1	0,5	0
-	Late summer-autumn	not	29	28	27	26	25	24	20	16	12	8	4	0	0	0	0	0	0	0
		Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
	Solid manure																			
-	Winter-spring	< 12 (6)	13	16	19	22	25	26	26	27	28	29	29	30	32	33	35	38	49	54
-	Winter-spring	> 12 (6)	18	16	14	12	10	11	11	12	13	14	14	15	15	15	15	14	14	15
-	Winter-spring	not	19	18	17	16	15	14	14	13	12	11	11	10	10	10	10	9	10	11
+	Spring-summer	not	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+	Late summer-autumn	not	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-	Late summer-autumn	< 12 (6)	13	16	19	22	25	25	25	25	25	25	25	25	25	25	25	26	18	13
-	Late summer-autumn	> 12 (6)	13	11	9	7	5	5	5	5	5	5	5	5	5	5	5	5	3	2
-	Late summer-autumn	I not	24	23	22	21	20	19	19	18	17	16	16	15	13	12	10	9	6	5
		Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Emission

The ammonia emission arising in connection with the application of animal manure on the field occurs during the time when the manure lies on the surface of the soil. The emission varies from between approximately 2 – 30 percent of the N-content in the fertiliser (N ex storage), depending on the timing and method of application (Sommer, 1998). A slight ammonia loss, corresponding to approximately 1 percent of the N-content (0.5 percent under drag hose application) is assumed under the application process itself (Rom et al. 1999). With use of injection/in-corporation techniques, loss of ammonia under the application process is considered not to occur.

Table 23 lists the emission factors employed which are based on an estimate of DIAS (Sommer 1998). The emission includes the 0.5 – 1 percent emission, which occurs under the application process itself. The emission is largest in the case where liquid slurry is applied with traditional broad spreaders, a practice which has been banned since 1 August 2003.

By far the largest part of liquid animal manure is applied to growing crops with drag hoses, where the fertiliser is not subsequently ploughed into the earth. The resultant emission can vary significantly depending on when in the growth season the application takes place. The emission will be relatively high in the beginning of the growth season, where the plants, by virtue of their small size, do not contribute significantly with shade or shelter. Under application which occurs later in the season the emission will be significantly lower, despite the higher air temperatures, as a result of the greater leaf area available. In addition to the shade and shelter effect provided by the leaves which lowers the emission, a proportion of the ammonia in gaseous form will be taken up by the leaves themselves.

According to Danish livestock regulations, lying time permitted has been reduced from 12 to 6 hours from 2002. It is assumed that the decrease in emission factor resulting from a reduction in lying time from 12 to 6 hours will be 1/3 (Sommer, pers. comm.). In the Table below, the emission under conditions where the manure lies for 6 hours is presented in brackets.

Table 23 Emission factors for application of animal manure (Sommer, 1998)

Crop status	Time of application	Lying time	Emisison factor under application (NH_3-N i pct. of total N ex storage)			
			Liquid manure			Solid manure
		No. of hours	Injected/incorporated direct[1]	Drag hoses[2]	Broad spreading	Traditional
-	Winter-spring	< 12 (6)	2	7,5 (5,2)	8 (5,7)	4
-	Winter-spring	> 12 (6)	2	10,5	11	5,5
-/+	Winter-spring	> 1 week	2	20,5	21	11
+	Spring-summer	> 1 week	2	6,5	31	16
+	Late summer-autumn	> 1 week	2	2,5	31	16
-	Late summer-autumn	< 12 (6)	2	10,5 (7,2)	11 (7,7)	6
-	Late summer-autumn	> 12 (6)	2	20,5	21	11
-	Late summer-autumn	> 1 week	2	25,5	26	13

[1]Sommer, pers. comm.

[2]Emission with a lying time of 6 hours presented in brackets - corresponding to a reduction of 1/3 in relation to the emission with a lying time of 12 hours.

Grazing

A proportion of the manure from dairy cattle, heifers, suckling cows, sheep, goats and horses is deposited on the field under grazing. It is assumed that dairy cows on average are grazing 15 percent of the year, which when translated to number of days corresponds to 55 days. The equivalent estimate for suckling cows is 224 days, with 196 days for heifers, 183 days for horses and 265 days for sheep and goats (Poulsen et al. 2001). The number of grazing days for suckling cows and breeding has been rising, however this does not affect the total ammonia emission significantly.

It should be underlined that uncertainty exists with regard to these evaluations and the average calculations mentioned should be considered as best possible estimates.

An emission factor of 7 percent of the N-content of the manure is used for all livestock categories. The emission factor is based on studies of grazing cattle in Holland and England (Andersen et al. 2001a).

Table 24 Number of grazing days corresponding to the proportion of N in manure deposited on the field during grazing.

Livestock	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Horses	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183
Heifers	165	165	165	165	165	165	171	177	184	190	196	196	196	196	196	196	196	196
Dairy cows	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Suckling cows	184	184	184	184	184	184	192	200	208	216	224	224	224	224	224	224	224	224
Sheep	265	265	265	265	265	265	265	265	265	265	265	265	265	265	265	265	265	265
Goats	265	265	265	265	265	265	265	265	265	265	265	265	265	265	265	265	265	265

5.2 Mineral fertilisers

The emission from mineral fertilisers depends on type as well as amount used. Data for consumption (Table 25) and fertiliser type are obtained from the Danish Plant Directorate (2003).

The Plant Directorate estimates that 1 – 2 percent of mineral fertilisers are used in parks, golf courses and sports grounds, etc. (Troels Knudsen, pers. comm., 2003) – i.e. areas not that are not directly associated with agricultural activities. However, the 1 – 2 percent of the emission from these sources is included in the emission from agriculture. In this way, the consumption matches with data from Statistics Denmark's agricultural statistics, which is used for comparison on an international basis. In reporting to the UNECE, it is noted that all mineral fertiliser use is not related to agriculture.

Table 25 Mineral fertiliser consumption 1985 – 2002 (Danish Plant Directorate)

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Consumption								M kg N										
Used in agriculture	392.3	376.3	375.5	361.2	371.2	394.6	389.1	363.7	327.1	320.4	310.1	285.0	281.8	277.4	256.9	245.7	228.7	206.3
Other	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.0	4.5
Total	**398.1**	**382.1**	**381.3**	**367.0**	**377.0**	**400.4**	**394.9**	**369.5**	**332.9**	**326.2**	**315.9**	**290.8**	**287.6**	**283.2**	**262.7**	**251.5**	**233.7**	**210.8**

The emission coefficients for the various fertiliser types are listed in Table 26 and are based on a range of studies carried out by, among others, Sommer & Ersbøll (1996) and Sommer & Jensen (1994).

Table 26 Emission factors used for mineral fertiliser

Consumption of nitrogen in mineral fertiliser 2002[1]	Emission factor[2] [Percent. of N in fertiliser]	Consumption [M kg N][3]
Fertiliser type:		
Lime and boron-lime-saltpetre	2	0.5
Ammonium sulphate	5	3.6
(and other saltpetre (e.g. sodium-lime-saltpetre)	2	78.5
Ammonium nitrate	2	21.1
Liquid ammonia	1	7.9
Urea	15	0.5
Other single fertilisers	5	10.3
NPK fertiliser	2	75.2
Diammonium phosphate (18-20-0)	5	0.5
Other NP fertilisers	2	2.4
NK fertilisers	2	10.3
Average	**2.2**	**210.8**

[1] Inc. consumption relating to parks, sports grounds, etc. – representing approx. 2%

[2] Sommer & Christensen (1992), and Sommer & Jensen (1994), Sommer & Ersbøll (1996)

[3] Danish Plant Directorate (2003)

The consumption of mineral fertilisers in the period from 1985 to 2002 is shown in Table 25. Here it is seen that consumption since 1985 has declined by 35 percent over the period. This fall in consumption relates to the increasing requirement to utilise the nitrogen contained in animal mnaure. This has led to a fall in the ammonia emission from mineral fertilisers (Table 27).

Table 27 Ammonia emission from mineral fertilisers 1985 – 2002 (Source: Danish Plant Directorate)

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Emission									tonnes NH_3-N									
Agriculture	7,754	7,199	7,216	7,030	7,328	8,546	8,311	7,750	7,453	7,745	7,489	6,528	6,055	6,118	5,671	5,466	5,043	4,503
Other	116	116	116	116	116	116	116	116	116	116	116	116	116	116	116	116	100	90
Total	**7,900**	**7,300**	**7,300**	**7,100**	**7,400**	**8,700**	**8,400**	**7,900**	**7,600**	**7,900**	**7,600**	**6,600**	**6,200**	**6,200**	**5,800**	**5,600**	**5,100**	**4,600**

5.3 Crops

Plants exchange ammonia in relation to the surrounding air both by absorbing and expelling ammonia. 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 (Andersen et al. 1999). Some uncertainty is linked with quantification of the emission from crops, which is presumably the reason why the emission from crops is excluded from the fixed emission ceilings set by the UNECE and EU.

In the Danish emissions inventory, the emission from crops has been included as the results from recent studies continue to show that an emission can come from crops – up to 5 kg NH_3-N per hectare (Schjoerring & Mattsson 2001). The inclusion of the emission from crops can be regarded as a form of worst case scenario.

On the basis of a study by Schjoerring & Mattsson (2001) an emission factor of 5 kg N/ha is employed for crops in a rotation and 3 kg N/ha for grass and clover.

The inventory for agricultural land is based on information from Statistics Denmark.

Table 28 Emission factor (kg N/ha) used for crops

Emission from crops	Ammonia emission
	kg N/ha
All crops (excl. grass)	5
Grass/clover in a rotation	3
Permanent/long-term grass	3

Table 29 Emission from crops 1985 – 2002

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
									1,000 ha									
Total area cultivated	2,834	2,819	2,800	2,787	2,774	2,788	2,770	2,756	2,739	2,691	2,726	2,716	2,688	2,672	2,644	2,647	2,676	2,666
Emission									tonnes NH_3-N									
NH_3-N	13,200	13,100	13,100	13,000	12,900	13,000	12,900	12,800	11,800	11,500	11,600	11,600	11,800	11,700	11,200	11,100	11,200	11,100

Table 29 shows the emission from crops in the period 1985 to 2002, where a fall of 16 percent can be seen. The most important reason for this decrease is the fall in the area of land under agricultural production. Changes with regard to organically cultivated areas are of limited significance as organically farmed areas constitute 6 percent of the total area under agricultural production (2002).

5.4 Sludge

Sludge from wastewater treatment and the manufacturing industry is applied to agricultural land and, therefore, is included as a source of ammonia emission. Information on the sludge applied on agricultural land is obtained from reports prepared by the Danish Environmental Protection Agency (latest reports concerning 2002 data – Danish EPA 2003 and 2004).

The ammonia emission from industrial sludge is assessed to be very limited (Andersen et al. 1999) as the largest part is tied up in organic matter. Therefore, the emission is not included as a source in the ammonia inventory.

Around half of the sludge from wastewater treatment is applied to agricultural land. The Danish Environmental Protection Agency estimates that the ammonia emission is 3 percent of the N-content in the sludge. The N-content varies from year to year and is usually 4 – 5 percent.

No evaluation in relation to the practical handling in relation to the application of sewage sludge exists. It is estimated that a quarter of the sludge is not incorporated, whilst the remaining three-quarters is incorporated within 6 hours. It is estimated that the emission is halved by incorporation of the sludge in the soil. This means that the emission factor for sewage sludge applied on agricultural land can be calculated to 1.9 percent.

$EF_{sewage\ sludge} = 0.25 * 0.03 + 0.75 * 0.015 = 0.01875$

Table 30 shows that the amount of sewage sludge applied to agricultural land increased from 1985 to the middle of the 1990s, but that here after to 2002 the amount fell. This is due to the increased interest in the use of sewage sludge in industrial processes, for example, in connection with cement production and the production of sandblasting material.

Table 30 Emission from sewage sludge applied to agricultural land 1985-2002

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
	1000 tonnes dry matter																	
Sludge applied to agricultural land	50	50	52	58	70	78	80	96	123	111	112	104	90	87	86	84	81	80
	pct.																	
N-content	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.1	4.4	4.4	4.3	4.3	4.3	4.4	4.4
	tonnes dry matter																	
N applied to agricultural land	2,000	2,000	2,100	2,300	2,800	3,100	3,200	3,800	4,900	4,400	4,600	4,500	4,000	3,800	3,700	3,600	3,500	3,500
	tonnes NH_3-N																	
NH_3-N emission	38	38	39	44	52	58	60	72	93	83	87	85	74	70	69	68	66	66

5.5 Ammonia-treated straw

Ammonia-treated straw is used as fodder for cattle. The addition of ammonia promotes breakdown of the straw, which aids the digestion processes. It is assumed that the sale of ammonia in the second half-year is used for the treatment of straw with ammonia. Information on ammonia sales is obtained from the suppliers.

Studies show that 80 - 90 percent of the ammoniacal nitrogen in the straw can evaporate (Andersen et al., 1999). However, through measuring the dose of ammonia in relation to the dry matter content of the straw, the emission can be reduced significantly. It is, therefore, estimated that the emission constitutes 65 percent of the amount of ammoniacal nitrogen added.

Table 31 Emission from ammonia treated straw, 1985-2002

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Consumption of NH_3-N	8,285	10,186	11,305	9,181	11,399	12,912	10,951	9,722	9,600	10,264	8,406	6,412	5,672	4,685	2,630	3,125	2,050	1,191
Emission of NH_3-N	5,400	6,600	7,300	6,000	7,400	8,400	7,100	6,300	6,200	6,700	5,500	4,200	3,700	3,000	1,700	2,000	1,300	800

Table 31 shows that, in the period from 1985 to 2002, there has been a considerable increase in the emission from ammoniacal nitrogen from ammonia-treated straw. According to the latest changes to the livestock regulations, the process is no longer permitted from 1 August 2004.

5.6 Straw burning

A ban on the burning of straw on fields was introduced in 1990. The burning of straw on fields may only take place in connection with the cultivation of grass seed or after dispensation in years characterised by heavy rainfall. As a result, the extent of the emission from this source is not considered to be significant and, therefore, has no longer included in the emissions inventory.

Table 32 lists the emission from straw burning up to 1989 as stated in the emissions inventories. The emission is calculated as the proportion of the N-content in the burnt straw, calculated on the basis of data from Statistics Denmark (Andersen et al., 2001a).

Table 32 Emission from straw burning 1985–1989

Non-salvaged straw		1985	1986	1987	1988	1989	1990
Burnt straw	1,000 tonnes	1,094	938	901	708	1,065	0
Burnt straw	tonnes N	6,374	5,518	5,168	4,169	5,857	0
Emission	tonnes NH_3-N	255	221	207	167	234	0

6 Methane emission

The CH_4 emission stems primarily from livestock's digestive processes, whereas a smaller part comes from bacterial breakdown of animal manure under anaerobic conditions (primarily in slurry). The methane emission from the digestive system can be regarded as an energy loss under the digestion process. It is chiefly ruminants that produce CH_4 whereas livestock possessing just one stomach – i.e. pigs, horses, poultry and animals bred for their skins – produce CH_4 to a much lower degree.

Under distribution of the methane gas emission according to the various livestock categories, cattle were responsible for 70 percent of the emission and pigs less than 26 percent in 2002. The share associated with pig production has increased in recent years as a result of increased production as well as the reduction in cattle populations.

The amount of CH_4 produced depends on feed consumption and type and, thereby, the emission is determined by the feed's gross energy content (BE).

According to the international guidelines (IPCC 1996), methane production is calculated on the basis of the individual animal's gross energy consumption in MJ (Mega Joule). Energy consumption is divided up in relation to contributions to:

1. Maintenance
2. Foetus production
3. Growth
4. Milk production
5. Work

In the Danish normative values (Poulsen et al. 2001) these factors are included, just as the feeding costs incurred under changes in herd composition. Therefore, the normative values can be used in the emissions inventories.

For calculation of CH_4 the same data is used for feed intake, livestock production, housing-type distribution, etc. as employed in the calculation of the ammonia emission.

6.1 CH_4 emission from digestive processes

Methane production from the digestive system is calculated on the basis of the animal's total gross energy intake (BE).

Equation 1

$$CH_{4_{år}} = \frac{BE_{year} * Y_m}{55.65}$$

where CH_4 = CH_4, kg animal^{-1} year^{-1}

$BE_{år}$ = gross energy intake, MJ, år^{-1}

Y_m = methane formation factor (IPCC 1996)

55.65 = conversion factor – from MJ to kg CH_4 (IPCC 1996)

For the conversion of MJ to kg CH_4 and for calculation of the methane emission from digestion (methane factor – Y_m), the values recommended by the IPCC are used. Y_m varies depending on the breed of animal and the respective feed strategy.

6.1.1 Energy content in feed

BE_{Prot} = gross energy in protein, MJ kg^{-1} dry matter

BE_{Fedt} = gross energy in fat, MJ kg^{-1} dry matter

BE_{Kul} = gross energy in carbohydrates, MJ kg^{-1} dry matter

FE_{100} = FE per 100 kg feed

In the calculation of the energy content in feed – i.e. in the conversion to the number of MJ – pigs and other livestock types are distinguished between (Table 33). In calculation of BE a feed plan is used based on an average feed consumption.

Table 33 Energy factors used to calculate energy content of feed in MJ

	Protein	Fat	Carbohydrate
Pigs (EFOS-method)[1]	0.237	0.389	0.175
Other livestock types	0.242	0.342	0.173

[1]Source: Info Svin (specialist pig production database), National Committee for Pig Production (Landsudvalget for Svin), Dansk Slagterier as well as the Handbook for Cattle Breeding and Management (Håndbog for Kvæghold), DIAS. EFOS is the new method for calculating the energy content of different amino acids.

For grazing animals (except dairy cows) the energy content in the winter period's feed plan and the energy content in grass are distinguished between.

The division of energy intake between the winter and the summer feed plans is calculated in the normative values Table (Poulsen et al. 2001). It is estimated that the share of energy intake in the summer period for horses, heifers, suckling cows, sheep and goats is 0.5, 0.537, 0.614, 0.726 and 0.726, respectively, which corresponds to the distribution used in the inventory for the ammonia emission.

For free-range pigs, hens, etc. it is assumed that grazing does not contribute to feed intake, therefore, the feed's BE is calculated on the basis of complete fodder.

For dairy cows, energy intake is calculated to be 18.3 MJ $FE^{-1}{}_{cattle}$ in a standard winter feed (Torben Hvelplund, pers. comm., Olesen et al. 2001), regardless of whether the animal grazes or not.

For calves under ½ year, as well as bull calves older than ½ year for slaughter, the same energy content value is used as for dairy cows.

For horses, heifers, suckling cows, sheep and goats, an average winter feed plan is put together (Refsgaard Andersen (DIAS), Eric Calusen (DAAS), Hanne Bang Bilgaard (DAAS), Anette Holmenlund (DAAS), pers. comm.s). The resulting gross energy content is calculated - see Appendix C.

For the remaining categories of livestock, BE in feed is calculated on the basis of the individual feed's protein, fat and carbohydrate content measured via analyses of complete feed undertaken by the Danish Plant Directorate in 2002 (Danish Plant Directorate, 2002). Average values are stated in Table 34. Background data for calculation is provided in Appendix C.

The BE content in feeds is measured as the energy content per FE, which is assumed not to have changed since 1987. Therefore, changes in feed efficiency are reflected in changes in feed consumption.

Table 34 Feed consumption for 2002 and conversion factors to determine the methane emission from livestock digestive processes. For cattle, pigs, horses, sheep and goats, feed consumption is stated in FE and for remaining livestock categories in kg

Livestock category	Feed intake	Gross energy (BE)		Feed on grass	Methane formation	Emission 2002	
	2002 [a]	Winter feed	Summer feed	Proportion	Y_m [b]	Per unit produced	Total
	FE animal^{-1}year^{-1}	MJ FE^{-1}animal^{-1}year^{-1}	MJ FE^{-1}animal^{-1}year^{-1}	Pct.	Pct.	Kg CH_4 prod. animal^{-1}year^{-1}	Gg CH_4
Cattle:							
Dairy cattle, large breed (Jersey)	6100 (5100)	18.30	18.30	-	6	117.95	71.90
Heifer calves, < ½ year	188 (158)[c]	18.30	18.83	-	6	3.66	2.83
Breeding calves, ½ year to calving	1406 (1018)[c]	25.75	18.83	54	6	32.39	24.51
Young bulls, < ½ year	620 (442)	18.30	18.83	-	4	8.78	1.90
Young bulls, ½ year to slaughter (440 kg)	1280 (1007)	18.30	18.83	-	4	16.63	5.18
Suckling cows	2515	34.02	18.83	61	6	66.97	8.06
Pigs:							
Sows inc. pigs < 7.2 kg	1340	17.49	17.49	-	0.6	2.53	2.85
Weaners pigs, 7.2-30 kg	47	16.46	16.46	-	0.6	0.08	2.05
Slaughter pigs, > 30 kg	202	17.25	17.25	-	0.6	0.37	8.89
Other:							
Horses	2555[d]	29.83	18.83	50	2.5	23.91	3.66
Sheep (incl.lambs)	728	29.95	18.83	73	6	17.17	1.27
Dairy goats (incl. kids)	669	29.95	18.83	73	5	13.15	0.14
	Kg feed animal^{-1}year^{-1}	MJ kg^{-1} feed	MJ kg^{-1} feed				
Battery hens	40	17.46	17.46	-	-	-	-
Broilers 40 days	4	18.99	18.99	-	-	-	-
Mink incl. young:	196	11.71	11.71	-	-	-	-
From digestive processes in total							**133.23**

[a] Data from DIAS. Consumption changes as a result of changes in productivity

[b] IPCC's standard values

[c] FE are reported in the normative value Tables as part of the year's breeding. This is converted to FE dyr^{-1} in Statistics Denmark's calculations by dividing by the proportion of breeding found within the group. FE is calculated as proportions of the year's young cattle stock.

[d] 600 kg horse

The emission from poultry and animals bred for their skins is not included in the CH_4 emission from digestion processes. Although an emission will occur, the size of the emission is considered to be so small as to be insignificant. However, the calculation of the gross intake is still calculated as this is used in the further calculation of the CH_4 emission from the handling of manure – see Section 6.2.

6.2 CH_4 emission from the handling of animal manure

Methane gas production from animal manure is calculated on the basis of the energy in animal manure taking into account storage conditions. In the emission inventory, consideration is given to that in the different types of housing systems energy is added as a result of spreading straw and spilt feed based on information from Poulsen et al. (2001).

Storage conditions for livestock manure have an effect on methane production. Anaerobic conditions, as found in slurry, promote methane formation, while methane production is low in solid manure. Developments over recent years, whereby more livestock are housed in open housing units and in slurry-based stable systems, have led to relatively high methane production.

CH_4 formation from animal manure is calculated on the basis of the IPCC guidelines, where the proportion of the organic matter, *VS* (Volatile Solids) is determined (Equation 3) and, on the basis of this, the CH_4 emission is calculated.

Equation 1

$$VS_{feed} = \frac{BE}{18.45} * (1 - \frac{FK}{100}) * (1 - \frac{\% \, ash}{100})$$

where	VS	=kg organic matter (Volatile Solids)
	BE	=Gross energy intake
	18.45	=Conversion factor from MJ to kg dry matter
	FK	=Digestion coefficient
	% ash	=Fertilisers' ash content (IPCC 1996)

The average digestion coefficients (FK) for different livestock types are provided in the normative values report (Poulsen et al. 2001) and also in Table 36. For livestock categories where FK are not available, estimates are obtained from comparisons with similar livestock types. In order to determine the ash content in the fertiliser, the IPCC's standard values are used – i.e. 8 percent for ruminants and horses and 2 percent for other livestock. The calculation also takes the straw utilisation into account in the different housing systems.

Equation 4

$$VS_{straw} = \frac{Straw \ consumption}{18.45} * TS_{straw}$$

where	VS_{halm}	=kg organic matter (Volatile Solids) in straw
	TS_{halm}	=Percent dry matter (85%)
	18.45	=Conversion factor from MJ to kg dry matter

The amount of methane produced is determined from Equation 5, where *VS* is multiplied with the maximum methane capacity B_0 which is particular to each livestock type and the maximum methane formation factor *MCF*, which is dependent on the actual temperature and storage conditions. Denmark is located in a cold climate and, therefore, has a relatively low *MCF*.

Equation 5

$$CH_{4,i} = VS_i * B_{0,i} * 0.67 * MCF_i$$

where $CH_{4,i}$ =Methane emission for livestock category *i*

B_0 =Maximum methane formation capacity (IPCC 1996)

MCF =Methane conversion factor (IPCC 1996)

Table 36 provides the B_0 values employed in the inventory, based on IPCC standard values. Here it is demonstrated that methane formation is significantly higher with regard to pig manure than that of cattle.

Table 35 lists the *MCF* factors used. The IPCC has suggested that the *MCF* factor should be raised from 10 percent to 39 percent for liquid manure in cold climates. However, documentation is available which puts the *MCF* under Danish conditions at around 10 percent (Husted 1994, Massé et al. 2003). Moreover, Finland and Sweden also used this value.

Table 35 Values used for methane conversion factor MCF

	MCF
Solid manure and deep litter, excl. poultry	1 %
Liquid manure and slurry	10 %
Poultry manure	1.5 %
Manure excreted on grass	1 %

Animal manure brought out on the field should, according to the IPCC, be stated as having the same *MCF* as solid manure in storage.

In Table 36, an overview of the data used to calculate the methane emission form animal manure from the different categories of livestock.

Table 36 Conversion factors to determine the methane emission from handling animal manure

Livestock category	Digestion coefficient (FK)		Ash content	Methane formation capacity	Emission 2002	
	Winter	Summer	Share	B_o	Per unit produced	Total
	Pct.	Pct	Pct.	m^3 CH_4/ kg VS	Kg CH_4 prod. animal^{-1}year^{-1}	Gg CH_4
Cattle						
Dairy cattle	71	71	8.0	0.24	17.26	10.52
Heifer calves, < ½ year	78	78	8.0	0.17	0.07	0.05
Young cows, ½ year to calving	71	78	8.0	0.17	1.66	1.26
Bull calves, < ½ year	79	79	8.0	0.17	0.14	0.04
Bull calves, ½ år til slagtning (440 kg)	75	75	8.0	0.17	1.43	0.45
Suckling cows	67	77	8.0	0.17	1.10	0.13
Pigs (produced)						
Sows inc. pigs < 7.2 kg	81	81	2.2	0.45	5.05	5.70
Weaners, 7.2-30 kg	81	81	2.2	0.45	0.20	5.02
Slaughter pigs, > 30 kg	81	81	2.2	0.45	0.94	22.25
Other						
Horses	75	67	8.0	0.33	1.74	0.27
Sheep (incl. lambs)	75	67	8.0	0.19	0.32	0.02
Dairy goats (incl. kids)	75	67	8.0	0.17	0.26	0.00
Poultry (produced)	81	81	8.0	0.32	(per 100 prod.) 0.20	0.30
Animals bred for skins (incl. foxes)	81	81	2.0	0.48	0.44	1.06
Total from animal manure						**47.07**

6.3 Burning surplus straw

Burning straw gives rise to the formation of CH_4. Since 1990 the practice of burning surplus straw on the field has only been permitted for straw from seed grass production. The amount of methane formed from this process is considered to be minimal and, therefore, has been omitted from the inventories since 1990. The emission of CH_4 in the period 1985 to 1989 is calculated on the basis of data on the burning of straw from Statistics Denmark. The emission of CH_4 from this practice is calculated according to Equation 6.

Equation 6

$$CH_{4,straw\,burning} = Ts_{straw} * C_{Ts} * EF_{straw\,burning} * \frac{16}{12}$$

where T_s is the amount of dry burnt straw material, C_{Ts} is the carbon content of the straw (half wheat to half barley straw is used here giving a carbon proportion of 0.47), $EF_{straw\ burning}$ is the methane emission factor (0.005) and 16 and 12 are the respective molecular weights.

Table 37 Contribution of straw burning to the CH4 emission, 1985 – 1989

	1985	1986	1987	1988	1989
Straw burning, M tonnes straw	1.094	0.938	0.901	0.708	1.065
CH_4-emission, 1,000 tons CH_4	2.9	2.5	2.4	1.9	2.8

6.4 CH_4 reduction from biogas treated slurry

The first biogas plant was established in 1984 and at the present there are around 20 communal plants in Denmark, as well as 50 – 55 plants operating on farms. In 2002, 1.4 million tonnes of animal manure were treated, equivalent to approximately 4 percent of the total animal manure, supplemented with around 200,000 tonnes organic waste from industry, wastewater treatment works and households (Biogas Branch Association 2003). The total energy production is shown in Table form in Appendix D.

Using slurry in biogas plants reduces the emission of both methane and nitrous oxide. No descriptions on how to include this reduction in the inventories are provided in the IPCC guidelines. Therefore, the Danish inventory uses data based on Danish studies (Sommer et al. 2001). It is expected that the CH_4 emission from biogas treated slurry can be reduced by 30 percent in relation to cattle slurry and 50 percent from pig slurry (Table 38).

Table 38 Reduction of CH_4 emission from treatment in a large communal biogas plant. Capacity: 550 m3 per day-1 (Source: Nielsen et al. 2002 based on Sommer et al. 2001)

Reduction of methane	Untreated	Biogas treatment	Reduction following biogas treatment	Reduction in emission ($R_{N2O,potential}$)
	tonne CH_4	tonne CH_4	tonne CH_4	Pct
Cattle slurry	263.1	183.6	-79.5	30
Pig slurry	197.7	97.2	-100.5	50

In evaluation of the effect of biogas plants on the emission of greenhouse gases, the frequent addition of animal fat to increase productivity in the process should also be taken into account. Moreover, that biogas substitutes the burning of fossil fuels is not taken into account in the calculation. Under the assumption that the 1,703 TJ (Terra Joule = 10^{12} Joule) of energy produced at slurry-based biogas plants in 2002 substituted natural gas, a reduction in CO_2 emissions of 0.097 million tonnes results (1,703 TJ * 57,25 tonnes CO_2 per TJ).

The reduction in the CH_4 emission is based on the amount of organic matter VS (Volatile Solids). The amount of VS in treated slurry is calculated as shown in Equation 5. It is assumed that slurry from cattle stems from dairy cattle and that slurry from pigs stems from slaughter pigs. The Danish Energy Authority (Søren Tafdrup, pers. comm. 2003) estimates that cattle slurry represents 45 percent and that pig slurry represents 55 percent of the total amount of biogas treated slurry.

Equation 7

$$\mathrm{CH4}_{reduction,i} = \mathrm{VS}_{treatedslurry,i} * \mathrm{B}_{\mathrm{o,i}} * \mathrm{MCF} * 0.67 * \mathrm{R}_{CH4-potetial,i}$$

where $CH_{4\ reduction}$ is the reduction in the amount of methane from livestock type *i*, VS treated slurry is the amount of treated slurry, B_0 is the maximum methane forming capacity, MCF is the methane conversion factor and $R_{CH4\text{-}potential}$ is the reduction potential – i.e. 30 percent for cattle slurry and 50 percent for pig slurry. Table 39 provides the background data employed for the calculation of the methane reduction resulting from biogas production.

Table 39 Data used in the calculation of VS in biogas treated slurry and the reduction in the CH_4 emission i 2002

2002	Amount of slurry used in biogas production	Dry matter (Ts)[a]	VS of Ts[b]	VS in treated slurry	Reduced CH_4 emission as result of biogas treatment
	M tonne slurry	pct	pct	10^6 kg VS	Gg CH_4
Cattle slurry	0.63	10.3	80	15.69	0.25
Pig slurry	0.78	6.1	80	18.92	0.57
Total reduction					**0.82**

[a] after Poulsen et al. 2001

[b] after Henrik.B. Møller, DIAS (pers. comm. 2003), Husted 1994 and Massé et al. 2003

In 2002, the total effect of biogas plants was calculated at a reduction of 0.82 Gg CH_4, which corresponds to 0.5 percent of the total CH_4 emission from the agricultural sector. The extent of the reduction is expected to rise in coming years due to increased focus on biogas production as a potential approach in relation to reducing the greenhouse emission from agricultural activities.

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

6.5 Deviations from IPCC CH_4 standard values

IPCC guidelines recommend that national production Figures are used as far as possible. In earlier emissions inventories, emission factors were based on Danish standard values, but aligned with production conditions in 1995. This means that the same emission factor was used for all years and that this was calculated on the basis of feed intake and housing type, corresponding to conditions in 1995. Recalculation of the CH_4 emission is based on further development of the methodology previously used. The recalculations now take into account that a change in feed intake and housing type distribution has taken place over the years, which is reflected as changes in emission factors.

In order to be able to compare the emission factors with the IPCC recommended standard values, the Danish emission factors are calculated in Table 40 as the average methane emission per year for each livestock category. I.e. the calculated emission factor corresponds to the emission per livestock unit, which in turn corresponds with the number provided in Statistics Denmark's agricultural statistics.

Table 40 Comparison of IPCC standard values against the emission factors calculated in earlier emissions inventories and in the revised inventory

	IPCC	Earlier calculation	Recalculation	
	Tier 1	Tier 2	Tier 2	Tier 2
	kg CH_4/animal/yr	kg CH_4/ animal/yr	kg CH_4/ animal/yr	kg CH_4/ animal/yr
			1985	2002
Digestion				
Dairy cattle	100.00	104.14	109.31	117.95
Other cattle	48.00	37.77	32.81	35.80
Sheep (incl. lambs)	8.00	8.00	17.17	17.17
Slaughter pigs + weaners	1.50	1.50	0.92	0.94
Horses	18.00	18.00	23.90	23.90
Goats (incl. kids)	5.00	Not calculated	13.15	13.15
Sows	1.50	1.50	2.40	2.53
Animal manure				
Dairy cattle	14.00	21.80	13.57	17.26
Other cattle	6.00	1.60	2.47	1.62
Slaughter pigs + weaners	3.00	2.10	1.65	2.35
Sows	3.00	6.00	4.00	5.05
Sheep (incl. lambs)	0.19	0.46	0.32	0.32
Horses	1.60	1.10	1.74	1.74
Hens + pullets	0.08	0.07	0.03	0.02
Broilers	0.08	0.02	0.01	0.01
Ducks, geese and turkeys	0.08	0.06	0.02	0.03
Animals bred for skins	Not calculated	Not calculated	0.23	0.44
Goats (incl. kids)	0.12	Not calculated	0.26	0.26

For dairy cows, the emission factor arrived at in the recalculation agrees more closely with the emission from other lands with comparable production conditions (USA and Holland). The emission factor for dairy cows is higher than the IPCC standard value due to Danish agricultural conditions with high lactating dairy cows and their associated higher feed consumption. Feed consumption for dairy cows, large breed, has increased from 5,700 FE in 1985 to 6,100 in 2002.

The emission factor calculated for other cattle types is somewhat lower than that stated in the IPCC guidelines. Among other things, this can be due to the relatively low number of sucklers, a large proportion of food intake taking place in the stable and the relatively high productivity level in Danish agriculture.

In the recalculation of the CH_4 emission for pigs, distinction is drawn between sows, weaners and slaughter pigs, as opposed to previously, where the emission associated with digestive processes did not distinguish between the various sub-categories. The same value, as that recommended by the IPCC is, therefore, used in the calculation – i.e. 1.5 kg CH_4 per year per animal.

The emission factor for sheep and goats is almost twice as high compared with the IPCC standard values. This can be seen in the light of the inclusion of the emission from lambs and kids in the Danish values. The emission factor calculated for horses is, similarly, higher than the values stated by the IPCC.

The IPCC has not prepared guidelines for the methane emission associated with animals bred for their skins. In consideration of that Denmark is the world's largest producer of mink, it has been decided that the emission from this type of livestock should be included in the inventory. It is not expected that a significant methane emission stems here from digestive processes, so the emission stems exclusively from the handling of the manure for this category of livestock.

7 Nitrous oxide emission

Nitrous oxide is formed in the majority of reactions where nitrogen is present which means, to a large degree, that the emission of N_2O is associated with all stages in agricultural production. From Figure 7, it can be seen that the largest part of the emission is linked to the use of animal and mineral fertilisers. The emission from nitrogen leaching represents the largest single emission source in the inventory at around 32 percent of the total N_2O emission from agriculture in 2002. The direct emission from artificial and animal manure applied on the field constitutes 20 percent and 17 percent, respectively, of the total emission from the sector.

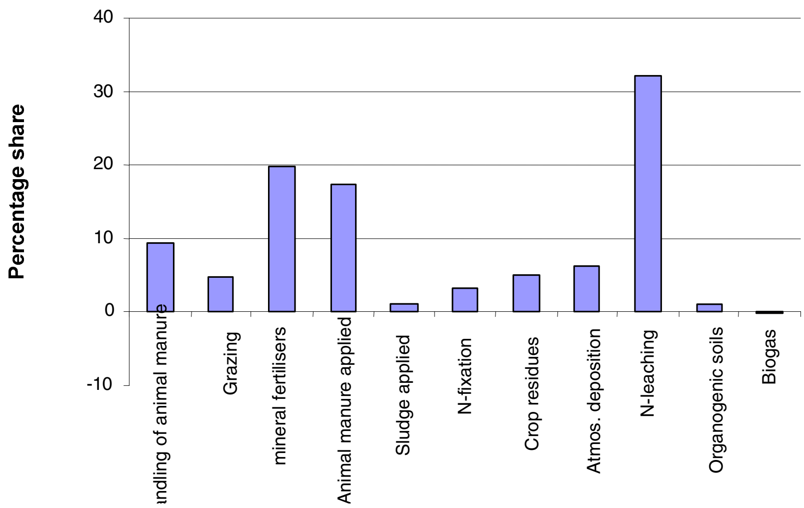

Figure 7 Distribution of the N_2O-emission, 2002, according to source (percent)

7.1 Emission factors

The emission of N_2O is determined as a fraction of the amount of nitrogen for each source. The fraction varies between sources and is often highly uncertain as the emission depends on the actual prevailing biological and climatic conditions.

Table 41 shows the sources from which the N_2O emission is calculated. In determining the emission, standard values for emission factors recommended by the IPCC are employed. The N_2O-N emission is calculated according to Equation 8.

Equation 8

$$N_2O = N_i * EF_i * \frac{44}{28}$$

Where N_i is the N in the nitrogen source and EF_i is the emission factor. The conversion from N_2O-N to N_2O is carried out by multiplying the respective molecular weights.

Table 41 Emission factors employed to determine the emission of nitrous oxide

Source		Emission factor (IPCC)	
Handling of animal manure:	- solid sTable manure and deep litter	EF_1	0.02
	- slurry and liquid manure	EF_2	0.001
	- poultry housed without solid floor	EF_3	0.005
Manure deposited on grass under grazing		EF_4	0.02
Mineral fertiliser applied to agricultural land[a]		EF_5	0.0125
Animal manure applied to agricultural land[b]		EF_6	0.0125
Sludge applied to agricultural land		EF_7	0.01
N-fiixing crops		EF_8	0.0125
Crop residues left on the field after harvest		EF_9	0.0125
NH_3 and NO_x evaporation		EF_{10}	0.01
Leaching		EF_{11}	0.025
Cultivation of organogenic soils[c]		EF_{12}	8 kg/ha (0.0125)
Straw burning		EF_{13}	0.007

[a] Calculated as the amount of N sold in mineral fertilisers minus the NH_3 emission

[b] Calculated as N ex storage minus the NH_3 emission from application

[c] The emission from organic soils has been changed in a new version. It is now estimated from the amout of degraded organic matter in organic soils as calculated in the LULUCF sector and the C:N-relationship in the organic matter using an EF of 0.0125 (see Gyldenkærne et al. 2005).

7.2 N_2O from stored animal manure and grazing

The amount of N in animal manure is determined from the normative Figures (Poulsen et al. 2001). Under the anaerobic conditions in slurry and liquid manure it is expected that the emission of N_2O is relatively low, while the emission from deep litter systems and solid manure in the housing units is expected to be higher.

Equation 9

$$N_2O - N_{handling\ of\ manure} = \sum N_{ex\ animal,\ fertilser\ type, i} * EF_i$$

where $N_2O–N_{handling\ of\ manure}$ is the emission of $N_2O–N$ from handling manure, $N_{ex\ animal,\ manure\ type,\ i}$ is the amount of nitrogen ex animal distributed according to manure type (liquid manure, slurry, solid manure, deep litter manure) and EF_i is the emission factor for the respective animal manure type. For solid and deep litter manure, the emission factor is 0.02 (EF_1) and for liquid manure and slurry, 0.01 (EF_2). For poultry housed without solid flooring, the emission factor is 0.005 (EF_3). For animal manure applied on grass, the emission factor is calculated at 0.02 (EF_4).

As the emission factor for liquid manure is lower than for solid manure, the transition from the previously more traditional straw-based housing systems to slurry-based systems leads to a reduction in the emission of nitrous oxide.

In Figure 8, the total amount of nitrogen in animal manure (N ex animal) is shown for the period 1985 to 2002. N ex animal has fallen from 316,000 tonne in 1985 to 277,000 tonne in 2002, which equates to a reduction of 12 percent. From 1985, the population of cattle has fallen against a rise in pig production. The reduction in N ex animal should be viewed in the light of the marked improvement in feed utilisation.

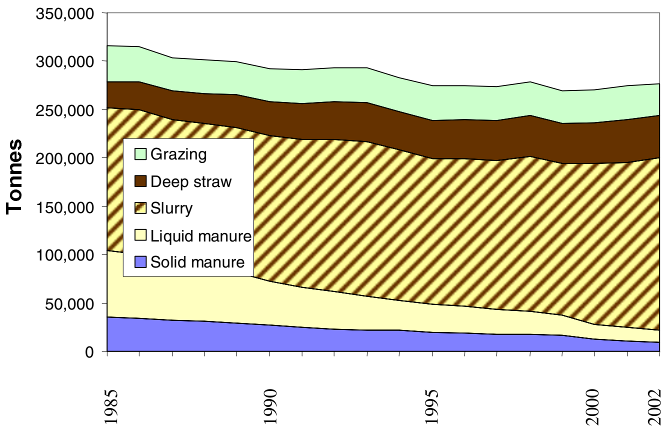

Figure 8 Total amount of nitrogen in animal manure (N ex animal)

7.3 N_2O from nitrogen applied to agricultural land

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

Equation 10

$$N_2O - N_{fertiliser} = \begin{cases} (N_{mineral\ fertiliser} - N_{NH_3,mineral}) * EF_5 + \\ (N_{animal\ manure,ex\ storage} - N_{NH_3,application}) * EF_6 + \\ (N_{sludge} - N_{NH_3,sludge}) * EF_7 \end{cases}$$

where:

N_2O–$N_{\text{fertiliser}}$ is the emission of N_2O–N, $N_{\text{mineral fertiliser}}$ is the consumption of mineral fertiliser, $N_{\text{NH3, mineral}}$ is the ammonia emission from mineral fertiliser, $N_{\text{animal manure,,ex storage}}$ is the amount of nitrogen in animal manure ex storage, $N_{\text{NH3, application}}$ is the ammonia loss under the spreading of animal manure, N_{sludge} is the amount of nitrogen in sewage or industrial sludge applied to agricultural land with $N_{\text{NH3, sludge}}$ as the associated ammonia emission. EF_x is the emission coefficient (see Table 41). All Figures are stated in the same units.

Animal manure which is incorporated as plant nutrients is calculated in the same way as N ex storage from the normative values (Poulsen et al. 2001) minus the NH_3 emission which occurs under the application process determined in the ammonia inventory.

Nitrogen associated with the consumption of mineral fertilisers is calculated by the Danish Plant Directorate and the ammonia emission, calculated in the ammonia inventory, is subtracted (see Section 5.2).

The amount of nitrogen in sludge from wastewater treatment works, as well as sludges from industry, applied on agricultural land is calculated by the Danish EPA (see Section 5.4). The emission from sludge is calculated in the ammonia inventory.

Table 42 shows the total amount of nitrogen from animal manure, mineral fertilisers and sludge applied on agricultural land, as well as the emission of nitrous oxide, in the period 1985 to 2002. The N_2O emission from application to crops fell from 7.35 kg Gg N_2O-N in 1985 to 5.00 kg Gg N_2O-N in 2002 – i.e. 32 percent over the period. The reduction is primarily due to the reduction in the use of mineral fertilisers.

Table 42 Nitrous oxide emission calculated in the basis of the amount of nitrogen applied on agricultural land minus the ammonia emission

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
N applied on field								kt N										
N in mineral fertilisers	398.1	382.1	381.3	367.0	377.0	400.4	394.9	369.5	332.9	326.2	315.9	290.8	287.6	283.2	262.7	251.5	233.7	210.8
NH_3-N, mineral fertiliser	7.9	7.3	7.3	7.1	7.4	8.7	8.4	7.9	7.6	7.9	7.6	6.6	6.2	6.2	5.8	5.6	5.1	4.6
N in animal manure	279.1	279.0	269.1	266.9	264.9	258.1	255.9	257.6	257.3	247.9	238.5	239.1	238.7	244.0	235.8	236.5	240.0	244.0
NH_3-N, animal manure	84.5	84.3	80.9	80.0	78.8	76.8	74.9	74.6	72.9	69.0	64.8	63.6	63.9	65.5	63.4	62.9	63.1	62.0
N i sludge	3.5	3.5	3.6	3.8	4.3	4.6	5.9	6.9	9.5	8.9	9.1	9.2	8.5	8.9	8.0	8.8	10.8	11.5
NH_3-N, sludge	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N-total	588.3	572.9	565.7	550.5	559.8	577.6	573.3	551.4	519.0	506.0	491.0	468.8	464.7	464.3	437.3	428.3	416.2	399.7
Emission																		
Gg N_2O-N	7.35	7.16	7.07	6.88	7.00	7.22	7.17	6.89	6.49	6.33	6.14	5.86	5.81	5.80	5.47	5.35	5.20	5.00
Gg N_2O	11.56	11.25	11.11	10.81	11.00	11.35	11.26	10.83	10.20	9.94	9.65	9.21	9.13	9.12	8.59	8.41	8.18	7.85
Gg CO_2-equiv.	3.58	3.49	3.44	3.35	3.41	3.52	3.49	3.36	3.16	3.08	2.99	2.85	2.83	2.83	2.66	2.61	2.53	2.43

The emission factor of 1.25 percent for mineral and animal manure is currently under discussion. It is argued that the factor for animal manure is presumably somewhat higher than that for mineral fertiliser as the carbon content in the former promotes N_2O formation. This could mean that the emission factor for mineral fertiliser could be reduced to 0.7 - 0.8 percent and the emission factor for animal manure be increased by 2.5 percent. A change in the emission factors would mean a lower reduction of nitrous oxide in the period 1985 to 2002 due to the marked fall in the consumption of mineral fertilisers. The Danish soils are generally light soils favouring lower N_2O formation than the standard IPPC values. Changes in the emission factor will therefore not take place before validated emission factors under conditions than the Danish soils has been performed to avoid unnecessary uncertainties in the inventory.

7.4 N_2O from nitrogen fixing plants

Nitrogen fixing plants contribute to the N_2O emission. According to the IPCC guidelines, the total amount of nitrogen from nitrogen fixing plants should be included in determination of the N_2O emission.

The calculation of N-fixation for legumes, peas/barley (whole-crop), lucerne and clover grass is based on the harvest yield, while that of grass field legumes for the production of seed and peas for conservation is based on the area under cultivation. Yield and area for the individual nitrogen fixing plants are based on data from Statistics Denmark.

The method for calculations associated with N-fixation in crops is based on calculations and data from DIAS (Kyllingsbæk 2002, Kristensen 2003). The amount of nitrogen fixed in crops is determined on the basis of the N-content in the yield for the individual year, calculated, in turn, on the basis of information on dry matter content and raw protein from the feedstuffs Table (DAAS, 2000). The N-content in roots and stubble is taken into consideration in the calculation as well as the size of the proportion of the N-content in the plant, which can be attributed to nitrogen fixation (Equation 11).

Equation 11

$$N_2O\text{ - }N_{N\text{-fix}} = \sum (Ts_{i,\text{ yield}} * N_{i,\text{ pct}} * (1 + N_{i,\text{ pct in root and stubble}}) * A_{\text{pct fix}}) * EF_8$$

where $N_2O\text{-}N$ = nitrous oxide emission

Ts_{iyield} = dry matter, yield, kg per ha for crop i

$N_{i,pct}$ = nitrogen percentage in dry matter

$N_{i,pct\ root\ +\ stubble}$ = nitrogen percentage in root and stubble

$A_{pct\ fix}$ = percentage of nitrogen which is fixed

Table 43 provides background data for the calculation of the amount of nitrogen from nitrogen fixing crops.

Table 43 Background data for calculation of N from nitrogen fixing crops

Crop	Dry matter content[1]	N-content i DM[1]	Straw yield in pct. of grain yield[2]	Share, root+ stubble[3]	Share of N in crop which is fixed[3]	N-fixed
	pct.	pct.	pct.	pct.	pct.	kg N/tonnes harvested
Based on yield						
Legumes grown to maturity						
Grain	85	3.97		25	75	
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 and clover fields as well as fields sown with an undercrop	13	4.00		75	90	8.2
Based on area	kg N/ha/year					
Peas for conservation (N-fixed is as legume to maturity – assumed that peas constitute 80% of the area)						
Seed production:						
Red clover	200					
White clover	180					
Medick (*Medicago*)	180					

[1] Feedstuff Table (DAAS, 2000)

[2] Kyllingsbæk (2000)

[3] Kristensen (2003) and Kyllingsbæk (2000)

In calculating N-fixation, the proportion of nitrogen-fixing plants in the various crops is taken into account. The proportions, evaluated by DIAS (Kyllingsbæk 2000), are shown in Table 44. The share of peas (whole crop) in cereals, for silage, increased in the period from 1985 to 2002 as did the share of clover as an undercrop and fields of clover grass as well as the clover percent in clover grass fields.

Table 44 Estimate of the share of nitrogen fixing plants in crops (Kyllingsbæk 2000)

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
								pct.										
Cereals for silage																		
of which share of peas (whole-crop)	15	20	20	25	25	30	30	35	35	40	40	45	45	50	50	50	50	50
of which share of peas in whole-crop	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Legumes, marrow-stem kale and other green fodder																		
Share with legumes:	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
of which share with peas	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Peas for conservation	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
Clover grass in rotation																		
Share of clover in clover grass field	66	68	70	72	74	76	78	80	82	84	85	86	87	88	89	90	90	90
Clover percentage	20	20	20	20	20	20	20	20	20	20	22	24	26	28	30	30	30	30
Grass not in a rotation																		
Clover percentage	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Fields with undercrop																		
Share with clover grass	66	68	70	72	74	76	78	80	82	84	85	86	87	88	89	90	90	90
Clover percentage	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30

Table 45 shows the values for nitrogen fixation for the various different crops. From the first column in the Table, it can be seen that N-fixation per hectare has varied significantly over the years as a result of differences in yield level. In 2002, total N-fixation is calculated to be 33,800 tonnes N. According to the IPCC standard values, it is assumed that the N_2O emission constitutes 1.25 percent of the amount of nitrogen fixed, which corresponds to 0.66 Gg N_2O or, calculated as CO_2-equivalents, 0.21 tonnes. The main part of this emission, i.e. approximately 75 percent, comes from fields of clover grass and from the cultivation of legumes to maturity.

Table 45 N-fixation per hectare as well as fixation for 2002

	N-fixation per hectare Variations		N- fixation 2002	
	1985-2002	2002	N- fixation	Distribution
	kg N/ha	kg N/ha	kg N fix	pct.
Legumes to maturity	95-179	139	5,572	16
Corn for silage	10-38	23	2,598	8
Legumes/marrow-stem kale	0-1	0	50	0
Lucerne	307-517	449	1,600	5
Clover grass in rotation	41-94	90	19,685	58
Grass not in rotation	6-11	9	1,515	4
Fields with undercrop	6-15	6	1,590	5
Peas for conservation	76-144	111	480	1
Seeds for sowing	181-186	182	757	2
Total N-fix			**33,846**	**100**

As illustrated in Figure 9, the level of nitrogen fixation has not changed significantly in the period from 1985 to 2002. N-fixation from the cultivation of legumes to maturity reduced, while that in clover grass fields has increased as a result of a rise in the clover percentage used.

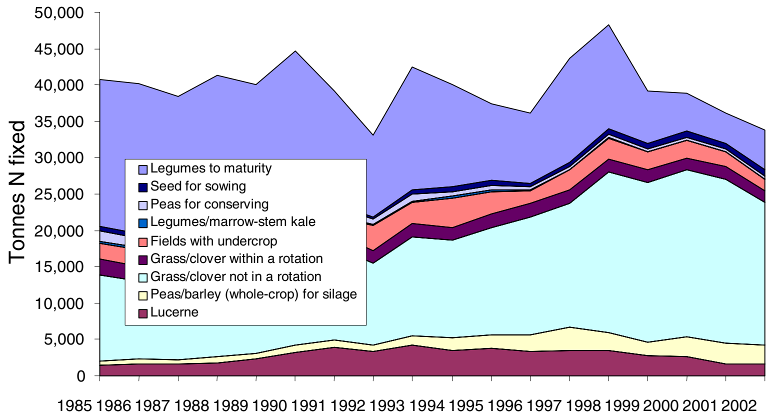

Figure 9 Total nitrogen fixation 1985-2002

7.5 Crops residues

According to the IPCC guidelines, the nitrogen transformation from crop residues left on the field after harvest should be included as a source in the inventory for nitrous oxide.

The IPCC guidelines are based on the general values for the relationship between grain and straw yields. National values for N-content in crop residues are used in the Danish inventory, based on data from DIAS. Data for yield and area cultivated are collected from Statistics Denmark.

7.5.1 N-content in crops

For the content of nitrogen in crop residues, N-content in the various plant parts – i.e. chaff, stubble, crop tops (potatoes, fodder beets) as well as leaf debris from grass and set-aside fields. The N-content is based on the calculations of Djurhuus and Hansen (2003). Crops residues in the form of straw are calculated as the amounts of non-salvaged straw provided in the agricultural statistics compiled by Statistics Denmark.

The total amount of nitrogen is calculated, hereafter, as shown in Equation 12.

Equation 12

$$N_2O-N_{crop\ residue,j} = \sum_{1}^{N} ha_{i,j} * ((\frac{N_{i,stubble}}{N_{i,ploughing\ frequency.}}) + N_{i,chaff} + N_{i,tops} + N_{i,leaf\ debris}) * EF_9$$

where i is the crop, j is the year, ha is the area on which the crop is grown, N_i is nitrogen derived from chaff, stubble, plant tops and leaf debris in kg ha^{-1}, $N_{i,\ plouging\ frequency}$ is the number of years between ploughing and EF_9 is the IPCC standard emission factor (0.0125).

The amount of N in the respective plant parts under Danish conditions is shown in Table 46. If the N-content is not provided in Djurhuus and Hansen (2003) for a crop type, values for similar crop types are used. The N-content is calculated on the basis of the relatively few observations, however, is the result of the best data available at the present time.

In the inventory it is assumed that grass fields on average are ploughed every other year and set-aside fields every 10 years.

Table 46 Overview of the N-content in residues from agricultural crops under conditions of normal fertilising (Djurhuus & Hansen, 2003).

	Stubble	Chaff	Tops	Leaf debris	Ploughing frequency	N-content in crop remains	
Crop	kg N/ha	kg N/ha	kg N/ha	kg N/ha	years between ploughing	kg N/ha/year	M kg N/year
Winter wheat	6.3	10.7	-	-	1	17.0	9.60
Spring wheat	6.3	7.4	-	-	1	13.7	0.15
Winter rye	6.3	10.7	-	-	1	17.0	0.79
Triticale	6.3	10.7	-	-	1	17.0	0.61
Winter barley	6.3	5.9	-	-	1	11.3	1.32
Spring barley	6.3	4.1	-	-	1	10.4	7.30
Oats	6.3	4.1	-	-	1	10.4	0.57
Winter rape	4.4	-	-	-	1	4.4	0.34
Spring rape	4.4	-	-	-	1	4.4	0.03
Potato (tops)	-	-	48.7	-	1	48.7	1.83
Fodder beet (tops) – not salvaged	-	-	53.9[a]	-	1	53.9	3.65
Straw – not salvaged	-	-	-	-	1	7.6[a]	11.67
Maize for silage	6.3	-	-	-	1	6.3	0.60
Barley/peas (whole-crop) for silage	6.3					6.3	0.21
Grain for silage	6.3	-	-	-	1	6.3	0.35
Legumes, marrow-stem kale and other green fodder	6.3	-	-	-	1	6.3	0.00
Peas for conservation	11.3	-	-	-	1	11.3	0.01
Vegetables	11.3	-	-	-	1	11.3	0.07
Grass and clover grass in a rotation	32.3		-	10.0	2	26.2	5.63
Grass and clover grass not in a rotation	38.8		-	20.0	-	20.0	3.55
Set-aside	38.8			15.0	10	18.9	4.26
Total N from crop residues – 2002							**52.55**

[a] Value for 2002 – varies from year to year. Calculated on the basis of yield calculated by Statistics Denmark, as well as the N-content based on feedstuff Tables.

7.5.2 N-content in straw and fodder beet tops

For straw and fodder beet tops, which are ploughed in, the amount of nitrogen is calculated as for straw (not salvaged) in Statistics Denmark's calculations of straw yield and the amount of salvaged straw and fodder beet leaves.

The largest part of the straw which is not salvaged constitutes wheat and rye straw. The amount of N is calculated, therefore, as the total amount of unsalvaged straw, multiplied by the dry matter percentage and the N-content for wheat straw. In the feedstuffs Table, the raw protein content is calculated at 3.3 percent and 6.25 is used as a conversion factor for the calculation of the N-content.

For beet leaves, it is assumed that factory and fodder beets have the same top yield. The total area of decomposed beet leaves is calculated as the difference between the total fodder beet area and the amount of stored fodder beet tops divided by fodder beet yield (Statistics Denmark's agricultural statistics, Table 10.1). The nitrogen content in fodder beet tops is calculated on the basis of the feedstuffs Table's calculations for fresh fodder beet tops (Fodder code 353) with a dry matter content of 12 percent and a raw protein content of 16.4 percent.

7.5.3 Emission

Table 47 shows the amount of nitrogen in crop residues according to various different sources. A rise in the amount of nitrogen can be seen over the period from 1985 to 2002. In addition to the introduction of the set-aside scheme in 1991, the rise is due to the increasing proportion of straw which is left on the field after harvest. The nitrous oxide emission has risen over the period from 0.57 Gg N_2O-N to 0.66 Gg N_2O-N, representing an increase of 0.04 million tonnes CO_2-equivalents.

Table 47 M kg N in crop residues distributed according to stubble, chaff, tops and straw, as well as the N_2O emission, 1985 to 2002

N_2O emission from crop residues	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Total crop residues (mil. kg N)	45.9	45.1	44.7	45.1	49.5	57.6	56.1	48.4	49.8	50.4	54.9	55.9	54.9	54.8	53.5	54.9	56.4	52.6
- of which stubble	17.6	17.3	15.9	16.8	17.2	17.3	17.0	17.3	17.4	17.1	17.0	17.6	17.4	17.4	17.6	17.9	17.9	15.6
- of which chaff	10.2	10.1	10.3	9.7	10.7	11.3	11.0	11.7	11.2	11.3	11.4	12.1	12.4	12.4	11.6	11.8	12.1	10.7
- of which beet and potato tops	4.8	4.7	4.7	5.5	5.7	7.1	7.1	6.7	7.2	6.1	5.8	5.9	5.5	5.7	5.4	5.3	5.2	5.5
- of which leaf debris	7.2	6.9	6.7	6.9	6.9	6.8	6.7	6.7	10.1	10.4	10.3	9.7	8.1	7.9	8.7	9.0	9.2	9.1
- of which straw	6.1	6.1	7.0	6.2	9.0	15.1	14.3	6.1	3.9	5.4	10.4	10.7	11.6	11.4	10.1	10.8	12.0	11.7
Emission																		
Gg N_2O-N	0.57	0.56	0.56	0.56	0.62	0.72	0.70	0.61	0.62	0.63	0.69	0.70	0.69	0.68	0.67	0.69	0.71	0.66
Gg N_2O	0.90	0.89	0.88	0.89	0.97	1.13	1.10	0.95	0.98	0.99	1.08	1.10	1.08	1.08	1.05	1.08	1.11	1.03
M tonnes CO_2-equiv.	0.28	0.27	0.27	0.27	0.30	0.35	0.34	0.29	0.30	0.31	0.33	0.34	0.33	0.33	0.33	0.33	0.34	0.32

7.6 Atmospheric deposition of ammonia and nitrous oxides (NO_X)

The emission of NH_3 and NO_X gases contributes to the emission of nitrous oxide. According to the IPCC guidelines, the emission of nitrous oxides derived from ammonia evaporation should be included as a source in the N_2O emission. The IPCC recommends that the amount of ammonia emitted should alone be included in the inventory and not that resulting from surrounding countries' NH_3 emissions.

Around 98 percent of the total ammonia emission stems from agriculture (Illerup et al. 2002). In addition to the formation of N_2O, a release of N_2 and NO_X also occurs. In the guidelines no recommendation is given on the amount of NO_X. Danish data with regard to the quantification of NO_X formation is not available either. The total emission from the evaporation of ammonia and nitrous oxides is therefore in this case calculated exclusively on the basis of the ammonia emission.

The emission is calculated as illustrated in Equation 13 - i.e. as the total ammonia emission multiplied by the IPCC standard value for the emission factor of 0.01 (EF_{10}).

Equation 13

$$N_2O - N_{dep} = (NH3_{livestock} + NH3_{artificial\ fertil.} + NH3_{sludge} + NH3_{crops} + NH3_{amm.straw}) * EF_{10}$$

The ammonia emission and the associated N_2O emission from agriculture are shown in Table 48. The emission fell from 1,100 Gg N_2O in 1985 to 800 Gg N_2O in 2002, which equates to a fall of 0.16 tonnes in CO_2 equivalents or a fall of 29 percent.

Table 48 Total ammonia emission and associated N2O emission, 1985 – 2002 (Source: NERI 2004a)

Emission per year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Ammonia emission tonnes NH_3-N	113800	114200	111400	108800	109300	109300	105900	104200	101100	97600	92000	88600	88100	88900	84500	84100	83200	80800
Nitrous oxide emission N_2O-N, tonnes	1138	1142	1114	1088	1093	1093	1059	1042	1011	976	920	886	881	889	845	841	832	808
CO_2 emission M tonnes CO_2-equiv.	0.55	0.56	0.54	0.53	0.53	0.53	0.52	0.51	0.49	0.48	0.45	0.43	0.43	0.43	0.41	0.41	0.41	0.39

7.7 Leaching

Nitrogen which is transported out of the root zone can be transformed to N_2O. According to the IPCC, it is recommended that an N_2O emission factor of 0.025 is employed, of which 0.015 stems from leaching to groundwater, 0.0075 stems from further transport to watercourses and 0.0025 from transport out to sea. The N_2O emission from nitrogen leaching is calculated as the amount of nitrogen leached from the root zone multiplied by the emission factor, stated as the standard value by the IPCC.

Equation 14

$$N_2O - N_{leaching} = N_{leaching} * EF_{11}$$

In connection with the end evaluations of the VMP II (Plan for the Water Environment II), data for nitrogen leaching has be re-evaluated. Determination of the amount of nitrogen leached is based on two different model calculations – SKEP/Daisy and N-Les2 (Børgesen & Grant 2003) carried out by DIAS and NERI. SKEP/DAISY is a dynamical crop growth model taking into account the growth factors, where as N-Les2 is an empirical leaching model based on more than 1200 leaching studies performed in Denmark during the last 15 years. The models provide rather similar results for nitrogen leaching on a national basis. An average of the results from the two models is used in the end evaluation of VMP II and the same average is used in connection with the emissions inventory.

In the period 1985 to 2002, the amount of nitrogen leached has almost halved as a result of the marked fall in the consumption of mineral fertilisers and the increased utilisation of the nitrogen content in animal manure (Table 49). Another important factor is that animal manure at present are applied to the field in spring and not in the autumn as in the 80s. This has, at the same time, contributed to a corresponding reduction in the emission of N_2O from 7.6 Gg N_2O-N in 1985 to 4.2 Gg N_2O-N in 1985, or 1.66 million tonnes CO_2 equivalents.

Table 49 Leaching of nitrogen 1985 - 2002 (Børgesen & Grant, 2003)

	N-leaching kt N	Gg N_2O-N	M tonnes CO_2-equiv.
1985	304	7.59	3.70
1986	296	7.40	3.61
1987	289	7.22	3.51
1988	281	7.03	3.42
1989	274	6.84	3.33
1990	267	6.68	3.25
1991	261	6.52	3.18
1992	254	6.36	3.10
1993	248	6.20	3.02
1994	241	6.04	2.94
1995	235	5.88	2.86
1996	219	5.48	2.67
1997	213	5.32	2.59
1998	207	5.18	2.52
1999	192	4.81	2.34
2000	179	4.48	2.18
2001	174	4.35	2.12
2002	168	4.19	2.04

Figure 10 illustrates the total amount of nitrogen applied as fertiliser on agricultural land in the form of animal manure, mineral fertiliser and sludge compared with the amount of N leached. It can be seen that N leached as a percentage of N applied fell from 42 percent in 1985 to 34 percent in 2002. The standard IPCC value is 30 percent.

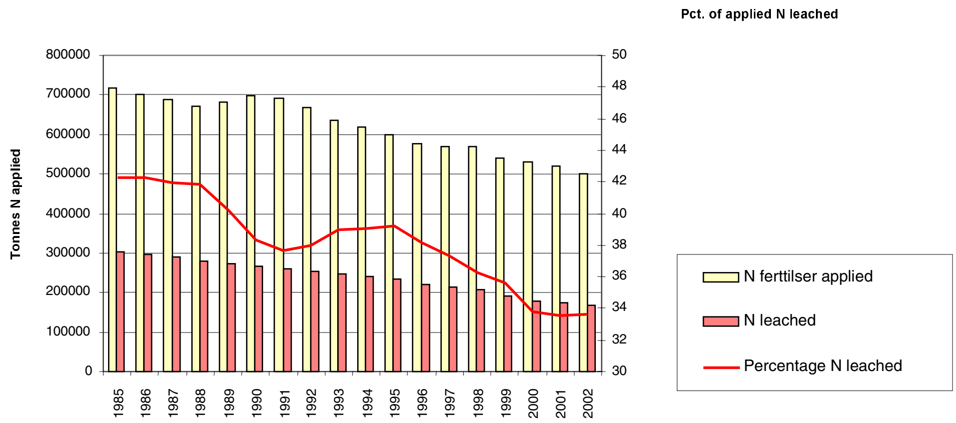

Figure 10 Leaching of nitrogen 1985 to 2002

In the calculation of leaching (Børgesen & Grant, 2003), the nitrogen-removal effect, which the establishment of wetlands can contribute to, has not been taken into account. The effect of wetlands must be regarded as of little significance on a national scale at the present time. Up to the end of 2003, the establishment of 1,880 ha of wetland had been completed and a commitment had been made in relation to a further 3,200 ha (Danish Forest and Nature Agency, 2003). Furthermore, a commitment to devote resources to initial studies for 66 projects, covering a total of around 10,000 ha, had been made. These measures could result in effects which could be of a scale where they should be included in emissions inventories.

7.8 Cultivation of organogenic soils

Under cultivation of organogenic soils (humus-rich soils), organic matter is broken down and, thereby, releases both CO_2 and N_2O. The size of the emission depends on the circumstances surrounding cultivation (crop-type, rotation, mechanical soil processing, saturation, pH, etc.).

In earlier inventories, the emission from the cultivation of organogenic soils is calculated as a fixed area for all the years from 1985 to 2002 – i.e. 18,400 ha. The area corresponds to 10 percent of land defined as JB 11 in the Danish soil classification. In this calculation the emission is estimated to 8 kg N_2O-N/ha. In the latest update of the Danish emission inventories is the N_2O emission calculated in the LULUCF sector where it is based on the annual degradation of ortganic matter and the associated C:N ratio in the organic matter multiplied with an emission factor of 1.25% (For further details see Gyldenkærne et al. 2005). This gives an approximately emission of 3-4 kg N_2O-N ha^{-1} yr^{-1}.

7.9 N_2O reduction from biogas-treated slurry

The use of slurry in biogas plants contributes to a reduction in the emission of N_2O. A part of the most easily converted dry matter is removed in the biogas treatment of slurry. The treatment will – all else being equal – lead to a reduction in the emission of N_2O under and after the spreading of animal manure.

Danish studies reveal that the N_2O emission from the application of biogas-treated slurry can be expected to be reduced by 36 percent in the case of cattle slurry and by 40 percent with pig slurry.

Table 50 Reduction of N_2O emission from the treatment of slurry in a large biogas plant. Capacity: 550 m^3 dag^{-1}. (Nielsen et al., 2002 on the basis of Sommer et al., 2001)

Reduction of N_2O	Untreated	Biogas treatment	Reduction resulting from biogas treatment	Reduction in emission
	tonne N_2O	tonne N_2O	tonne N_2O	pct
Cattle slurry	2,518	1,601	-917	36
Pig slurry	2,483	1,489	1,014	40

The reduction in the emission achieved is calculated as described in Equation 15 – i.e. as the amount of nitrogen in treated slurry multiplied by the reduction potential.

Equation 15

$$N_2O - N_{reduction} = N_{i,slurry,treated} * N_{content} * R_{N_2O,potential} * EF_{N_2O}$$

where N_2O-N $_{reduction}$ is the reduction in the amount of N_2O, N $_{i,\ slurry,\ treated}$ is the amount of N in treated slurry from livestock type *i*, R $_{N20,\ potential}$ is the reduction potential – i.e. 36 percent for cattle and 40 percent for pig slurry. For the emission factor for N_2O emission EF_{N2O} , the IPCC standard value of 1.25 percent is used.

The background data for the calculation of the reduction in N_2O is shown in Table 51.

Table 51 Data used in calculation of the reduction in N_2O emission in 2002

2002	Amount of slurry used in i biogas production	Average N-content in slurry[a]	Reduced N_2O emission
	M tonne slurry	pct	Gg N_2O
Cattle slurry	0.63	0.00538	0.02
Pig slurry	0.78	0.00541	0.02
Reduction in total			**0.04**

[a] after Poulsen et al. 2001

For 2002, the N_2O reduction is calculated at 0.04 Gg which represents less than 0.5 percent of the total N_2O emission from the agricultural sector.

In the emission inventory the effect is subtracted from biogas-treated slurry in the emission from dairy cattle and slaughter pigs, respectively.

The total reduction from 1990 to 2002, which stems from biogas plant operations, is shown in Appendix D.

7.10 Burning of straw

N_2O is emitted when surplus straw from harvest is burnt. The burning of straw has been banned since 1990 except for the burning of straw resulting from the cultivation of grass seed. In the period 1985 to 1989, the N_2O emission was calculated as the amount of nitrogen in the straw burnt multiplied by the emission factor of 0.007, based on the standard value recommended by the IPCC. The background data for the burning of straw is based on Statistics Denmark's Figures.

Equation 16

$$N_2O - N_{,straw\,burning} = N_{content} * EF_{straw\,burning}$$

Table 52 The contribution to the N_2O emission from the burning of straw, 1985 – 1989

	1985	1986	1987	1988	1989
Straw burning, M tonnes straw	1.094	0.938	0.901	0.708	1.065
N-content	6.374	5.518	5.168	4.169	5.857
N_2O-emission, Gg N_2O	0.07	0.06	0.06	0.05	0.06
CO_2-emission, M tonnes CO_2-eq.	0.02	0.02	0.02	0.01	0.02

7.11 Deviations from the IPCC N_2O standard values

Emission factors based on standard values recommended in the IPCC guidelines are employed in the calculation of the N_2O emission (IPCC, 1996; 2000). However, national values are employed for the NH_3 emission, which has an indirect effect on the N_2O emission.

In relation to the NH_3 emission from mineral fertilisers, the emission factor of 10 percent is recommended in the IPCC guidelines, whereas a factor of 2.2 percent is used in the Danish inventories. The difference should most likely be viewed in the light of the distribution of fertiliser types. Use of urea, which has a high emissions factor, represents less than 1 percent of the total consumption of mineral fertilisers in Denmark (see Table 26).

In all IPCC guidelines, the standard value for the NH_3 emission from animal manure is 20 percent of nitrogen content in animal manure (N ex animal). In the Danish inventory, data which comes directly from the ammonia inventory is used and the emission falls from 27 percent to 23 percent in the period from 1985 to 2002.

As mentioned in the section concerning the N_2O emission from the leaching of nitrogen, the share of nitrogen leached, calculated in relation to the amount of N applied on the field as fertiliser, is higher than the standard value provided by the IPCC. From 1990 to 2002, the leached share fell from 38 percent to 35 percent, while a value of 30 percent is used by the IPCC. The reduction in the leaching factor is due to changed agricultural practice where field application of animal manure has changed from autumn application to spring application. This change effects the leaching factor because Denmark during summer has an upwards movement of soil water due to precipitation deficit in contradiction to winter where there is a precipitation surplus with downwards movement of the soil water.

If the N_2O emission is calculated on the basis of IPCC standard values for the ammonia emission and N-leaching, then the emission would be 11 percent lower in 1985 and 4 percent lower in 2002. The most important reason for this difference is that the Danish inventory uses a higher percentage for the leaching of nitrogen. Furthermore, the Danish inventory takes into account the ammonia emission from the cultivation of crops and from ammonia-treated straw.

8 CO_2 from agricultural soil

Changes in the carbon content of soil should be included in the inventory for greenhouse gases under the assumption that the changes relate only to human activities. As a result of the changes in cultivation practices over time, the soil's carbon balance is influenced, which leads in turn to changes in the CO_2 emission. Moreover, the application of lime and the cultivation of organogenic soils similarly affect the CO_2 emission.

According to IPCC guidelines, the emission from these sources should not be included in the inventory for the agricultural sector, but rather under LUCF (Land Use Change and Forestry). The first estimate for the emission from the cultivation of agricultural land will be implemented in LUCF in the Danish greenhouse gas inventory under reporting of the emission for 2003.

The methodology for Land Use is described in a separate report from NERI (Gyldenkærne et al. 2005).

9 Conclusion

In response to a number of international conventions, Denmark has taken on the obligation to calculate the Danish emission to the atmosphere of a range of different substances. For the agricultural sector, these substances are ammonia and the greenhouses gases, methane and nitrous oxide. Denmark's National Environmental Research Institute (NERI) is responsible for preparation and reporting of the annual emissions inventories. In addition to the emissions inventories themselves, requirements in the various conventions call for documentation of the methods used in the calculations used in the inventories. This report should be viewed in the light of the reporting requirements of these conventions and, therefore, covers the inventory of emissions from the agricultural sector in the period 1985 to 2002 and a description of the methodology and the background for the data which form the basis for the inventories.

9.1 Emissions from 1985 to 2002

The emission of ammonia and greenhouse gases from agriculture stem primarily from livestock production, while a lesser part of the emission relates to the fertilising and cultivation of crops.

The ammonia emission fell in the period 1985 to 2002 from 138,400 tonnes pure ammonia (NH_3) to 98,300 tonnes NH_3, which corresponds to a 29 percent reduction. Similarly, greenhouse gas emissions over the same period fell from 13.79 M tonnes to 10.15 M tonnes CO_2-eq. which corresponds to a reduction of 26 percent.

The most significant reasons for the reduction in the emission of ammonia and greenhouse gases from agriculture come to light in consideration of the measures which have been put in place in connection with the Action Plans for the Aquatic Environment (VMPs). The results have, among other things, comprised an improvement in the utilisation of nitrogen in animal manure and, as a knock-on effect, a fall in the consumption of mineral fertiliser and an associated reduction in emissions. The improvement in the utilisation of nitrogen has occurred via improvements in feed efficiency and stricter legal requirements surrounding the handling of animal manure in storage and application.

9.2 Description of the methodology for the emissions inventories

Preparation of the Danish emissions inventories is based on international guidelines (EEA, 2004; IPCC, 1996 and IPCC, 2000). In Denmark, a relatively large amount of data and information is available concerning agricultural production, which, among other areas, includes data concerning livestock populations, slaughter activity, feed intake, N-separation, etc. Where data relevant for Danish agricultural production is not available, standard values recommended in the international guidelines are used.

Data used in the emissions inventories is collected, assessed and discussed in cooperation with a range of different institutions involved in research or administration within the agricultural sector. Especially of relevance here are Statistics Denmark, the Danish Institute of Agricultural Sciences (DIAS) and the Danish Agricultural Advisory Service (DAAS), but also the Danish Environmental Protection Agency (Danish EPA), the Danish Plant Directorate, the Danish Association of Agricultural Contractors and the Danish Energy Authority.

The foundations underpinning the methodology and 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.

10 Quality Assurance/Quality Control

10.1 Data delivery

In connection with the establishment of a formal Danish QA/QC-plan for the GHG inventories, arrangements on data delivery has be made with the following organisations:

Danish Institute of Agricultural Sciences:
Updated N excretion values

Updated feeding values

Updated number of grazing days

Updated ammonia emission factors

The Danish Plantdirectorate:
Consumption of mineral fertiliser

Annually updated stable type distribution

Amount of waste/sludge applied to farmland

Statistics Denmark:
Animal numbers

Detailed slaughter statistics

Peat excavation and Peat import and export

10.2 External review

This methodology report has been reviewed by Statistics Sweden, who is responsible for the Swedish agricultural inventory with the following comments:

"The report gives me a very impressive impact. It is well written and the calculation of the different emissions shows to be well integrated. Furthermore calculations have been made from 1985. I find that the report can be an inspiration for us, however, at the moment I am not able to give any specific suggestions for improvement."

Rolf Adolpsson, Statistics Sweden

15 May 2005

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Appendix

A) Ammonia emission from Danish agriculture 1985 - 2002

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
									tonnes NH_3-N									
Emission (NH_3-N)																		
Animal manure[1]	87,000	86,900	83,400	82,400	81,200	79,200	77,400	77,100	75,400	71,500	67,300	66,100	66,400	67,900	65,700	65,200	65,500	64,300
Mineral fertiliser[2]	7,900	7,300	7,300	7,100	7,400	8,700	8,400	7,900	7,600	7,900	7,600	6,600	6,200	6,200	5,800	5,600	5,100	4,600
Crops	13,200	13,100	13,100	13,000	12,900	13,000	12,9000	12,800	11,800	11,500	11,600	11,600	11,800	11,700	11,200	11,100	11,200	11,100
NH3 treated straw	5,400	6,600	7,300	6,000	7,400	8,400	7,100	6,300	6,200	6,700	5,500	4,200	3,700	3,000	1,700	2,000	1,300	800
Sewage sludge	0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Straw burning	300	200	200	200	200	0	0	0	0	0	0	0	0	0	0	0	0	0
Emission total	**113,800**	**114,200**	**111,400**	**108,800**	**109,300**	**109,300**	**105,900**	**104,200**	**101,100**	**97,600**	**92,000**	**88,600**	**88,100**	**88,900**	**84,500**	**84,100**	**83,200**	**80,800**

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
									tonnes NH_3									
Emission (NH_3)																		
Animal manure[1]	105,900	105,700	101,400	100,300	98,800	96,400	94,100	93,800	91,800	87,000	81,900	80,400	80,8000	82,600	80,000	79,400	79,700	78,200
Mineral fertiliser[2]	9,600	8,900	8,900	8,700	9,100	10,500	10,300	9,600	9,200	9,600	9,300	8,100	7,500	7,600	7,000	6,800	6,300	5,600
Crops	16,000	16,000	15,900	15,800	15,700	15,800	15,700	15,600	14,300	14,000	14,100	14,200	14,300	14,200	13,700	13,600	13,600	13,500
NH_3 treated straw	6,600	8,100	8,900	7,300	9,000	10,200	8,700	7,700	7,600	8,100	6,600	5,100	4,500	3,700	2,100	2,500	1,600	900
Sewage sludge	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Straw burning	300	300	300	200	300	0	0	0	0	0	0	0	0	0	0	0	0	0
Emission total	**138,400**	**138,900**	**135,500**	**132,300**	**132,900**	**133,000**	**128,800**	**126,700**	**123,000**	**118,700**	**112,000**	**107,800**	**107,200**	**108,200**	**102,800**	**102,300**	**101,300**	**98,300**

[1] Inc. horses at riding schools – corresponding to 3 – 4 times the Figure provided by DSt

[2] Inc. consumption used outside agriculture corresponding to 1-2% of the total consusmption

B) Nitrogen separation and ammonia emission according to livestock category 1985 - 2002

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
	tonnes N																	
N-separation																		
Cattle	170,413	165,196	157,344	152,913	152,094	151,860	149,672	145,344	145,305	139,681	138,707	138,641	132,760	131,614	125,901	125,426	126,280	122,101
Pigs	120,004	122,402	117,714	115,967	112,822	110,404	111,860	116,814	120,287	113,411	106,592	107,179	110,925	116,744	114,314	114,842	117,213	123,629
Poultry	7,609	7,972	8,191	9,246	10,367	10,510	10,441	10,995	11,816	13,119	12,156	11,950	11,759	11,541	11,893	11,912	12,062	12,040
Horses	7,000	6,950	6,900	6,850	6,800	6,599	6,521	6,438	6,353	6,264	6,172	6,237	6,302	6,367	6,432	6,497	6,561	6,626
Sheep and goats	1,003	1,269	1,417	1,710	1,926	2,125	2,459	2,388	2,098	1,940	1,969	2,076	1,601	1,537	1,359	1,547	1,745	1,436
Animals bred for skins	10,062	11,397	12,268	14,481	15,069	11,089	10,189	10,952	7,295	8,588	8,604	8,931	10,289	10,889	9,674	10,171	10,641	11,174
N-separation total	**316,091**	**315,185**	**303,833**	**301,167**	**299,078**	**292,587**	**291,142**	**292,932**	**293,153**	**283,004**	**274,200**	**275,015**	**273,635**	**278,693**	**269,573**	**270,395**	**274,503**	**277,006**

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
	tonnes NH_3-N																	
Ammonia emission																		
Horses	1,208	1,192	1,175	1,159	1,143	1,108	1,093	1,078	1,062	1,046	1,029	1,037	1,044	1,051	1,080	1,075	1,073	1,073
Cattle	35,624	34,259	32,374	31,164	30,756	30,999	29,731	28,120	27,394	25,677	24,836	24,252	23,207	23,048	22,136	22,633	22,627	21,135
Sheep and goats	126	159	176	212	237	261	302	293	256	237	240	253	195	187	167	187	210	171
Pigs	43,443	43,985	41,974	41,040	39,613	38,961	38,685	39,560	39,866	36,756	33,718	33,072	33,972	35,517	34,600	33,427	33,570	33,800
Poultry	2,620	2,716	2,789	3,137	3,519	3,550	3,551	3,754	4,029	4,454	4,156	4,057	4,025	3,959	4,075	4,127	4,141	4,092
Animals bred for skins	4,027	4,546	4,876	5,736	5,946	4,370	3,997	4,287	2,841	3,327	3,315	3,424	3,933	4,149	3,674	3,779	3,878	3,989
Emission total	**87,048**	**86,856**	**83,365**	**82,447**	**81,215**	**79,249**	**77,358**	**77,091**	**75,449**	**71,497**	**67,294**	**66,095**	**66,376**	**67,910**	**65,732**	**65,228**	**65,498**	**64,259**

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
	tonnes NH_3-N																	
Ammonia emission																		
Housing	30,713	31,362	30,641	31,127	31,013	29,287	29,036	29,901	29,208	28,508	27,084	27,136	27,821	28,798	27,707	28,173	28,712	29,689
Storage	13,936	13,862	13,232	12,996	12,736	12,298	12,133	12,206	12,239	11,685	11,125	11,030	11,053	11,260	11,051	10,198	10,326	9,741
Fertiliser application	39,808	39,100	37,062	35,923	35,070	35,250	33,720	32,513	31,489	28,844	26,586	25,413	25,061	25,423	24,610	24,487	24,047	22,522
Grass	2,591	2,533	2,430	2,401	2,395	2,413	2,470	2,471	2,512	2,459	2,500	2,517	2,442	2,430	2,365	2,370	2,414	2,308
Emission total	**87,048**	**86,856**	**83,365**	**82,447**	**81,215**	**79,249**	**77,358**	**77,091**	**75,449**	**71,497**	**67,294**	**66,095**	**66,376**	**67,910**	**65,732**	**65,228**	**65,498**	**64,259**

C) Feeding plans Average feedingstuff analyses for full feeding made by the Danish Plant Directorate in 2002

Winter feeding plans		Feeding code	% dm	% Crude protein	% Raw fatt	% Raw ashes	% Carbon-hydrates	FE/kg dms	kg feed/day	MJ/day	MJ/FE
		PDIR (2002)									
Heifers:	Straw	781	85	4	1,9	4,5	89,6	0,23	33,4	571,76	
	Maize silage	593	31	8,7	2,2	4,2	84,9	0,85	57,5	1008,95	
	Toasted soya	155	87,5	49,1	3,2	7,4	40,3	1,37	8,1	161,71	
									99	1742,41	**25,75**
Suckling cows:	Straw	781	85	4	1,9	4,5	89,6	0,23	1,60	119,09	
Periode 1 (2 mth)	Toasted soya	155	87,5	49,1	3,2	7,4	40,3	1,37	3,40	49,55	
	Barley	201	85	11,20	2,90	2,20	83,70	1,12	1,80	29,22	
Periode 2 (4 mth)	Straw	781	85	4	1,9	4,5	89,6	0,23	3,20	238,18	
	Toasted soya	155	87,5	49,1	3,2	7,4	40,3	1,37	3,00	29,14	
	Barley	202	85	11,20	2,90	2,20	83,70	1,12	3,20	51,96	
									15,20	517,12	**34,02**
Horses:	Straw	781	85	4	1,9	4,5	89,6	0,23	4,00	58,20	
	Hay	665	85	12,10	2,60	7,70	77,60	0,63	3,00	43,97	
	Oat	202	86	12,10	5,70	2,70	79,50	0,93	2,50	40,06	
	Supplemental		86,4	15,39	4,28	6,60	73,73	1,04	1,00	15,51	
										157,74	**29,83**
Sheep and Goats:	Straw	781	85	4	1,9	4,5	89,6	0,23	1,00	14,55	
	Toasted soya	155	87,5	49,1	3,2	7,4	40,3	1,37	0,10	1,75	
	Barley	202	85	11,20	2,90	2,20	83,70	1,12	0,40	6,18	
	Grass pills (dried)	707	92,0	17,00	3,10	11,00	68,90	0,63	1,00	15,73	
										38,21	**29,95**
Summer grazing[1]											
Grazing	Clover grass, 2 weeks old	422	18	22	4,1	9,4	64,5	0,95	1	18,83	
									1	18,83	**18,83**
Pigs:	Full feeding										
	Sows	-	87,1	16,08	5,17	5,53	73,22	1,20	-	64,21	**17,49**
	Weaners	-	87,4	18,81	5,73	5,51	69,95	1,28	-	2,12	**16,46**
	Slaugther pigs	-	86,9	17,0	4,65	5,09	73,25	1,21	-	9,55	**17,25**

D. Biogas production

Production of biogas 1990-2002, and the amount of slurry used (Source: Søren Tafdrup, Energistyrelsen and own calculations).

	Energy production			Estimated M tonnes slurry used in biogas production		Reduction		
	Communal plants T Joule	Farm plants T Joule	Total T Joule	Cattle slurry, M tonnes	Pig slurry, M tonnes	Gg CH_4	Gg N_2O	CO_2-eq. M tons CO_2
1990	211	19	230	0,09	0,10	0,111	0,0025	0,003
1991	369	19	388	0,14	0,18	0,187	0,0043	0,005
1992	449	24	473	0,18	0,21	0,228	0,0052	0,006
1993	529	27	556	0,21	0,25	0,268	0,0061	0,008
1994	632	26	658	0,24	0,30	0,315	0,0072	0,009
1995	745	27	772	0,29	0,35	0,373	0,0085	0,010
1996	803	27	830	0,31	0,38	0,403	0,0092	0,011
1997	973	32	1005	0,37	0,46	0,484	0,0111	0,014
1998	1166	56	1222	0,45	0,56	0,589	0,0135	0,017
1999	1183	70	1253	0,47	0,57	0,607	0,0139	0,017
2000	1279	129	1408	0,52	0,64	0,677	0,0155	0,019
2001	1345	179	1524	0,57	0,69	0,735	0,0168	0,021
2002	1403	300	1703	0,63	0,78	0,823	0,0188	0,023

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