THE FINNISH ENVIRONMENT 8 | 2009

ENVIRONMENTAL PROTECTION

Development of the ammonia emission inventory in Finland

Revised model for agriculture

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FOREWORD

The aim of the study was to construct a calculation model for gaseous agricultural nitrogen emissions (ammonia NH_3, nitrous oxide N_2O and nitric oxide NO) thereby developing and updating the emission calculation procedure to better reflect the development of these emissions in Finland. The new model will integrate the greenhouse gas and air pollutant inventories for nitrogen emissions. Also, the model enables reporting of emissions at the level of detail required by the reporting guidelines of the UNECE CLRTAP[1] and the UNFCCC[2].

In the Finnish air emission inventory system, greenhouse gas emissions from agriculture are calculated for the UNFCCC by the MTT Agrifood Research Finland. Ammonia emissions for the UNECE CLRTAP and EU NEC Directive are calculated and reported by the Finnish Environment Institute (SYKE). Because the Finnish ammonia and greenhouse gas emissions are currently calculated and reported separately, the new model includes both emissions from manure management (NH_3 and N_2O) in the same calculation model and ensures that the same activity data and emission factors are used in both inventories consistently.

Agriculture is the main source of ammonia emissions in Finland comprising nearly 90% of the total emissions annually. The inventory of ammonia emissions is carried out according to the EMEP/CORINAIR Atmospheric Emission Inventory Guidebook using activity data and emission factors for calculating emissions from each source. In Finland, national emission factors for each animal type have been used. However, some of the national emission factors have not been available at the required level of detail of emission source categories. Also, revision of the emission factors to reflect the development of emissions during the last decade was needed. In the project, a new model for the ammonia inventory was developed on the basis of the previous model (Grönroos et al. 1998). The parameters in the model were revised where new data could be found. Ammonia measurements were carried out in animal shelters (pig houses and cow sheds) in order to get national data for improving the existing emission factors.

Nitrous oxide emissions from manure management are reported annually to the UNFCCC. The share of nitrous oxide originating from manure compared to total greenhouse gas emissions in Finland is small, 0.7% in 2006. However, it is important that emissions from manure management in the both inventories are calculated consistently. In order to ensure this, the calculation of nitrous oxide emissions from manure management was also included in the NH_3 model. Detailed documentation of the model was prepared to improve transparency of the inventory.

The project was carried out in co-operation with the Finnish Environment Institute (SYKE) and MTT Agrifood Research Finland (MTT) between 2006 and 2008. The project group consisted of senior research scientist Juha Grönroos (SYKE), senior research scientist Pasi Mattila (SYKE), principal research scientist Kristiina Regina (MTT), research scientist Jouni Nousiainen (MTT) research scientist Paula Perälä (MTT), team leader Kristina Saarinen (SYKE), and coordinator Johanna Mikkola-Pusa. The steering group of the project was made up of representatives from the related administration and research institutes: Mr. Heikki Granholm (Ministry of Agriculture and Forestry, chairman), Councellor Anneli Karjalainen (Ministry of the Environment), Mr. Kimmo Silvo (Finnish Environment Institute), Dr. Riitta Pipatti

[1] United Nations Economic Commission for Europe Convention on Long-Range Transboundary Air Pollution

[2] United Nations Framework Convention on Climate Change

(Statistics Finland), Professor Martti Esala (MTT) and senior research scientist Tapio Salo (MTT). The Ministry of the Environment and the Ministry of Agriculture and Forestry are greatly acknowledged for funding the project.

Helsinki 31 October 2008

Juha Grönroos, Pasi Mattila, Kristiina Regina, Jouni Nousiainen, Paula Perälä, Kristina Saarinen and Johanna Mikkola-Pusa

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1 Introduction

1.1

Sources and controlling factors of ammonia emissions

Ammonia (NH_3) is released in the biological degradation of nitrogen-containing organic compounds, primarily urea and proteins. Emissions may occur directly and indirectly from the animal digestive system, manure storage and soil (Dämmgen and Erisman 2005). Other potential NH_3 sources are mineral fertilisers, crops and crop residues (Bussink and Oenema 1998).

Mammalian animals excrete surplus nitrogen as urea in urine. Also faeces contain nitrogen as proteins and various other organic compounds. Most ammonia emissions arise from the hydrolysis of urea in the presence of the enzyme urease forming ammonia (Dämmgen and Erisman 2005). Birds excrete uric acid, which is then oxidized and hydrolyzed enzymatically to form urea. In faeces, enzymatic activity degrades proteins to amino acids, which decompose further and yield free ammonia (Dämmgen and Erisman 2005), if the faeces contain excess nitrogen compared to the content of easily degradable organic carbon compounds. Because nitrogen in urea has a high potential for NH_3 volatilization, ammonia emissions can be reduced by optimizing nitrogen intake and retention in animals and thus minimizing the amount of excreted nitrogen (Bussink and Oenema, 1998).

Emissions from animal shelters are affected by animal type, forage (effect on N excretion), characteristics of the building (floor, ventilation, temperature, bedding material) and manure storage (outdoor temperature, material used for coverage). Measures to reduce ammonia emissions from animal shelters include improved management of manure in the building, such as urine separation, cooling of manure, using air filters and covering of manure storage (Sannö et al. 2003; Gustafsson et al. 2003).

The emissions of ammonia from the field application of manure are affected by manure type, soil type, slurry infiltration and particle distribution (Sommer et al. 2006). Also application technique and weather conditions such as temperature and wind speed have an effect on how much ammonia is emitted from the field. Most of the ammonia emissions from field-applied manure occur within two to three days after the application, a major part of the emissions may occur during the first few hours after application. Measures to reduce ammonia emissions from manure application include incorporation of manure with the soil or injection of slurry into the soil, and dilution or acidification of the slurry (Bussink and Oenema 1998).

Ammonia may also be emitted from mineral fertilisers. Urea is often included in mineral fertilisers because it is manufactured for fertilizer use and is hydrolyzed to ammonium after application to soil. According to Sommer et al. (2004), the following order of strength of NH_3 emissions from different fertilisers when applied to soils exists in general: ammonium bicarbonate > urea > diammoniumphosphate > ammonium sulphate > calcium-ammonium nitrate, monoammonium phosphate. Ammonia emissions depend on the properties of fertilisers, soil properties and environmental variables such as moisture and temperature.

According to Dämmgen and Erisman (2005), the annual average of NH_3 concentration in clean air is 0.1–0.5 µg m^{-3}. Agricultural regions in Central Europe may have concentrations of 1–3 µg m^{-3} and regions with intensive animal production in Central Europe may have NH_3 concentrations as high as 5–20 µg m^{-3}. Concentrations are highly variable with time and NH_3 may be transported over long distances. Ammonia is removed from the atmosphere as wet or dry deposition, which may have an effect on vegetation or watercourses. Reduction of ammonia emissions from agriculture requires a holistic farm approach because if emissions are reduced in one part, they may increase in another part and also nitrogen leaching or emissions of the greenhouse gas nitrous oxide may increase (Bussink and Oenema 1998). Bussink and Oenema (1998) suggest the reduction of total N input in the farm in the form of forage, concentrates and fertilizers in order to reduce NH_3 emissions.

In the literature, ammonia emissions are expressed in different units. Emission rates can be expressed for example as NH_3 or NH_3-N. The coefficient 14/17 is used to convert NH_3 to NH_3-N. Emissions may also be expressed as percentage NH_3-N of total N, percentage NH_3-N of total ammoniacal nitrogen (TAN) or percentage NH_3-N of NH_4-N. Total ammoniacal nitrogen means the sum of NH_3-N and NH_4^+-N. Factors such as the amount of protein in animal diet, animal weight and performance affect the amount of TAN in manure (Dämmgen and Hutchings, 2005). Also the activity of micro-organisms (e.g. nitrification and immobilization) has an effect on TAN (Sommer et al. 2004). Emissions may be expressed as per animal, per animal place or per livestock unit (LU), where 1 LU equals to 500 kg of live weight. The varying notations complicate the comparison of the results in the different literature sources and require careful checking of units to ensure correct comparison.

1.2 Ammonia emission inventory in Finland

Ammonia emissions into the air are inventoried annually according to the UNECE Convention on Long-Range Transboundary Air Pollution and according to the EU's National Emission Ceilings Directive requirements. As in other European countries, agriculture is the main source of ammonia emissions in Finland comprising up to 90% of total emissions.

The documentation of the earlier model used for calculating Finland's ammonia emissions was published in Finnish only (Grönroos et al. 1998). The report includes a thorough literature review of existing data on ammonia emissions, general information about ammonia volatilization, emission sources, documentation of previous methods for estimating ammonia emissions from agriculture in Finland and in other countries, and information on potential abatement measures. The publication also documents the current model for calculating ammonia emissions from manure management through the whole manure management chain from the animal shelter to the soil during manure application. The publication also includes information on the parameters used in different ammonia models in Finland and in other countries, such as volatilization rates in animal shelters. Activity data for the model was collected from the Information Centre of the Finnish Ministry of Agriculture and Forestry, professional and scientific publications, surveys and by expert interviews. A separate part of the publication describes potential abatement measures and the costs of these measures.

1.3

Nitrous oxide emissions in the greenhouse gas inventory

Finland reports the emissions of nitrous oxide (N_2O) and other greenhouse gases annually under the United Nations Framework Convention on Climate Change (UNFCCC) and under the Kyoto Protocol. Agriculture is the second largest source of greenhouse gases after the energy sector in Finland. Manure management is one source of N_2O emissions in agriculture representing approximately 9% of total agricultural greenhouse gas emissions. N_2O may be emitted into the air directly from manure applied to agricultural land or excreted to pasture by grazing animals. Indirect N_2O emissions may arise when NH_3 volatilized from manure is deposited. N_2O may also be emitted directly from animal shelters and manure storage but little information exists about these emissions in Finland.

1.4

Aims of the study

In the current project, the ammonia emission model was revised and improved by expanding and updating the model with new data on manure management systems, nitrogen excretion rates and emission factors. The aim was to provide more detailed and defined information on the development of ammonia emissions during recent decades.

During the project, measurements of ammonia concentrations in animal shelters were carried out to provide information on the range of the actual emission levels. Furthermore, calculation of N_2O emissions from manure and mineral fertilizers was added to the model to enable consistent calculation of both ammonia and N_2O emissions using the same activity data.

2 Material and methods

2.1

Structure of the model

The model for the calculation of ammonia emissions from Finnish agriculture is composed on an Excel spreadsheet and was introduced in Finnish by Grönroos et al. (1998). In the revision of the model, its structure was improved and its parameters were revised to meet the current knowledge on manure management practices and ammonia volatilization. Calculation of nitrous oxide emissions from manure management was inserted into the model to enable the use of the same activity data for the calculation of ammonia emissions, as well as direct and indirect nitrous oxide emissions.

The ammonia emission model includes emissions from livestock by animal category and manure management stage, and emissions from mineral fertilizers. The animal categories are dairy cows, suckler cows, heifers, bulls, calves (<1 yr), sows (with piglets), fattening pigs (>50 kg), boars, weaned pigs (20–50 kg), laying hens, broilers, chickens, cockerels, broiler hens, turkeys, other poultry, sheep with lambs, goats with gilts, horses, ponies, minks and fitches, foxes and raccoons, and reindeer.

The manure management systems considered are slurry, deep litter, solid manure (farmyard manure: urine+dung+litter), urine (dung stored separately) and dung (urine stored separately). Emissions from grazing were calculated in a separate module.

The model calculates ammonia emissions from manure separately for each animal category and, within each animal category, separately for each manure management system. The calculation is based on the mass flow approach, where the starting point is the amount of excreted nitrogen calculated from animal numbers and animal specific nitrogen excretion rates. The fate of the excreted nitrogen is then followed during the manure management chain. *Ammonia* and *nitrous oxide* emissions into the atmosphere are calculated in each phase of the chain. Adding up the phase specific emissions gives the total emissions. Animal specific ammonia emission factors are calculated by dividing the total emission of an animal category by the number of animals in the category. *Nitric oxide* (NO) emissions are assessed for mineral fertilizers only.

The model enables calculating not only present and past emissions but also emission estimates for the future. Emissions for the years 1990–2007 are calculated based on existing statistics and other information available for those years (see chapter 2.2). Emission projections (2008–2050) are mainly based on the assumed development of animal numbers in Finland while other factors like manure management systems and manure nitrogen content are assumed to be somewhat the same as in 2007.

2.2

Basic model parameters

2.2.1

Animal numbers and use of mineral fertilizers

Numbers of cattle, pigs, poultry, goats and sheep and the use of mineral N-fertilizers for the years 1990–2007 (Appendix 1) were acquired from the Information Centre of the Ministry of Agriculture and Forestry (Tike). Numbers of horses and ponies were based on the statistics of Suomen Hippos, the Finnish Trotting and Breeding Association, the numbers of fur animals on the statistics of the Finnish Fur Breeders' Association and the numbers of reindeer on the statistics of the Reindeer Herders' Association. Estimated animal numbers and mineral N-fertilizer use for the years 2008–2050 were based on the *Dynamic regional sector model of Finnish agriculture*, Dremfia (Lehtonen 2001) except for fur animals and reindeer, for which the numbers were estimated based on the numbers of the previous years assuming that there will not be any major changes in coming years.

2.2.2

Nitrogen excretion rates

The values of animal specific nitrogen excretion rates (Appendix 2) were based on nutrient balance calculations. Excretion rate was obtained by subtracting the nitrogen included in animal products and growth from the nitrogen intake through feeding.

In all animal groups, excluding horses and fur animals, the main sources of information are the agricultural statistics. The important statistical data are the number of farm animals, the milk, meat and egg production, and the slaughter weights. For the number of horses the statistics of Suomen Hippos and for fur animals the pelt production statistics of the Finnish Fur Breeders Association were utilised.

Nitrogen excretion was in most cases calculated with nitrogen balance estimation and is close to the methods described by Smith and Frost (2000) and Smith et al. (2000). Exceptions are described in the paragraph for each particular animal group. The feed tables and feeding recommendations, later only referred to as feeding recommendations, by Salo et al. (1990), Tuori et al. (1996), Tuori et al. (2000), MTT (2004), and MTT (2006) were used.

The nitrogen consumption of horses was estimated according to the feeding recommendations and diet formulation examples presented in Saastamoinen and Teräväinen (2007). The calculations were based on the group distribution and estimated use of horses according to the statistics of Suomen Hippos. The nitrogen excretion is the difference between the nitrogen intake of horses and the amount of nitrogen in culled horses (about 7% of horse population) divided by the horse population.

The nitrogen intake of dairy cows was calculated with the yearly feed consumption data from the Finnish Milk Recording of Rural Advisory Centres. For suckler cows nitrogen intake was estimated according to feeding experiment results (Manninen 2007) and diet formulation examples (Komulainen 1997). For calves, heifers and bulls, first the yearly growth curves (Gomperz in males, Richards in females, Perotto et al. (1992)) were estimated based on bull and heifer slaughter weights and cow mature weights. The weight and age information presented in Aronen et al. (1992) and Huuskonen et al. (2007) were utilised when estimating the bull growth curve parameters. The heifers were divided into slaughtered and recruitment animals. With the growth curve, daily weight and growth values can be calculated. The energy requirement is based on these values. The feed nitrogen content was obtained from the feed consumption data of the Finnish Milk Recording that also contains information on cattle feeding.

For pigs, the calculation method was close to the one presented by Fernández et. al (1999). For sows, information to enable calculations was obtained from the litter recording scheme of FABA breeding (Finnish breeding organization) and from the pig production recording and economic monitoring of Rural Advisory Centres. For growing pigs, the calculations were based on feed conversion results of the FABA breeding central station testing, the estimated differences in farm conditions and several feeding experiments. The nitrogen content of feed was estimated from the digestible protein recommendations. Also diet formulation examples (Komulainen 1989, Kyntäjä et al. 1999 and Siljander-Rasi et al. 2006) were utilised.

For sheep, information from the Finnish sheep production recording and economical monitoring of Rural Advisory Centres, diet formulation examples (Savolainen and Teräväinen 2000) and feeding recommendations were used in the nitrogen intake and retention calculations. The wide variations in the sheep production systems as well as seasonality made these calculations challenging.

For poultry, nitrogen intake was estimated with feed consumption per kilogramme of eggs or per one slaughtered or full grown bird. The feed utilisation values were obtained from the literature (for example Näsi 2002), commercial poultry breeders and several Finnish feeding experiments. The nitrogen content of the feed was obtained from commercial concentrate manufacturers and feeding recommendations. The nitrogen excretion of other poultry, which includes ducks, geese, ranched pheasant, ranched mallards, guinea fowl, quails, ostriches and emus, was estimated to equal to that of laying hens.

For fur animals nitrogen intake is based on the amount of feed consumed per one produced pelt in the feeding recommendations. Nitrogen content of feed between 1990 and 2007 was obtained from laboratory results published in the journal "Turkistalous".

Nitrogen excretion by reindeer was estimated to equal that of goats according to the Finnish greenhouse gas inventory (Statistics Finland 2007).

For emission projections for the years 2008–2050 nitrogen excretion was estimated to be the same as in 2007 for other animals than dairy cows for which nitrogen excretion in 2007–2050 was assessed based on the milk yields obtained from the Dynamic regional sector model of Finnish agriculture, Dremfia (Lehtonen 2001).

2.2.3 Ammonia volatilization parameters

2.2.3.1 Literature review on ammonia volatilization

A thorough literature review of parameters for ammonia volatilization (eg. volatilization rates for different manure management systems) was presented by Grönroos et al. (1998). The results of the studies were summarized and the summary data were used in the emission model. In the current project, the literature review was expanded to cover recent years from 1994 to 2007, and the summary data used in the previous project were updated. The detailed results of the literature review are presented in Appendix 3.

Ammonia volatilization losses from animal shelter and manure storage were expressed as percentages of total manure N (Table 1), whereas the losses from manure application were related to the ammoniacal manure N (Table 2). The proportion of ammoniacal N of the total N was calculated from the manure analysis statistics of the Finnish Soil Analysis Service (Table 3).

Table 1. Estimated loss of manure N by ammonia volatilization from animal shelter and manure storage without abatement (% of total manure N, *in italics*) and estimated reduction of losses achieved with abatement measures (% of loss without abatement).

Manure management phase	Ammonia volatilization abatement measure	Slurry	Deep litter	Solid manure (incl. urine)
Animal shelter	*Loss without abatement (% of total N)*	*10*	*20*	*10*
	Reduction of loss, %			
	rapid urine separation			15
	flushing	60		
	improved cleaning	10		10
	increased manure removal frequency	10		10
	biological or chemical air scrubbers	85	85	85
Filling the manure storage	*Loss without abatement (% of total N)*			
	filling from the top	*10*		
	filling from the bottom	2		
Storing (including slurry stirring)	*Loss without abatement (% of total N)*	15	25	30
	Reduction of loss, %			
	tight roof (concrete)	95		
	semi-tight roof (floating covers)	75		
	natural crust	45		
	solid manure covering		20	20
	filling solid manure storage from the bottom			30
	tent, roof	80	80	80
Aerating	*Loss without abatement (% of total N)*	*20*		
	Reduction of loss, %			
	aeration with special attention to N losses	50		

Table 2. Estimated loss of manure N by ammonia volatilization from surface application by broadcast spreading and from pasture without abatement (% of ammoniacal manure N, *in italics*) and estimated reduction of losses achieved with abatement measures (% of loss without abatement).

Manure management phase	Ammonia volatilization abatement measure	Slurry	Deep litter	Solid manure (incl. urine)
Spreading on arable land in spring	*Loss from broadcast spreading (% of NH_4-N)*	*40*	*30*	*30*
	Reduction of loss, %			
	incorporation with ploughing < 4 hrs	70	70	70
	incorporation with ploughing < 12 hrs	40	40	40
	incorporation with ploughing > 12 hrs	15	15	15
	incorporation with harrowing < 4 hrs	60	60	60
	incorporation with harrowing < 12 hrs	25	25	25
	incorporation with harrowing > 12 hrs	10	10	10
	injection	85		
	band spreading	25		
	slurry dilution 1:1 (broadcast spreading)	35		
Spreading on plant covered land in summer	*Loss with broadcast spreading (% of NH_4-N)*	*50*	*30*	*30*
	Reduction of loss, %			
	band spreading	40		
	injection	85		
	slurry dilution 1:1 (broadcast spreading)	35		
Spreading on stubble in autumn	*Loss with broadcast spreading (% of NH_4-N)*	*60*	*30*	*30*
	Reduction of loss, %			
	incorporation with ploughing < 4 hrs	75	75	75
	incorporation with ploughing < 12 hrs	40	40	40
	incorporation with ploughing > 12 hrs	15	15	15
	incorporation with harrowing < 4 hrs	65	65	65
	incorporation with harrowing < 12 hrs	30	30	30
	incorporation with harrowing > 12 hrs	10	10	10
	injection	85		
	band spreading	30		
	slurry dilution 1:1 (broadcast spreading)	35		
Pasturing	*Loss from urine (% of NH_4-N)*	*10*		
	Loss from dung (% of NH_4-N)	*3*		

Table 3. Nitrogen content of animal manures in Finland. Averages of manure analyses conducted by the Finnish Soil Analysis Service in 2000–2004 (Viljavuuspalvelu 2008).

Animal	Manure type	Total N kg/t	No. of samples	Soluble N (NH_4-N) kg/t	No. of samples	Percentage of soluble N % of total N
Cattle	Solid	5.4	3953	1.7	3822	32
	Slurry	3.0	3388	1.8	3330	60
	Urine	2.5	2554	1.8	2732	72
Pigs	Solid	7.4	603	2.3	588	31
	Slurry	3.8	883	2.5	864	66
	Urine	2.1	330	1.6	351	76
Chickens	Solid	16.8	342	7.1	339	42
Sheep	Solid	8.7	130	2.2	127	25
Horses	Solid	4.5	359	0.9	341	20
Fur animals	Solid	17.1	71	6.9	71	40

2.2.3.2 Temperature correction factors

Information on parameters affecting ammonia volatilization is mainly acquired from foreign studies representing climatic conditions different from those in Finland. The most important distinction can be found in outdoor temperature (Table 4). In the British MARACCAS model (Cowell and ApSimon 1996), for example, emissions in Southern Europe were corrected with a factor which is based on the assumption that a rise of 3˚C in temperature increases volatilization of ammonia by 10% (Oldenburg 1989). This means that emissions in Italy, for instance, were corrected with the factor 1.2. However, MARACCAS did not use temperature correction in calculating emissions for Northern Europe. The difference of 6˚C in the annual average outdoor temperature between Finland and Central Europe (Table 4) would mean a reduction of 20% in ammonia volatilization giving a correction factor of 0.8 for Finland. However, the temperature difference varies over a year with the largest difference in winter and the smallest in summer.

In Finland, manure is mainly spread in spring (April and May) before sowing and in autumn (August to November) after harvest. The application of manure in summer (June and July) has increased in recent years because of administrative restrictions on the rate and timing of manure application especially in autumn. Winter application of manure is prohibited. The difference in the average temperature was calculated separately for each of the three periods of manure application (Table 4). The calculation was simplified by assuming that in spring all the manure was applied to bare soil, in summer to plant covered soil, and in autumn to stubble, which are the most common surfaces for each application period. The effect of temperature difference on ammonia emissions from manure application was estimated according to the values presented in Table 5I of the EMEP/CORINAIR Emission Inventory Guidebook (EEA 2007). In the table, reduction in temperature from 10˚C to 5˚C lowers ammonia emission 25…50% for cattle slurry and 33…60% for pig slurry. A 30% reduction was estimated for the Finnish spring and autumn periods of manure application, where the difference in the average temperature is about 5˚C compared to Central Europe. This gives a temperature correction factor of 0.7 for spring and autumn. In summer, however, the average temperature in Finland is only 0.8˚C lower. A reduction of 5% in ammonia emission from manure application was estimated and a temperature correction factor of 0.95 was used for summer applications.

The emissions of ammonia from manure storage and other manure management in outdoor conditions are corrected with the factor 0.8, which is based on a difference of 6˚C over the whole-year average temperature between Finland and Central Europe (Table 4). There are no significant differences in the indoor temperatures of animal buildings, but in the Central European conditions higher outdoor temperatures result in a need for greater ventilation, which increasingly affects emissions. In non-isolated animal shelters the indoor temperature closely follows the outdoor temperature. For these reasons, a temperature correction factor of 0.9 was used for animal shelters.

Table 4. Average outdoor temperature (°C) in Finland (mean of Jokioinen, Jyväskylä and Oulu) and in Central Europe (mean of Hannover (Germany), De Bilt (the Netherlands) and Birmingham (England) in 1961–1990 (The Weather Network 2008).

	Whole year	April–May	June–July	August–Nov.
Finland	3.3	5.1	15.0	6.3
Central Europe	9.2	10.0	15.8	11.5
Difference	*5.9*	*4.9*	*0.8*	*5.2*

2.2.4

Manure management data

In Finland, there is no systematic collection of information on manure management systems and application methods. The Information Centre of the Ministry of Agriculture and Forestry collects some information about manure management but the data was found to be too limited for the purpose of this work. In order to find out more information about manure management systems a questionnaire was designed and sent to Regional Employment and Economic Development Centres (15 centres altogether) and to Regional Environment Centres (13 centres altogether). The questionnaire was targeted at people who were assumed to know about the current state of manure management for different animal groups in their region. In the survey there were questions about the distribution of current manure management systems, past manure management systems and assessments of future development. The respondents were also asked for information about manure application methods and time of application. Additional questions considered manure composting and biogas. In addition to the results of the survey and statistical data, the judgments of two experts were used (Ilkka Sipilä and Petri Kapuinen, MTT Agrifood Research Finland). The expert judgments were the only information sources when manure management in the future was assessed. The estimated manure management data for 2015 were also used for the years 2016–2050 because no other data were available.

On basis of the questionnaire it became obvious that very little information exists about the distribution of manure management systems in Finland. Data on the distribution of manure management systems is not collected systematically in the areas where the questionnaire was targeted. Data may be collected for different purposes in different places but no synthesis of it is available. Only 8 questionnaires were returned and they were also filled in incompletely. The reason for this could be that the questionnaire was very detailed and the respondents felt that it was too laborious to fill in. Most of the responses that were returned were not based on statistics but expert judgment. Some respondents commented that it was not possible to get all the information for the survey because it would take too much time and resources to collect all the data. We can conclude that in most areas this information is not easily available, and therefore that it is not possible to make clear conclusions about the distribution of manure management systems in Finland on the basis of this survey. However, the information received can be used to give additional information about the situation. The distribution of manure management systems was estimated for ammonia calculations using data from the Information Centre of the Ministry of Agriculture and Forestry, the survey and expert interviews (Tables 5–11).

Table 5. General information on cattle manure management and pasturing in Finland in 1995 and 2005. Values for 1995 are only given if they differ from the year 2005. Values for the future are equal to those for 2005.

	Dairy cows		Suckler cows		Heifers	Bulls	Calves <1 yr
	1995	2005	1995	2005	2005	2005	2005
Manure management							
Treated as slurry (%)	35	63	5	30	36	40	38
Treated as deep litter (%)		1		39	3	6	3
Treated as solid manure (%), of which	64	36	56	31	61	54	59
urine not separated (%)		50		50	50	50	50
urine separated (%)		50		50	50	50	50
Pasturing							
Pasturing period (days)		125		140	140	0	100
Pastured animals (%)		90		95	90	0	25
Animals inside in nights (%)		25		0	0	0	0
Time inside at night (h)		14		0	0	0	0
Manure excreted on pasture (%)		26		36	35	0	7

Table 6. General information on manure management and pasturing of sheep, goats, horses, ponies, fur animals and reindeer in Finland in 1995 and 2005. Values for 1995 are only given if they differ from the year 2005. Values for the future are equal to those for 2005.

	Sheep	Goats	Horses		Ponies		Fur animals	Rein-deer
	2005	2005	1995	2005	1995	2005	2005	2005
Manure management								
Treated as slurry (%)	0	0		0		0	0	0
Treated as deep litter (%)	90	90	40	0	40	0	0	0
Treated as solid manure (%), of which	10	10	60	100	60	100	100	100
urine not separated (%)	100	100		100		100	100	100
urine separated (%)	0	0		0		0	0	0
Pasturing								
Pasturing period (days)	130	130		140		140	0	365
Pastured animals (%)	90	90		95		95	0	100
Animals inside in nights (%)	0	0		0		0	0	0
Time inside at night (h)	0	0		0		0	0	0
Manure excreted on pasture (%)	32	32		36		36	0	100

Table 7. Percentages (%) of management methods for pig manure in Finland in 1995 and 2005. Values for 1995 are only given if they differ from the year 2005. Values for the future are equal to those for 2005.

	Sows (+ piglets)		Fattening pigs		Boars		Weaned pigs	
	1995	2005	1995	2005	1995	2005	1995	2005
Treated as slurry (%)	25	30	75	80	25	30	75	80
Treated as deep litter (%)		5		5		5		5
Treated as solid manure (%), of which	70	65	20	15	70	65	20	15
urine not separated (%)		50		50		50		50
urine separated (%)		50		50		50		50

Table 8. Percentages (%) of management methods for poultry manure in Finland in 1995 and 2005. Values for 1995 are only given if they differ from the year 2005. Values for the future are equal to those for 2005.

	Laying hens	Broilers		Chickens		Cockerels		Broiler hens		Turkeys		Other poultry
	2005	1995	2005	1995	2005	1995	2005	1995	2005	1995	2005	2005
Surry	2	1	0	2	0	1	0	1	0	1	0	0
Deep litter	5	99	100		5		5	99	100	99	100	40
Solid manure	93		0	93	95	94	95		0		0	60

Table 9. Detailed information on manure management in animal shelters and manure storage in Finland. Values for the year 2015 are only given if they differ from the year 2005. Values for 1995 are equal to those for 2005. Data in the column for the year 2015 represent values that were used for emission projection calculations for the years 2015–2050.

Abatement measures	Slurry						Deep litter	Solid man.[1)]	Urine	Dung
	Cattle		Pigs		Poultry					
	2005	2015	2005	2015	2005	2015	2005	2005	2005	2005
Animal shelter (% of farms)										
No measures	90		90		90		100	100	95	95
Improved cleaning of surfaces	5		5		0		-	0	0	5
Flushing	0		0		0		-	0	-	-
Manure removed more frequently	5		5		5		-	0	-	0
Rapid urine separation	-	-	-	-	-	-	-	-	5	-
Biological or chemical air scrubbers	0		0		0		-	0	0	0
Drying of manure on manure belt	-	-	-	-	5		-	-	-	-
Manure storage (% of farms)										
No measures	30	20	60	40	60	40	95	70	25	70
Tight roof (concrete)	20	25	20	30	20	30	-	-	75	-
Semi-tight roof (floating covers)	10		10	15	10	15	-	-	-	-
Natural crust	30		0		0		-	-	-	-
Tent, roof	10	25	10	15	10	15	-	-	-	-
Solid manure covering	-	-	-	-	-	-	5	5	-	5
Filling of storage from the bottom	70		70		70		-	25	-	25
Aerating with special attention to N-losses (% of farms using aeration)	50		50		50		-	-	-	-
Additional information										
Percentage of farms using aeration	3		0		0		-	-	-	-
Percentage of deep litter stored after removal from animal shelter							20			

[1)]Urine and dung

Table 10. Detailed information on slurry and deep litter application in Finland. Values for 1995 and 2015 are only given if they differ from the year 2005. Data in the column for the year 2015 represent values that were used for emission projection calculations for the years 2015–2050.

	Slurry						Deep litter
Abatement measures	Cattle			Pigs and poultry			
	1995	2005	2015	1995	2005	2015	2005
Type of surface for application (% of manure applied)							
Arable land	60	65		60	65		100
Plant covered land	10	20		5	10		0
Stubble	30	15		35	25		0
Application on arable land (% of manure applied)							
No measures		10	5		10	5	10
Incorp. with ploughing < 4 h		0			0		0
Incorp. with ploughing < 12 h		0			0		20
Incorp. with ploughing > 12 h		0			0		20
Incorp. with harrowing < 4 h		5			5		10
Incorp. with harrowing < 12 h		40			40		20
Incorp. with harrowing > 12 h	40	35		40	35		20
Injection		0			0		-
Band spreading	5	10	15	5	10	15	-
Slurry dilution (broadcast spr.)		0			0		-
Application on plant covered land (% of manure applied)							
No measures		65			65	60	-
Band spreading		15			20	25	-
Injection		20			15		-
Slurry dilution (broadcast spr.)		0			0		-
Application on stubble (% of manure applied)							
No measures		10			10		-
Incorp. with ploughing < 4 hrs		5			5		-
Incorp. with ploughing < 12 h	40	35		40	35		-
Incorp. with ploughing > 12 h	40	35	30	40	35	30	-
Incorp. with harrowing < 4 h		0			0		-
Incorp. with harrowing < 12 h		0			0		-
Incorp. with harrowing > 12 h		0			0		-
Injection		5			5		-
Band spreading	0	10	15	0	10	15	-
Slurry dilution (broadcast spr.)		0			0		-

Table 11. Detailed information on solid manure, urine and dung application in Finland. Values for 1995 and 2015 are only given if they differ from the year 2005. Data in column "2015" represent values that were used for emission projection calculations for the years 2015–2050.

	Solid manure (urine and dung)				Urine			Dung		
	Cattle		Pigs and poultry	Sheep, goats and horses	Cattle and pigs			Cattle		Pigs
	1995	2005	2005	2005	1995	2005	2015	1995	2005	2005
Type of surface for application (% of manure applied)										
Arable land	98	96	100	98		50		98	96	100
Plant covered land	2	4	0	2		25		2	4	0
Stubble	-	-	-	-		25		-	-	-
Application on arable land (% of manure applied)										
No measures		10	10	10		10	5		10	10
Incorp. with ploughing < 4 h		0	0	0		0			0	0
Incorp. with ploughing < 12 h		20	20	20		0			20	20
Incorp. with ploughing > 12 h		20	20	20		0			20	20
Incorp. with harrowing < 4 h		10	10	10		5			10	10
Incorp. with harrowing < 12 h		20	20	20		40			20	20
Incorp. with harrowing > 12 h		20	20	20	40	35			20	20
Injection	-	-	-	-		0		-	-	-
Band spreading	-	-	-	-	5	10	15	-	-	-
Slurry dilution (broadcast spr.)	-	-	-	-	-	-	-	-	-	-
Application on plant covered land (% of manure applied)										
No measures		100	100	100		65			100	100
Band spreading	-	-	-	-	10	15		-	-	-
Injection	-	-	-	-	25	20		-	-	-
Slurry dilution (broadcast spr.)	-	-	-	-	-	-	-	-	-	-
Application on stubble (% of manure applied)										
No measures	-	-	-	-		10		-	-	-
Incorp. with ploughing < 4 h	-	-	-	-		5		-	-	-
Incorp. with ploughing < 12 h	-	-	-	-	40	35		-	-	-
Incorp. with ploughing > 12 h	-	-	-	-	40	35	30	-	-	-
Incorp. with harrowing < 4 h	-	-	-	-		0		-	-	-
Incorp. with harrowing < 12 h	-	-	-	-		0		-	-	-
Incorp. with harrowing > 12 h	-	-	-	-		0		-	-	-
Injection	-	-	-	-		5		-	-	-
Band spreading	-	-	-	-	0	10	15	-	-	-
Slurry dilution (broadcast spr.)	-	-	-	-	-	-	-	-	-	-

2.2.5

Calculation of NH_3 emissions from mineral N-fertilizers

Ammonia emissions due to the use of mineral N-fertilizers were calculated separately for different fertilizer types using the emission factors presented in the EMEP/Corinair Emission Inventory Guidebook (EEA 2007) (Table 12). The total amount of nitrogen sold annually in Finland was divided by fertilizer type using the information obtained from Yara Finland Ltd (Marko Toimela, pers.comm. 21.11.2007) (Table 12). Furthermore, the use of different mineral N-fertilizers was allocated between arable and grassland soils according to the agricultural land use statistics from the Information Centre of the Ministry of Agriculture and Forestry. In Finland, placement fertilization is typically used for cereals. Based on the emission reduction efficiencies of different manure application and emission abatement methods, it was supposed that placement fertilization reduces ammonia volatilization by 50% compared to surface application of mineral fertilizers. Thus, emission factors for arable land were multiplied by 0.5 except for nitrogen solutions for which placement fertilization is not used.

Table 12. Distribution of mineral N-fertilizers used in Finland by fertilizer type (%), distribution of each fertilizer type by application target (arable or grassland, %), and NH_3-emission factors (EF) for different fertilizer types applied to arable and grassland.

Spread as:	% of applied N	On arable land, %	On grassland, %	EF arable, %	EF grass, %
Ammonium sulphate	0.0	65	35	1.5	1.5
Ammonium nitrate	0.0	65	35	0.6	1.6
Calcium ammonium nitrate	19.6	65	35	0.6	1.6
Anhydrous ammonia	0.0	65	35	2.0	2.0
Urea	0.0	65	35	11.5	23.0
Nitrogen solutions[1)]	0.04	100	0	7.0	7.0
Ammonium phosphates	0.13	65	35	1.5	1.5
Other NK and NPK	80.2	65	35	0.6	1.6
Nitrate only	0.05	65	35	0.5	0.5

[1)] Nitrogen solutions are not used on grasslands. Because solutions are applied with sprayers, no emission correction factor due to placement fertilization was used.

2.2.6

Calculation of nitric and nitrous oxide emissions

In the EMEP/Corinair Emission Inventory Guidebook (EEA 2007) no nitric oxide (NO) emission factor for manure management is provided. Nitric oxide emissions from mineral fertilizers were calculated using the emission factor 0.7% of N applied (kg NO-N as a result). Direct and indirect nitrous oxide emissions (Table 13) were calculated in the model according to the IPCC 1997 Guidelines (IPCC 1997).

Indirect N_2O emissions from nitrogen leaching were not calculated. This was because there were no data on nitrogen leaching from manure management systems and the model was originally designed for emission calculation at the farm level, excluding the processes taking place outside the farming processes. Thus, the indirect N_2O emissions are only derived from ammonia and nitric oxide emissions from manure management and the application of manure and mineral fertilisers.

In addition to the normal calculation procedures, time series for direct and indirect N_2O emissions were also calculated using the same manure management data, animal numbers and N-excretion values as in ammonia emission calculations.

Table 13. Emission factors for direct and indirect nitrous oxide (N_20) emission calculations used in the model (IPCC 1997).

Source	EF for direct emission (% of total N)	EF for indirect emission (% of NH_3-N + NO-N)
Manure management		
Slurry and urine	0.1[1)]	
Deep litter	2.0[1)]	1.0
Solid manure	2.0[1)]	
Dung	2.0[1)]	
Manure application	1.25[2)]	1.0
Mineral N application	1.25[2)]	1.0
Grazing	2.0[2)]	1.0

[1)]% of excreted nitrogen
[2)]% of nitrogen applied on soil

2.3
Measurements of ammonia emissions in animal houses

Ammonia emissions were measured in some animal production facilities in order to estimate how well the modelled emission factors calculated on the basis of literature, statistics and expert judgment represent the emissions in Finnish conditions.

The emissions were measured in three pig houses and two cow houses located in Southern Finland. Two of the pig farms were rearing fattening pigs and one was a research facility with separate departments for fattening pigs, sows with piglets and weaning pigs. All locations had partly slatted floors and forced ventilation. In addition, one of the meat production units had a slurry cooling system for preventing ammonia emissions and for providing energy for warming the building in winter.

One of the cow houses collected the manure as farmyard manure and the other had a slurry-based system. Both had partly slatted floors and forced ventilation. Measurements were not carried out in the summer in the cow houses because the cows were grazing.

Measurement campaigns were carried out as described in Table 14. Measurement times were selected to represent different environmental conditions in order to evaluate the effect of ambient temperature on the results.

Table 14. Ammonia measurement campaigns in pig and cow houses.

	Winter period		Summer/spring/autumn period	
	Week number, duration	Animal number, weight	Week number, duration	Animal number, weight
Pig facilities				
Farm 1, weaned pigs, slurry	Wk 15, 9 days	354 pigs, 16 kg	Wk 28, 4 days	392 pigs, 16 kg
Farm 2, weaned pigs, cooled slurry	Wk 13, 7 days	346 pigs, 16 kg	Wk 32, 6 days	455 pigs, 13 kg
Farm 3, fatteners, slurry	Wk 6, 7 days	120 pigs, 40–100 kg	Wk 36, 4 days	128 pigs, 40–100 kg
Farm 3, sows with piglets, slurry	Wk 7, 6 days	7 sows + 71 piglets, 8 kg	Wk 37, 2 days	8 sows + 85 piglets, 3 kg
Farm 3, weaned pigs, slurry	Wk 7, 6 days	84 pigs, 25 kg	Wk 37, 2 days	32 pigs, 30 kg
Cowhouses				
Farm 4, dairy cows, slurry	Wk 9, 8 days	34 dairy cows, 15 calves	Wk 47, 7 days	33 dairy cows, 11 calves
Farm 5, dairy cows, farmyard manure	Wk 3, 6 days	65 dairy cows, 7 pregnant, 24 heifers	Wk 17, 8 days Wk 46, 6 days	65 dairy cows, 7 pregnant, 24 heifers 62 dairy cows, 10 pregnant, 24 heifers

For the gas measurements, teflon sampling lines were drawn from all outgoing air channels and one or two incoming air channels to the 1309 Multipoint Sampler (Innova AirTech Instruments A/S, Ballerup, Denmark). Filters were used at the end of the sampling lines in order to prevent dust in the pipes. The sampler took three consequent samples from each line at two minute intervals. The samples were led from the multipoint sampler to the 1412 Photoacoustic Field Gas Monitor (Innova AirTech Instruments A/S, Ballerup, Denmark) for analysis. Ammonia and water vapour concentrations in the incoming and outgoing air were usually measured over a period of about one week. The temperature of the air was measured every four hours using Elcolog data loggers (Elcoplast Oy, Tampere, Finland) which were placed into the air channels. Data about the number of animals and the weight of the animals were collected. The ventilation rate of the building was estimated indirectly from the moisture balance by calculating the theoretical moisture production of the animals and comparing the moisture of the incoming air to the moisture of the outgoing air (Teye and Hautala 2007). By knowing the amount of water produced from the animals and the observed increase of moisture in the outgoing air it was possible to estimate the mass flow of outgoing air. The ammonia emission for the measurement period was calculated by multiplying the average ammonia concentration by the volume of the air that had left the building during that period. The ammonia emission factors per animal or animal place were determined by calculating the emission rates for winter and spring/summer/autumn periods and taking into account the amount of animals. The months from November to the end of March were considered as winter months.

3 Results

3.1
Ammonia emissions in Finland

3.1.1
Ammonia emission factors for livestock

The emission factor of an animal category depends largely on the amount of nitrogen it excretes. The percentage of the emitted nitrogen from the excreted nitrogen is largest with poultry and lowest with reindeer (Table 15). When emission factors for the year 1995 are calculated with the revised model and compared with previous emission factors calculated with the old version of the model (Grönroos et al. 1998), both increases and decreases can be identified (Table 15). The emission factors of dairy cows and bulls have increased, whereas those of sows and fattening pigs have decreased, for example. The main reason for the differences between these two emission factor sets are differences in nitrogen excretion values. In most of the animal categories, updated estimates of N excretion are lower than the earlier values.

Table 15. Ammonia emission factors for livestock animals by animal category as total factor with percentages of excreted nitrogen, and as values split by manure management phase (kg NH_3 per head (or animal place or pelt) per year) for the year 2007. For comparison, emission factors for 1995 as calculated with the old version of the model (Grönroos et al. 1998) and with the revised version are both presented.

	Total		Split				Emission factors for 1995	
		% of excr. N	Animal shelter	Manure storage	Manure application	Pasturing	Old model	Revised model
Dairy cows	33.9	23	9.9	11.7	10.7	1.7	31.5	24.7
Suckler cows	14.4	19	5.8	4.3	3.1	1.2	14.3	13.5
Heifers	12.7	21	3.7	5.2	2.9	0.9	13.2	11.0
Bulls	23.6	29	7.7	9.8	6.1	0.0	20.7	20.1
Calves < 1 yr.	12.7	28	3.9	5.4	3.2	0.1	9.1	10.6
Sows (with piglets)	10.3	30	3.3	4.8	2.3	0.0	14.9	9.4
Fattening pigs (kg NH_3 per animal place)	3.31	31	1.01	1.07	1.23	0.00	4.2	3.0
Boars	7.14	30	2.26	3.28	1.59	0.00	3.4	6.5
Weaned pigs (20–50 kg)	1.04	31	0.32	0.34	0.38	0.00	–	1.0
Laying hens	0.39	48	0.25	0.11	0.03	0.00	0.34	0.40
Broilers (kg NH_3 per animal place)	0.16	33	0.14	0.01	0.01	0.00	0.18	0.14
Chickens	0.21	48	0.13	0.06	0.02	0.00	0.085	0.20
Cockerels	0.58	48	0.38	0.16	0.04	0.00	0.5	0.58
Broiler hens	0.54	33	0.45	0.05	0.04	0.00	0.4	0.54
Turkeys	0.55	33	0.47	0.05	0.04	0.00	0.55	0.44
Other poultry	0.35	43	0.24	0.08	0.03	0.00	0.34	0.36
Sheep with lambs	2.09	17	1.26	0.41	0.24	0.17	4.2	1.8
Goats with gilts	2.09	17	1.26	0.41	0.24	0.17	4.2	1.8
Horses	16.5	22	4.23	9.40	1.68	1.18	17.6	14.4
Ponies	11.8	22	3.02	6.71	1.20	0.84		10.6
Minks and fitches (kg NH_3 per pelt)	0.42	26	0.00	0.40	0.02	0.00	0.51	0.41
Foxes and racoons (kg NH_3 per pelt)	0.74	26	0.00	0.71	0.03	0.00	0.97	0.71
Reindeer	0.57	4	0.00	0.00	0.00	0.57	–	0.57

3.1.2

Ammonia emissions 1990–2007 and emission projections 2008–2050

In 2007, the Finnish emissions of ammonia from agricultural sources (including reindeer) totalled 30 686 tonnes, of which over 60% originated from cattle manure (Figure 1). Dairy cows alone produced about one third of the total agricultural emissions (Appendix 4). Pigs, poultry and fur animals, too, have produced significant emissions, and the increasing number of horses results in growing emissions from that sector.

Time series for ammonia emissions from agriculture shows that there have been no large changes in the total emissions during the last 18 years (Figure 1). Despite the decreasing number of cattle during that period (Appendix 1), the emissions have remained near the present level. From 1994 to 1995 there is a clear drop in emissions, because the number of dairy cows declined faster than in other years. Emission projections for the years 2008–2050 show no significant changes in the future (Figure 2). Changes in cattle numbers is the reason for the temporary decline in total emissions between 2013 and 2020.

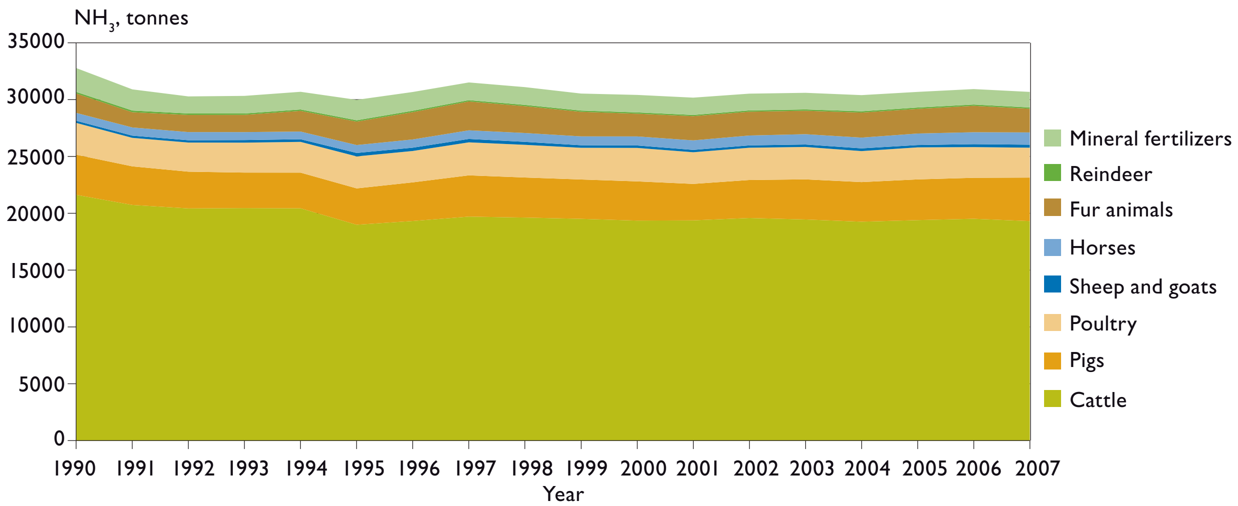

Figure 1. Ammonia emissions from agricultural sources (animal manure and mineral fertilizers) in Finland 1990–2007.

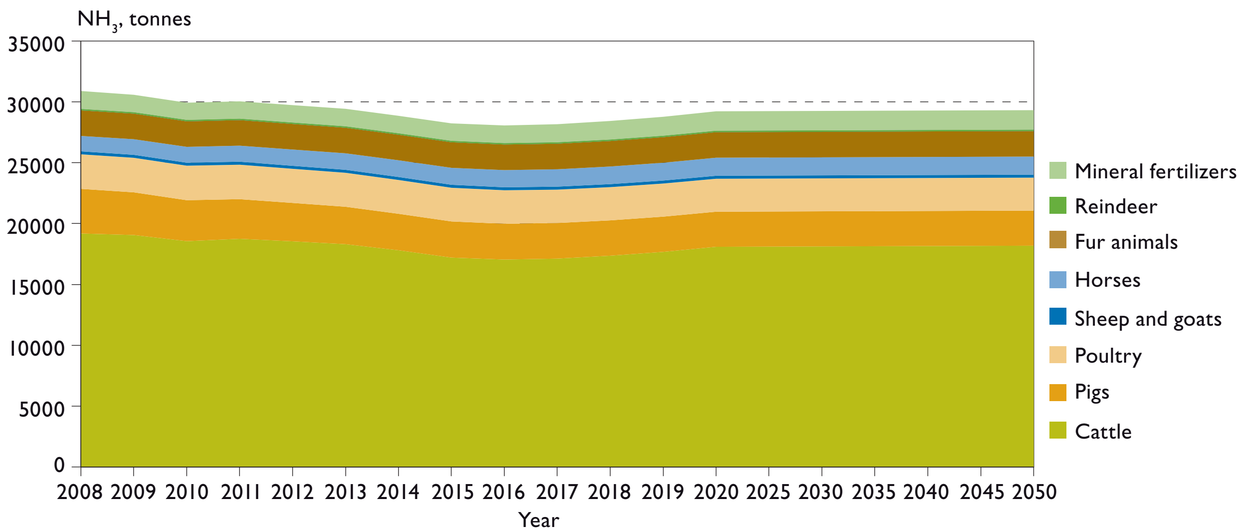

Figure 2. Agricultural ammonia emission projections for the years 2008–2050 in Finland. From the year 2020 onwards, one step in the time scale covers five years instead of one.

The main reason for the consistent emission of ammonia is the increased nitrogen excretion per animal, especially for cattle. Also the milk production per dairy cow has increased and there is a close correlation between the amounts of excreted nitrogen and the amount of milk produced (Figure 3). Between 1995 and 2007, dairy cows excreted on average 14.5–15.6 g nitrogen per litre of milk. Klimont and Brink (2004) also observed a close relationship between milk production and nitrogen excretion, and estimated missing nitrogen excretion values on the basis of milk production, when calculating ammonia emission estimates for European countries with the RAINS model. However, increased knowledge about animal nutrition opens possibilities to increase the efficiency of feedstuff N utilization and, thereby, to achieve the same production with less N in feed and lower N excretion by the livestock (Børsting et al. 2003). For the years 2017–2020, an increase is projected for the ammonia emissions from cattle, because the number of dairy cows does not decline any more while the nitrogen excretion per cow continues to increase.

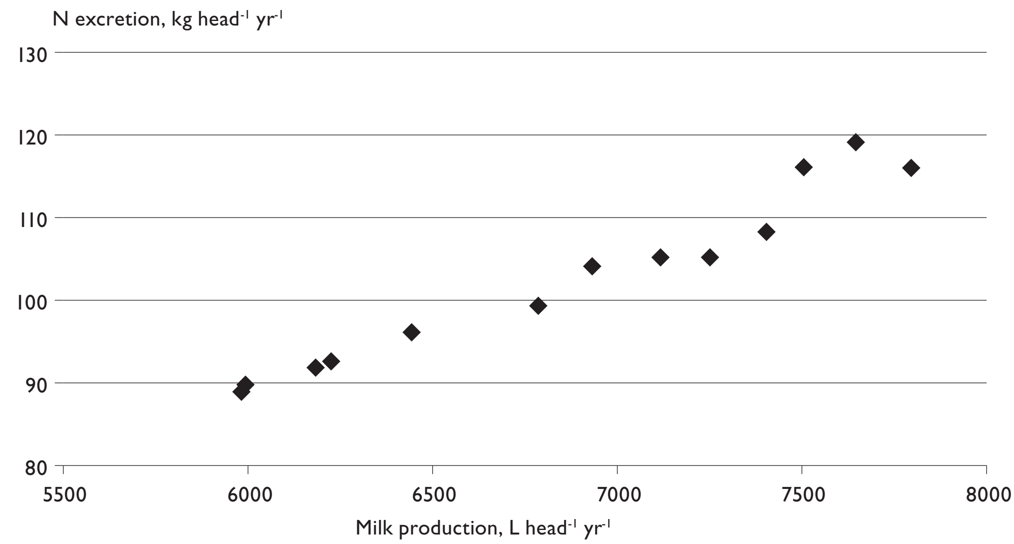

Figure 3. Relationship between calculated N excretion and average milk production (Tike 2008) of Finnish dairy cows 1995–2007.

3.1.3

Ammonia emission sources in livestock farming

Of the total NH_3-N emissions originating from agricultural sources (livestock animals, fur animals, reindeer and mineral fertilizers; 25 270 t NH_3-N) in 2007 approximately 96% (24 150 t) originated from manure. The total excreted amount of nitrogen in manure was 96 040 t. Thus, the share of evaporated NH_3-N during the total manure management chain covering animal shelter, manure storing and application was 25%.

Animal shelters were responsible for 32% of the total evaporated NH_3-N from animal manure. The shares of manure storing, manure spreading and pasturing were 41%, 24% and 3%, respectively. Approximately 40% of evaporated NH_3-N originated from slurry and 34% from farmyard manure, whereas the share of the other manure types totalled 26% (deep litter 7%, urine 10%, dung 6%, manure left on pasture 3%).

3.2

Nitrous oxide emissions in Finland

Direct and indirect nitrous oxide emissions from livestock manure were assessed from the emission sources fully covering the IPCC source category 4.B and partly the category 4.D (see Chapter 2.2.5, Table 13). Of the direct emission sources assessed, manure management and application, and mineral fertilizer N application both proved to be significant. Of the indirect sources assessed manure management was the most important because of the large ammonia emissions from manure (Table 16). In Finland, direct nitrous oxide emissions from manure management, manure application, mineral N spreading and pasturing totalled 5 808 tonnes of N_2O in 2007. The indirect N_2O emissions, however, arising from the deposited NH_3 and NO due to the emissions from manure management and application, and mineral fertilizers summed up to 414 tonnes (Table 16).

With liquid forms of manure (slurry and urine), most of the emissions are released after application in the field, whereas solid manure types release more nitrous oxide during manure management in animal houses and manure storage. This is due to the higher emission factor for solid manure types in manure management than for liquid ones. For this reason, the relative importance of cattle and pigs is lower in the N_2O-emissions from manure management compared to the emissions from manure application: manure of cattle and pigs is managed both in liquid and solid forms whereas for other animals only in solid form (Table 17). Of the direct N_2O-emissions from pasturing (570 tonnes in 2007), dairy cows were responsible for 52% of the emissions. The shares of heifers, reindeer and others (sum of sheep, goats, horses and other cattle) were 16%, 11% and 21%, respectively.

In 2007, the direct agricultural N_2O-N emission from manure and mineral fertilizers equalled 3696 tonnes of which 50% originated from mineral fertilizers and the rest from manure. Of the total excreted nitrogen in manure (96 040 t N in 2007) approximately 2% evaporated during manure management and after manure application in the form of N_2O-N.

Table 16. Direct and indirect N_2O emissions (tonnes N_2O) from manure management, pasturing and N-application in Finland in 2007 (animal categories included: see table 17).

Source	Direct emissions (tonnes N_2O)	Indirect emissions (tonnes N_2O)
Manure management		
slurry	50.6	
deep litter	200.3	
solid manure	798.6	
urine	12.1	
dung	197.4	
total	1 258.9	276.3
Manure application	1 057.3	90.7
Mineral N application	2 922.5	34.1
Pasturing	569.6	12.4

Table 17. Direct nitrous oxide emissions from manure management and manure application by animal category in Finland in 2007 (tonnes N_2O). Emissions from pasturing are not included.

	Manure management						Manure application					
	Slurry	Deep litter	Solid manure	Urine	Dung	Total	Slurry	Deep litter	Solid manure	Urine	Dung	Total
Dairy cows	26.3	8.4	150.4	4.1	67.7	256.9	231.3	4.0	61.5	36.4	31.4	364.6
Suckler cows	0.8	21.5	8.6	0.2	3.9	35.0	7.3	10.2	3.5	2.1	1.8	24.8
Heifers	3.1	5.2	52.5	1.4	23.6	85.9	27.2	2.4	21.5	12.7	11.0	74.8
Bulls	4.6	13.8	61.9	1.7	27.9	109.8	40.3	6.5	25.3	15.0	12.9	100.0
Calves < 1 v.	6.5	10.3	101.0	2.8	45.4	166.0	57.2	4.9	41.3	24.4	21.1	148.9
Sows (with piglets)	2.3	7.8	50.8	1.4	22.9	85.3	20.1	3.7	20.8	12.2	10.6	67.5
Fattening pigs	5.6	6.9	10.4	0.3	4.7	27.9	47.7	3.3	4.3	2.5	2.2	59.9
Boars	0.0	0.1	0.8	0.0	0.4	1.4	0.3	0.1	0.3	0.2	0.2	1.1
Weaned pigs (20–50 kg)	1.2	1.5	2.3	0.1	1.0	6.1	10.4	0.7	0.9	0.5	0.5	13.0
Laying hens	0.1	3.3	61.3	-	-	64.7	0.5	1.3	18.9	-	-	20.8
Broilers	-	63.5	0.0	-	-	63.5	-	25.7	0.0	-	-	25.7
Chickens	-	0.4	8.1	-	-	8.5	-	0.2	2.5	-	-	2.7
Cockerels	-	-	0.4	-	-	0.4	-	-	0.1	-	-	0.1
Broiler hens	-	14.6	0.0	-	-	14.6	-	5.9	0.0	-	-	5.9
Turkeys	-	18.6	0.0	-	-	18.6	-	7.5	0.0	-	-	7.5
Other poultry	-	0.2	0.3	-	-	0.5	-	0.1	0.1	-	-	0.2
Sheep with lambs												
Goats with gilts	-	24.1	2.7	-	-	26.8	-	11.4	1.1	-	-	12.5
Horses	-	-	72.4	-	-	72.4	-	-	29.6	-	-	29.6
Ponies	-	-	7.4	-	-	7.4	-	-	3.0	-	-	3.0
Minks and fitches	-	-	58.3	-	-	58.3	-	-	26.6	-	-	26.6
Foxes and racoons	-	-	149.0	-	-	149.0	-	-	68.0	-	-	68.0
Reindeer	-	-	-	-	-	0.0	-	-	-	-	-	0.0
TOTAL	50.6	200.3	798.6	12.1	197.4	1258.9	442.4	87.9	329.4	106.1	91.5	1057.3

A time series of agricultural nitrous oxide emissions in Finland, excluding indirect emissions arising from nitrogen leaching, shows that a decline in the use of mineral fertilizers has resulted in a reduction in nitrous oxide emissions (Figure 4). The projected increase of mineral fertilizer use between 2015 and 2020 increases the projected emissions in those years (Figure 5).

Most of the total nitrous oxide emission is comprised of direct emissions. The percentage of indirect emissions is 11–12% of the total for manure and about 1.3% for mineral fertilizer. The higher proportion of indirect emissions from manure is a result of larger ammonia emissions, which are the main source of indirect emissions of nitrous oxide.

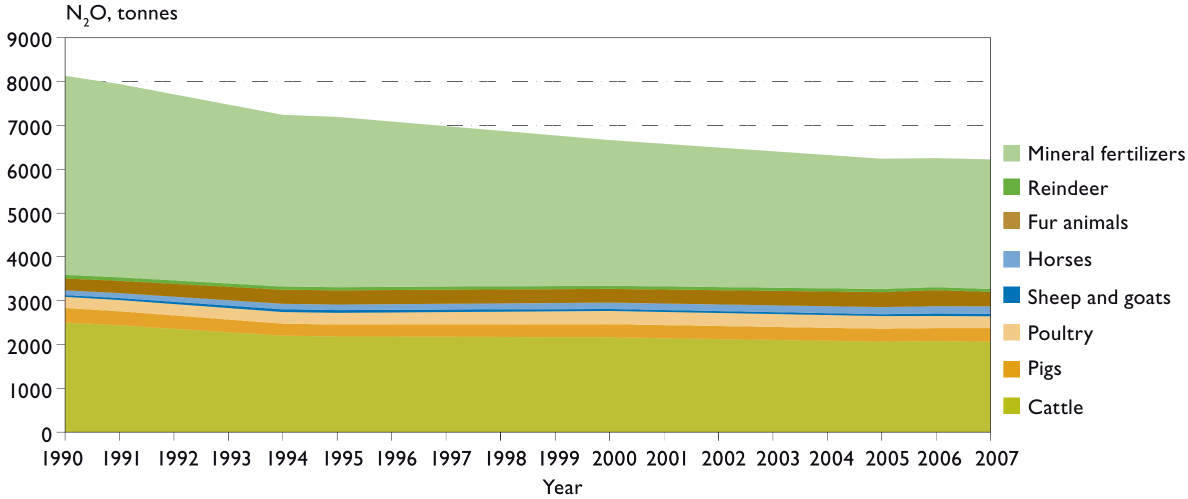

Figure 4. Nitrous oxide emissions (direct and indirect) from agricultural sources (animal manure and mineral fertilizers) in Finland for the years1990–2007. Indirect emissions do not include emissions arising from nitrogen leaching and runoff.

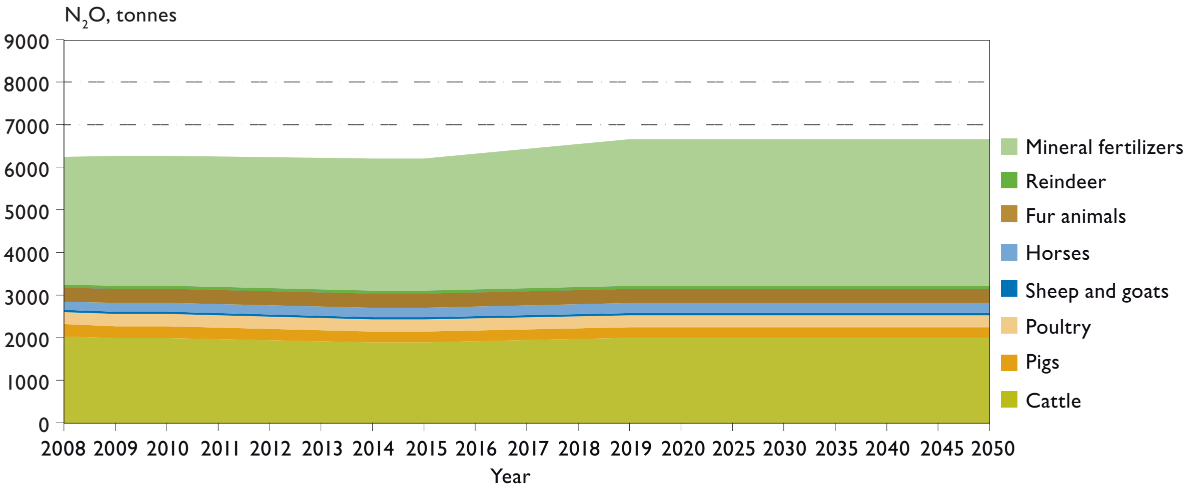

Figure 5. Agricultural nitrous oxide emission (direct and indirect) projections for the years 2008–2050 in Finland. From the year 2020 onwards, one step in the time scale covers five years instead of one. Indirect emissions do not include emissions arising from nitrogen leaching and runoff.

3.3

Measured ammonia emissions from animal houses

The annual ammonia emissions from fattening pigs were 3.3 kg animal place^{-1} year^{-1} (Table 18) which was higher than the calculated value for housing (1.0 kg animal place^{-1} year^{-1}) based on N excretion (Table 15). However, the air quality of the building where the measurements were carried out was exceptionally bad and as such does not represent a typical situation. The collective emission factor for a sow with 10 piglets was 5.7 kg head^{-1} year^{-1}. The measured value was thus higher than the estimated emission factor (3.4 kg head^{-1} year^{-1}). The measured results for weaned pigs were very different from one farm to another and the average annual emission factor of the three farms was 0.8 kg animal place^{-1} year^{-1} which was more than double the calculated value. The exceptionally high result for farm 3 in summer, based on only two days' data, is probably not reliable since the instrument was not functioning properly. An emission factor based only on measurements from farms 1 and 2 would be 0.5 kg animal place^{-1} year^{-1} which is much closer to the revised housing emission factor of 0.3 kg head^{-1} year^{-1} (Table 15).

Dairy cows in a slurry system had a higher emission factor (9.2 kg head^{-1} year^{-1}) than cows in a farmyard manure management system (2.7 kg head^{-1} year^{-1}). The average calculated housing emission factor for dairy cows was 9.7 kg head^{-1} year^{-1} (Table 15). The measured values were quite well in line with the modelled emission factors of 7.8 and 3.9 kg head^{-1} year^{-1} for slurry and farmyard manure, respectively (data not shown). The measured values were also close to those obtained by Misselbrook et al. (2000).

The results of the measurements suggest that the emission factors chosen for the model in general represent values typical for Finland. However, the number of animal shelters studied and the number of measurement days was very limited. The limited data set does not allow for any type of correction of the calculated emission factors at this stage. More NH_3 measurements from animal shelters are needed to improve the emission estimates.

Table 18. Measured annual ammonia emission factors

	kg NH_3 head^{-1} year^{-1}		
Type of production	Winter Nov–Mar	Summer Apr–Oct	Annual
Fattening pigs 40–100 kg Partly slatted floor, slurry	1.22	2.07	3.29
Sow + 10 piglets Partly slatted floor, slurry	2.12	3.55	5.67
Weaned pigs <20 kg			
Partly slatted floor, slurry			
Farm 1	0.02	0.18	0.20
Farm 2	0.65	0.23	0.88
Farm 3	0.15	1.12	1.27
Average	0.27	0.51	0.78
Dairy cow Slurry	6.00	3.17	9.17
Dairy cow Farmyard manure	1.33	1.33	2.66

4 Uncertainties

Animal numbers for the years 1990–2007 are from agricultural statistics and are relatively reliable (Statistics Finland 2007, p. 148). Animal number projections for the future are less sure because there is a lot of uncertainty in the development of agricultural policy and markets, which have a strong effect on the scale and intensity of animal production. The calculation of nitrogen excretion by livestock is based on data and knowledge about the amount of nitrogen in feedstuffs and animal products, and on practices of animal feeding. Intensive research has been carried out on the nutrition of cattle and pigs in Finland, which gives a good basis for nitrogen excretion calculations on these animal species that are the most important sources of manure and ammonia emissions in Finland. However, the actual nitrogen excretion is affected by variation in feeding strategies between farms and in the properties of feedstuffs caused by annual differences in weather conditions. The estimated variation of nitrogen excretion was in most of the animal categories ±10–20% of the average excretion.

Dairy cows are the most important animal group as a source of ammonia and nitrous oxide emissions. Projections for ammonia emissions are made assuming that the close correlation of excreted nitrogen and milk production level of the cows remains the same. However, if the ratio of excreted nitrogen to produced milk could be lowered with modified feeding, for example, the emissions could be lower than those predicted.

Compared with the amount of nitrogen excreted by livestock, there is more uncertainty in the manure management data and the proportions of volatilized nitrogen at the different phases of manure management. Variation between farms in the conditions of manure management and, consequently, in the level of ammonia emissions is large, which was observed in the emission measurements of the current project (Chapter 3.3). Estimating the distribution of manure management systems and the use of different manure application techniques is very uncertain because no systematic data collection exists in Finland. Some of this data is collected by the Information Centre of the Ministry of Agriculture and Forestry and also regionally for the environmental permit procedure but the synthesis of the data is defective.

There has been a lot of research into several of the potential measures to reduce ammonia emissions, mainly in Europe and in North America (Appendix 3). However, the effectiveness of the measures in practice is uncertain, because many factors, such as weather conditions, manure properties and details in the application of a technique, can differ significantly from the experimental circumstances.

A rough best case – worst case study shows that in extreme cases ammonia emission would be approximately 190% higher or 60% lower than in the default case (Table 19) In the worst case calculations, a high N-excretion value and high values for ammonia volatilization from manure management phases compared to the default case are used. In the best case, low values are used. If only uncertainty deriving from the manure management data and ammonia volatilization values was assessed, the ammonia emission would vary between +140% and -50% compared to the default case.

For nitrous oxide emission estimates, as well as the uncertainties of the IPCC emission factors, the same sources of uncertainty as for ammonia hold true, e.g. animal numbers, nitrogen excretion levels and amounts of nitrogen evaporated as ammonia in different manure management phases. All factors affect the amount of nitrogen flowing through the manure management chain and finally the amount of nitrogen which is applied to the field. For N_2O, the worst case (maximum N_2O-N emission) would consist of high N-excretion and low ammonia volatilization and the best case of low N-excretion and high ammonia volatilization (Table 19). This is because nitrous oxide emissions increase with increasing amounts of nitrogen entering the soil.

Table 19. Ammonia and nitrous oxide emissions in extreme best–worst -calculation example. In the default case NH_3-volatilization values (as percents, obtained from the NH_3-model) describing average volatilization levels in the total Finnish animal husbandry were used. For N-excretion a relative value "100" was used. In the other cases these values were changed: N-excretion values vary between ±20% compared to the default case. NH_3 volatilization values are in the worst case high (30%) and in the best case low (5%), with a value of 10% in the default case.

		For NH_3 emission				For N_2O emission	
		N -excr. + NH_3 -volat.[1]		NH_3 -volat.[2]		N -excr. + NH_3 -volat.[1]	
	default	worst	best	worst	best	worst	best
N-excretion (relative values)	100	120	80	100	100	120	80
N volatilization as NH_3-N (%) in animal shelter	*10 %*	*30 %*	*5 %*	*30 %*	*5 %*	*5 %*	*30 %*
N in manure before manure storing	90	84	76	70	95	114	56
N volatilization as NH_3-N (%) in manure storing	*10 %*	*30 %*	*5 %*	*30 %*	*5 %*	*5 %*	*30 %*
N in manure before manure spreading	81	59	72	49	90	108	39
N volatilization as NH_3-N (%) in manure spreading	*10 %*	*30 %*	*5 %*	*30 %*	*5 %*	*5 %*	*30 %*
N in manure after manure spreading and after N volatilization	72	41	69	34	86	103	27
as percents compared to default case		-43 %	-5 %	-52 %	19 %	43 %	-62 %
N evaporation as NH_3-N	27	78	11	65	13	16	52
as percents compared to default case		186 %	-61 %	139 %	-51 %	-41 %	91 %
Evaporates as NH_3-N of original N content	27 %	65 %	13 %	65 %	13 %	13 %	65 %
Direct N_2O-N emission from manure management	1.0	1.2	0.8	1.0	1.0	1.2	0.8
Direct N_2O-N from N application	0.9	0.5	0.9	0.4	1.1	1.3	0.3
Indirect N_2O-N due to ammonia emission	0.3	0.8	0.1	0.6	0.1	0.2	0.5
Direct+indirect N_2O-N emission	2.2	2.5	1.8	2.1	2.2	2.6	1.7
as percents compared to default case		15 %	-19 %	-4 %	2 %	22 %	**-23** %

[1] In the best case – worst case calculations variation in N-excretion and in NH_3 volatilization values were applied

[2] In the best case – worst case calculations only variations in NH_3 volatilization values are applied.

5 Discussion

Ammonia emissions in Finland have remained static in recent years and no big changes can be expected in the future as long as there are no drastic alterations in animal production. However, if changes in the agricultural policy of the European Union, such as the abolition of milk quotas, reduces animal production in Finland, a corresponding reduction is likely in ammonia emissions. If the prices of agricultural products increase, farmers are motivated to increase production, but higher production costs may undermine profitability. Thus, the uncertainty on the effects of agricultural policy and markets brings uncertainty to emission projections, too.

Similar to ammonia, the emissions of nitrous oxide depend on the extent of agricultural production. For nitrous oxide the use of mineral fertilizer nitrogen is crucial, because it is the main source of the emissions.

The ammonia emission factors obtained with the revised model are compared with emission factors from some other sources (Table 20). The RAINS model has been developed into the GAINS model (IIASA 2008), which uses several different scenarios of emission reduction measures and, correspondingly, produces many different sets of emission factors that are not presented here.

Nitrogen excretion has been estimated in several European countries based on the available data from statistics, surveys and research. Due to different data sources and calculation methods, there is variation between countries in nitrogen excretion estimates and the values may not be fully comparable (Table 21). The Finnish values for nitrogen excretion are in most cases close to those used in other countries.

Data collection about the distribution of manure management systems and the use of different manure application methods should be improved in the future. Data is needed both for national research purposes and also internationally, when research groups use models for estimating ammonia emissions of different countries, for example. Also, manure management data is needed in the greenhouse gas inventory for the UNFCCC. It is an advantage if Finland can provide this data when needed. Similar problems are encountered in other European countries, too. Examples of data collection in other countries are presented in Appendix 6.

Areas for further development

To ensure more accurate inventories there is a need for development in two areas:

1) More NH_3 measurements of ammonia emissions from animal shelters are needed to improve the emission estimates. Measurement should be carried out in a larger number of different shelters and over longer periods throughout the year to obtain more representative data.
2) More information on the distribution of manure management systems and the use of different manure application methods should be acquired.

Table 20. Ammonia emission factors for livestock animals by animal category (kg NH_3 per head (or animal place or pelt) per year) for the year 2007 calculated with the revised model compared with emission factors used by EMEP/CORINAIR (EEA 2007), RAINS-model (Klimont and Brink 2004) and Danish emission inventory (NERI 2008).

	Revised model	EMEP/ CORINAIR	RAINS[1)]	Denmark
Dairy cows	33.9	28.5	33.4	25.5
Suckler cows	14.4	14.3	15.9	25.5
Heifers	12.7	14.3	15.9	4.4
Bulls	23.6	14.3	15.9	4.4
Calves < 1 yr.	12.7			4.4
Sows (with piglets)	10.3	16.43		2.6
Fattening pigs (kg NH_3 per animal place)	3.31	6.39[2)]	3.5	2.6
Boars	7.14			2.6
Weaned pigs (20–50 kg)	1.04			2.6
Laying hens	0.39	0.37		0.26
Broilers (kg NH_3 per animal place)	0.16	0.28		0.26
Chickens	0.21			0.26
Cockerels	0.58			0.26
Broiler hens	0.54			0.26
Turkeys	0.55			0.26
Other poultry	0.35	0.92		0.26
Sheep with lambs	2.09	1.34[3)]		1.4
Goats with gilts	2.09	1.34[3)]		1.3
Horses	16.5	8.0		6.5
Ponies	11.8			6.5
Fur animals		1.69[3)]		
Minks and fitches (kg NH3 per pelt)	0.42			2.2
Foxes and racoons (kg NH3 per pelt)	0.74			2.2
Reindeer	0.57			

[1)] Emission factors for Finland based on general and country-specific data and on expert judgment.
[2)] Emission of an animal that is present throughout the whole year.
[3)] Emission factors are calculated for female adult animals. Emissions of young animals are included in the given values.

Table 21. Nitrogen excretion values used for the year 2007 in the calculation of ammonia emission in a selection of European countries (Appendix 2, NERI 2008, Swedish environmental protection agency 2008, Umweltbundesamt 2008, Federal Environment Agency 2006).

	Finland	Denmark	Sweden	Austria	Germany
Dairy cows	121.9	134.66	125	95.63	1)
Non-dairy cattle		38.0			
Beef cows			63		44
Cattle, 1–2 yr.			47	53.6	
Suckler cows	63.9			69.5	96
Heifers	50.3				
Bulls	66.4			68.4	42
Calves < 1 yr.	37.6		28	25.7	16
Swine		8.55			1)
Sows (with piglets)	28.5		34[2)]	29.1	
Fattening pigs (kg NH_3 per animal place)	8.90		10.08	10.3	
Boars	19.7		34		
Weaned pigs (20–50 kg)	2.79				
Poultry		0.63			
Laying hens	0.67		0.64		0.74
Broilers (kg NH_3 per animal place)	0.398				
Chickens	0.354		0.28		0.29
Cockerels	1.00				
Broiler hens	1.33		0.29		
Turkeys	1.371				
Other poultry	0.67			1.1	
Sheep with lambs	9.97	16.95[3)]	13[4)]	13.1 [3)]	13[3)]
Goats with gilts	10.7	16.36[3)]		12.3 [3)]	
Horses	60.9	43.31	50	47.9	64
Ponies	43.5				
Fur animals		5.18			
Minks and fitches (kg NH_3 per pelt)	1.305		4.1		
Foxes and racoons (kg NH_3 per pelt)	2.34				
Reindeer	10.7				

1) Calculation explained, general value not given.
2) Piglets not mentioned.
3) Lambs and gilts not mentioned.
4) Lambs excluded.

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Appendix 1. Animal numbers in Finland 1990–2050.

Numbers of cattle and pigs (in thousands) in Finland 1990–2007 (official statistics by Tike) and 2008–2050 (estimated by MTT Agrifood Research Finland).

Year	Dairy cows	Suckler cows	Heifers >1 yr	Bulls >1 yr	Calves <1 yr	Sows (with piglets)	Fattening pigs (>50 kg)	Boars	Weaned pigs (20–50 kg)
1990	489.9	14.2	218.8	148.9	487.9	178.8	437.7	5.9	313.3
1991	445.6	21.2	213.5	144.1	485.5	174.0	426.0	5.8	304.9
1992	428.2	27.9	211.1	143.3	462.7	168.0	411.3	5.6	294.3
1993	426.4	33.1	216.7	139.2	436.9	164.7	403.3	5.5	288.6
1994	416.7	32.6	214.8	143.5	425.4	168.0	411.4	5.6	294.4
1995	398.5	29.2	188.9	109.3	422.0	161.1	450.8	6.5	306.1
1996	392.2	31.1	201.1	114.7	406.5	179.8	444.7	6.6	308.8
1997	390.9	32.4	196.8	120.5	401.8	185.2	470.4	7.1	366.7
1998	383.1	30.6	190.3	114.7	398.4	186.5	420.6	7.8	357.4
1999	372.4	29.6	187.5	118.1	379.2	180.2	431.1	5.8	296.9
2000	364.1	27.8	185.0	114.9	364.8	184.3	404.9	6.0	289.2
2001	354.8	27.2	181.7	111.3	362.3	163.6	391.2	5.4	291.6
2002	347.8	28.1	180.0	115.3	354.2	172.2	404.8	5.3	296.0
2003	333.9	28.1	178.5	115.5	344.1	178.1	444.0	5.0	297.1
2004	324.4	30.8	173.1	110.5	330.4	175.0	441.2	4.7	291.3
2005	318.8	34.6	168.8	107.8	329.0	176.7	459.7	4.4	309.3
2006	309.4	38.9	170.8	112.5	317.7	170.9	457.4	4.0	326.6
2007	296.1	43.3	166.5	109.8	311.1	174.6	496.7	4.1	344.9
2008	290.0	43.4	166.7	100.0	313.4	175.6	456.7	4.4	307.3
2009	282.8	44.4	163.6	98.2	307.5	168.1	437.4	4.2	294.3
2010	273.8	45.6	159.7	95.8	300.2	161.2	419.3	4.0	282.1
2011	273.7	47.0	160.4	96.2	301.5	157.4	409.5	3.9	275.5
2012	267.1	48.7	157.9	94.7	296.9	154.1	400.9	3.8	269.8
2013	260.0	50.6	155.3	93.2	292.0	151.6	394.4	3.8	265.4
2014	248.8	52.7	150.7	90.4	283.4	149.2	388.1	3.7	261.2
2015	237.3	55.8	146.6	87.9	275.6	147.9	384.9	3.7	259.0
2016	229.8	59.2	144.5	86.7	271.6	146.4	380.9	3.6	256.3
2017	226.0	62.8	144.4	86.6	271.4	145.7	379.0	3.6	255.0
2018	224.6	66.5	145.6	87.4	273.7	144.7	376.3	3.6	253.2
2019	224.9	69.5	147.2	88.3	276.7	144.3	375.4	3.6	252.5
2020	229.3	72.7	151.0	90.6	283.9	143.5	373.4	3.6	251.2
2030	232.2	71.3	151.8	91.1	285.3	143.5	373.4	3.6	251.2
2040	233.9	69.4	151.7	91.0	285.1	143.5	373.4	3.6	251.2
2050	236.7	67.7	152.2	91.3	286.1	143.5	373.4	3.6	251.2

Numbers of poultry, sheep and goats (in thousands) in Finland 1990–2007 (official statistics by Tike) and 2008–2050 (estimated by MTT Agrifood Research Finland).

Year	Laying hens	Broilers	Chickens	Cockerels	Broiler hens	Turkeys	Other poultry[1)]	Sheep with lambs	Goats with gilts
1990	4844.8	2993.0	1632.5	49.7	61.8	59.9	20.8	103.3	5.9
1991	4138.0	3249.7	1303.5	44.8	97.2	63.9	31.8	106.7	5.4
1992	3968.9	3506.4	1597.5	39.9	132.6	67.9	42.9	108.4	4.8
1993	4024.9	3763.0	1522.3	35.0	167.9	72.0	54.1	120.4	4.8
1994	4089.8	4019.7	1421.6	30.1	203.3	76.0	65.2	121.1	5.7
1995	4178.8	4276.4	1482.3	25.2	239.8	80.0	75.2	158.6	6.0
1996	4183.5	4052.4	1245.6	24.6	278.6	95.8	54.3	149.5	6.5
1997	4151.5	4911.1	1287.8	32.0	299.2	111.6	33.4	150.1	8.0
1998	3801.8	5507.2	1184.7	29.5	347.1	144.8	34.5	128.3	8.1
1999	3361.3	5998.2	1025.3	17.2	382.4	210.0	39.2	106.6	7.9
2000	3110.0	7917.9	914.4	17.6	363.5	214.5	31.6	99.6	8.6
2001	3201.7	5412.1	1043.0	12.4	393.9	455.4	35.1	96.0	7.4
2002	3212.5	5766.3	772.3	9.4	401.6	530.5	41.4	95.9	6.6
2003	3016.2	6050.3	930.9	10.1	346.0	603.4	40.2	98.4	6.8
2004	3069.2	5573.2	911.6	10.4	287.4	535.3	18.1	108.9	7.3
2005	3127.6	5472.3	953.6	12.3	457.0	495.4	20.0	89.7	6.9
2006	3103.3	5366.1	844.0	13.4	404.5	492.6	15.0	116.7	6.7
2007	3134.4	5074.1	763.9	12.9	350.9	430.5	24.3	119.3	6.2
2008	3159.8	5468.0	968.7	12.3	456.6	495.0	30.0	108.9	7.3
2009	3129.7	5509.3	960.2	12.3	460.1	498.7	30.0	108.9	7.3
2010	3100.2	5554.5	952.0	12.3	463.9	502.8	30.0	108.9	7.3
2011	3071.1	5602.9	943.8	12.3	467.9	507.2	30.0	108.9	7.3
2012	3042.5	5541.4	935.8	12.3	462.8	501.7	30.0	108.9	7.3
2013	3014.5	5538.1	928.0	12.3	462.5	501.4	30.0	108.9	7.3
2014	2986.8	5535.8	920.2	12.3	462.3	501.1	30.0	108.9	7.3
2015	2959.7	5537.0	912.6	12.3	462.4	501.3	30.0	108.9	7.3
2016	2933.0	5534.9	905.1	12.3	462.2	501.1	30.0	108.9	7.3
2017	2906.7	5536.3	897.8	12.3	462.3	501.2	30.0	108.9	7.3
2018	2880.8	5535.1	890.5	12.3	462.2	501.1	30.0	108.9	7.3
2019	2855.4	5536.4	883.4	12.3	462.3	501.2	30.0	108.9	7.3
2020	2830.3	5535.8	876.4	12.3	462.3	501.1	30.0	108.9	7.3
2030	2830.3	5535.8	876.4	12.3	462.3	501.1	30.0	108.9	7.3
2040	2830.3	5535.8	876.4	12.3	462.3	501.1	30.0	108.9	7.3
2050	2830.3	5535.8	876.4	12.3	462.3	501.1	30.0	108.9	7.3

[1)] From 2008 onwards, the estimate of other poultry is based on the average of the preceding 10 years.

Appendix 1/3

Numbers of horses, ponies, fur animals and reindeer (in thousands) and use of mineral N-fertilisers (as 1000 kg of nitrogen) in Finland 1990–2007 (official statistics by Tike) and 2008–2050 (estimated by MTT Agrifood Research Finland).

Year	Horses	Ponies	Minks and fitches	Foxes and racoons	Reindeer	Mineral N-fertilisers
1990	39.4	6.0	1804.9	1477.6	239.1	228470
1991	41.7	6.4	1505.2	1091.6	259.6	202462
1992	42.7	6.4	1576.2	1272.3	231.6	163229
1993	42.7	6.3	1658.7	1220.8	215.4	168199
1994	42.1	6.2	1639.4	1644.7	214.3	169138
1995	43.7	6.2	1944.7	1803.9	208.1	195460
1996	45.6	6.4	1801.3	2343.9	212.9	179529
1997	47.9	6.8	1828.2	2493.4	202.6	169345
1998	49.2	6.9	1646.0	2321.8	196.1	169928
1999	49.6	6.6	1732.7	1972.3	195.4	162700
2000	50.7	6.7	1497.9	1862.6	203.4	167276
2001	51.9	6.7	1496.6	2043.9	185.7	165621
2002	52.1	7.0	1450.0	2020.0	199.7	160403
2003	52.9	7.3	1407.7	2002.6	196.7	159288
2004	53.8	7.3	1378.5	2205.9	201.1	154708
2005	56.1	7.7	1355.0	2174.7	207.2	149562
2006	58.1	8.0	1465.8	2320.0	197.8	148161
2007	59.5	8.5	1422.4	2025.4	193.3	162647
2008	70.0	9.6	1500.0	2000.0	205.0	159989
2009	71.0	9.7	1500.0	2000.0	205.0	155755
2010	72.0	9.8	1500.0	2000.0	205.0	153528
2011	73.0	10.0	1500.0	2000.0	205.0	154920
2012	74.0	10.1	1500.0	2000.0	205.0	155363
2013	75.0	10.2	1500.0	2000.0	205.0	156390
2014	76.0	10.4	1500.0	2000.0	205.0	156113
2015	77.0	10.5	1500.0	2000.0	205.0	156084
2016	78.0	10.6	1500.0	2000.0	205.0	157634
2017	79.0	10.8	1500.0	2000.0	205.0	161452
2018	80.0	10.9	1500.0	2000.0	205.0	165737
2019	81.0	11.1	1500.0	2000.0	205.0	169015
2020	82.0	11.2	1500.0	2000.0	205.0	173393
2030	82.0	11.2	1500.0	2000.0	205.0	174091
2040	82.0	11.2	1500.0	2000.0	205.0	184291
2050	82.0	11.2	1500.0	2000.0	205.0	164167

Appendix 2. Nitrogen excretion rates of farm animals in Finland 1990–2050. The calculation of the rates is reported in chapter 2.2.2.

Nitrogen excretion rates (kg N yr^{-1} $animal^{-1}$) of cattle and pigs in Finland in 1990–2050.

Year	Dairy cows	Suckler cows	Heifers >1 yr	Bulls >1 yr	Calves <1 yr	Sows (with piglets)	Fattening pigs[1)] (>50 kg)	Boars	Weaned pigs[1)] (20–50 kg)
1990	84.6	58.3	41.4	52.8	29.8	30.1	7.77	19.6	2.74
1991	85.8	58.6	42.4	53.7	30.0	30.8	7.31	19.7	2.74
1992	85.6	58.9	42.2	54.4	30.4	30.5	7.01	19.4	2.74
1993	82.9	59.3	42.3	55.1	30.9	30.8	6.86	19.3	2.74
1994	85.7	59.6	43.3	56.0	31.2	30.6	7.46	19.1	2.74
1995	88.9	59.9	43.6	56.7	31.6	26.0	8.08	17.9	2.74
1996	89.8	60.3	44.0	57.6	32.3	26.6	8.48	17.7	2.74
1997	91.8	60.6	45.2	58.2	32.8	26.3	8.41	19.1	2.75
1998	92.6	60.9	45.6	59.0	33.4	26.8	8.81	19.2	2.75
1999	96.1	61.3	46.4	59.8	33.9	27.4	8.74	16.8	2.76
2000	99.3	61.6	47.0	60.7	34.6	27.7	8.66	16.9	2.76
2001	104.1	61.9	48.2	61.6	34.9	27.1	8.82	17.9	2.76
2002	105.2	62.2	48.3	62.5	35.3	27.3	8.97	18.3	2.77
2003	105.2	62.6	48.5	63.3	35.6	27.4	8.43	18.7	2.77
2004	108.3	62.9	49.0	64.1	36.0	27.9	8.47	18.8	2.78
2005	116.1	63.2	49.0	65.0	36.4	28.0	8.44	19.3	2.78
2006	119.1	63.6	48.7	65.7	37.2	28.1	8.82	19.8	2.79
2007	121.9	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2008	124.3	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2009	126.7	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2010	129.2	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2011	131.8	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2012	134.3	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2013	136.6	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2014	138.9	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2015	141.1	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2016	143.4	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2017	145.8	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2018	148.1	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2019	150.5	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2020	152.9	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2030	164.8	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2040	171.1	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79
2050	177.6	63.9	50.3	66.4	37.6	28.5	8.90	19.7	2.79

[1)] Three batches.

Nitrogen excretion rates (kg N yr^{-1} $animal^{-1}$) of poultry, sheep and goats in Finland 1990–2050.

Year	Laying hens	Broilers[1)]	Chickens	Cockerels	Broiler hens	Turkeys[2)]	Other poultry[3)]	Sheep with lambs	Goats with gilts
1990	0.70	0.344	0.3541	1.00	1.33	0.801	0.70	8.46	10.70
1991	0.71	0.381	0.3541	1.00	1.33	0.941	0.71	8.51	10.70
1992	0.70	0.344	0.3541	1.00	1.33	0.954	0.70	8.58	10.70
1993	0.72	0.369	0.3541	1.00	1.33	1.073	0.72	8.66	10.70
1994	0.71	0.363	0.3541	1.00	1.33	1.014	0.71	8.73	10.70
1995	0.70	0.358	0.3541	1.00	1.33	1.078	0.70	8.69	10.70
1996	0.71	0.323	0.3541	1.00	1.33	1.072	0.71	8.85	10.70
1997	0.71	0.319	0.3541	1.00	1.33	1.118	0.71	8.86	10.70
1998	0.71	0.372	0.3541	1.00	1.33	1.163	0.71	8.97	10.70
1999	0.70	0.368	0.3541	1.00	1.33	1.208	0.70	9.15	10.70
2000	0.70	0.364	0.3541	1.00	1.33	1.286	0.70	9.32	10.70
2001	0.68	0.360	0.3541	1.00	1.33	1.296	0.68	9.46	10.70
2002	0.67	0.357	0.3541	1.00	1.33	1.355	0.67	9.57	10.70
2003	0.69	0.381	0.3541	1.00	1.33	1.364	0.69	9.60	10.70
2004	0.71	0.378	0.3541	1.00	1.33	1.422	0.71	9.64	10.70
2005	0.69	0.376	0.3541	1.00	1.33	1.430	0.69	9.88	10.70
2006	0.68	0.373	0.3541	1.00	1.33	1.371	0.68	9.97	10.70
2007	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2008	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2009	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2010	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2011	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2012	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2013	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2014	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2015	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2016	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2017	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2018	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2019	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2020	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2030	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2040	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70
2050	0.67	0.398	0.3541	1.00	1.33	1.371	0.67	9.97	10.70

[1)] 6 batches.
[2)] 2.5 batches.
[3)] Estimated equal to laying hens.

Nitrogen excretion rates (kg N yr^{-1} $animal^{-1}$) of horses, ponies, fur animals and reindeer in Finland 1990–2050.

Year	Horses	Ponies	Minks and fitches	Foxes and racoons	Reindeer[1)]
1990	59.4	43.4	1.244	2.13	10.70
1991	59.2	43.2	1.25	2.151	10.70
1992	59.1	43.2	1.256	2.172	10.70
1993	59.6	43.4	1.262	2.193	10.70
1994	60.1	43.9	1.268	2.214	10.70
1995	60.5	44.4	1.274	2.235	10.70
1996	60.5	44.2	1.28	2.256	10.70
1997	60.3	44.4	1.286	2.277	10.70
1998	60.0	44.3	1.292	2.298	10.70
1999	60.0	44.2	1.298	2.319	10.70
2000	60.1	44.1	1.305	2.34	10.70
2001	60.3	44.1	1.305	2.34	10.70
2002	60.5	44.2	1.305	2.34	10.70
2003	60.8	44.2	1.305	2.34	10.70
2004	61.0	44.0	1.305	2.34	10.70
2005	61.0	43.6	1.305	2.34	10.70
2006	60.9	43.5	1.305	2.34	10.70
2007	60.9	43.5	1.305	2.34	10.70
2008	60.9	43.5	1.305	2.34	10.70
2009	60.9	43.5	1.305	2.34	10.70
2010	60.9	43.5	1.305	2.34	10.70
2011	60.9	43.5	1.305	2.34	10.70
2012	60.9	43.5	1.305	2.34	10.70
2013	60.9	43.5	1.305	2.34	10.70
2014	60.9	43.5	1.305	2.34	10.70
2015	60.9	43.5	1.305	2.34	10.70
2016	60.9	43.5	1.305	2.34	10.70
2017	60.9	43.5	1.305	2.34	10.70
2018	60.9	43.5	1.305	2.34	10.70
2019	60.9	43.5	1.305	2.34	10.70
2020	60.9	43.5	1.305	2.34	10.70
2030	60.9	43.5	1.305	2.34	10.70
2040	60.9	43.5	1.305	2.34	10.70
2050	60.9	43.5	1.305	2.34	10.70

[1)] Estimated as equal to goats.

Appendix 3. Compilation of literature on the reduction potential of ammonia emissions by different measures.

Target / measure / animal type	Reference	Volatilized N (% of total N)	Volatilization reduction potential
Livestock buildings			
Pigs	Lundin 1988	10%	
Pigs, all manure management techniques	Claesson and Steineck 1991	12%	
Cattle	Lundin 1988	5%	
Cattle, all manure management techniques	Claesson and Sleineck 1991	7%	
Cattle	Ryden et al. 1987	2–20%	
Poultry	Lundin 1988	5–10%	
Poultry	Claesson and Steineck 1991	solid manure 10% slurry 3%	
Intensified separation or absorption of urine	Grönroos 1993		5–30% (estimate)
Intensified cleaning of surfaces, no flushing	Grönroos 1993		5–15% (estimate)
Flushing	Heimig 1991		up to 70%
Flushing, pig house	Oosthoek et al. 1990		60–70%
Less volatilization in cattle houses than in pig houses	Mannebeck and Oldenburg 1990		
Dairy cows, adjustment of feeding	Klaassen 1994		20–25%
Pigs, adjustment of feeding	Klaassen 1994		15%
Laying hens, adjustment of feeding	Klaassen 1994		10%
Other poultry, adjustment of feeding	Klaassen 1994		20%
Dairy cows, changes in animal house	Klaassen 1994		50%
Pigs, changes in animal house	Klaassen 1994		65%
Laying hens, changes in animal house	Klaassen 1994		60%
Other poultry, changes in animal house	Klaassen 1994		90%
Pig houses, biofiltering	Klaassen 1994		90%
Poultry, biofiltering	Klaassen 1994		80%
Biofiltering	Scholtens and Demmers 1990		>85%
Scrubbers	Scholtens and Demmers 1990		>95%

Target / measure / animal type	Reference	Volatilized N (% of total N)	Volatilization reduction potential
Manure storage			
Pig and cattle solid manure	Lundin 1988	20%	
Chicken solid manure	Lundin 1988	10%	
Solid manure, 4–7 months	Kirchmann 1988	0–50%	
Urine, open storage	Jordbruksverket 1991	50%	
During storage, cattle slurry, 2 months	Patni and Jui 1991	4–9%	
During storage, cattle slurry, 3–6 months	Gracey 1979	6%	
During storage, pig and cattle slurry, 5 months	De Bode 1990	5–15%, summer loss 2–3 x winter loss, pig slurry ca. 2 x	
Solid manure, normal compactness	Claesson and Steineck 1991	15–30%	
Solid manure, loose	Claesson and Steineck 1991	50%	
Urine, no cover	Claesson and Steineck 1991	50–75%	
Urine, covered storage	Claesson and Steineck 1991	25%	
Urine, tight lid	Claesson and Steineck 1991	7–8%	
Slurry	Claesson and Steineck 1991	10%	
Cattle slurry, filling from the bottom	Muck et al. 1984	3–8%	
Cattle slurry, filling from the top	Muck et al. 1984	29–39%	
Slurry stirring	Svensson 1991	Equal to volatilization during storage	
Slurry aerating	Skjelhaugen 1988	11%	
Tight lid, floating cover	Claesson and Steineck 1991		70–80%
Filling from the bottom	Muck et al. 1984		85%
Cattle slurry, natural crust	De Bode 1990		40%, 60–70% (straw added)
Straw	De Bode 1990, Sommer 1991		40–90%
Pig slurry, tent cover	De Bode 1990	84–94% (less in winter)	
Pig slurry, corrugated iron cover	De Bode 1990	54–84% (less in winter)	
Pig slurry, floating tight cover	De Bode 1990	73–94% (less in winter)	
Tent cover	De Bode 1990	71–84% (less in winter)	
Cattle slurry, corrugated iron cover	De Bode 1990	46–50% (less in winter)	
Cattle slurry, floating tight cover	De Bode 1990	78–86% (less in winter)	
Cattle, closed storage	Klaassen 1994		10%
Poultry, closed storage	Klaassen 1994		80%

Target / measure / animal type	Reference	Volatilization reduction potential
Manure storage continued		
Storage tank cover, pig slurry (measured on farm)	Hörnig et al. 1999	Chopped straw 79.9%, Granules (Pegülit M) 91.0% Granules (Pegülit R) 62.9%, Floating film 99.7%, Tent roof 99.5%
Storage tank cover, pig slurry (measured on laboratory)	Hörnig et al. 1999	Chopped straw 30%, Granules (Pegülit M,Pegülit R) 50–70%, Rapeseed oil 3 mm 50%, Rapeseed oil 6 mm 85%
Storage tank cover, pig slurry	Sommer et al. 1993	Lid 100% (Exp. 1), 95% (Exp. 2), PVC foil 98%, 91%, Peat 84%, 68%, Leca® 95%, 88%, Oil (rapeseed) 100%, 98%, Straw 97%, 83%, Crust 92%, 76%
Storage tank cover, cattle slurry	Sommer et al. 1993	Lid 99% (Exp. 1), 97% (Exp. 2), PVC foil 74%,93%, Peat 81% ,99%, Leca® 83%, 86%, Oil (rapeseed) 63%, 52%, Straw 40%,93%, Crust ”not developed”, 87%

Target / measure / animal type	Reference	Volatilized N (% of ammoniacal N, if not notified otherwise)
Application		
Solid manure, pig and cattle,	Lundin 1988	2–20% of total N
Solid manure, chicken	Lundin 1988	20% and more
Cattle solid manure	Lauer 1976	60–100%
Cattle solid manure	Sommer and Christensen 1990	37–45%
Pig and chicken solid manure	Sommer and Christensen 1990	16–28%
Chicken deep litter manure	Lockyer et al. 1989	37%
Cattle urine, grassland for hey	Ryden et al. 1987	9–25% of total N
Cattle dung, grassland for hey	Ryden et al. 1987	1–2% of total N
Cattle slurry, grassland for hey, surface application	Ryden et al. 1987	42–84%
Broadcast spreading, pig and cattle slurry	Vlassak et al. 1990, Amberger 1990, Döhler 1990	30–80%
Broadcast spreading, cattle slurry	Sipilä 1992	>30%
Broadcast spreading, cattle slurry	Sommer 1991	30–50%
Broadcast spr. + incorp. by harrowing within 8 h, cattle slurry	Sommer 1991	15%
Broadcast spr. + incorp. by harrowing immediately, cattle slurry	Sommer 1991	5%.
Broadcast spreading, cattle slurry	Sommer et al. 1991	40–60%
Broadcast spreading on grassland, pig and cattle slurry	Lockyer et al. 1989	at least 40% (40–80%)
Broadcast spreading	Lundin 1988	3–30% of total N
Broadcast spreading, cattle slurry	Klarenbeek and Bruins 1990	42–45%
Broadcast spreading, pig slurry	Klarenbeek and Bruins 1990	53–57%

Target / measure / animal type	Reference	Volatilized N (% of ammoniacal N, if not notified otherwise)
Application continued		
Broadcast spreading	Bless 1991	Relatively higher loss from cattle manure than from pig manure
Broadcast spreading on bare soil, cattle slurry	Beauchamp et al. 1982	24–33%
Broadcast spreading, cattle slurry	Sommer et al. 1991	23% (cold)–35% (warm) (within 12 h)
Broadcast spreading, cattle slurry	Sommer and Christensen 1990	30–100%
Broadcast spreading	Döhler 1990	50% pig manure, 65% cattle manure
Broadcast spreading + ploughing immediately, cattle slurry	Sommer and Christensen 1990	17%
Broadcast spreading, average of cattle and pig slurry	Bless 1991	66% (within 5 days)
Broadcast spreading	Pain et al. 1989	40% cattle manure, 7–62% pig manure
Broadcast spreading, cattle slurry	Döhler 1990	40–60%
Injection, cattle slurry	Döhler 1990	1–2%
Injection, slurry	Sommer and Christensen 1990	<17%
Urine spreading on grassland	Whitehead and Raistrick 1992	39%
Urine spreading on bare soil	Whitehead and Raistrick 1992	23%
Slurry method vs. pasturing	Pain 1990	Loss from conventional slurry treatment chain (animal house - storage - spreading) may be up to 10 times that from pasture
Urine, application on grassland	Ryden et al. 1987	6–21%
Cattle slurry, application on grassland	Ryden et al. 1987	42–84%
Urine, application on grassland	Whitehead et al. 1989	ca. 25% of total N
Urine, application on grassland	Ryden et al. 1987	9–25% of total N
Dung, application on grassland	Ryden et al. 1987	1–2% of total N
Pasture on a sandy soil	Vertregt and Rutgers 1990	urine, max. 10%
Cattle slurry, cut grassland	Mattila and Joki-Tokola 2003	broadcast 40–59%, band spread 31%, injected 0.4%
Pig slurry, pig peat manure, recently tilled arable land	Mattila 2006	broadcast <1% within 8 h from both manures, 9% from peat manure within 3 d

Target / measure / animal type	Reference	Volatilization reduction potential (compared to broadcast spreading on surface)
Application continued		
Cattle solid manure, immediate incorporation by harrowing	Sommer and Christensen 1990	70%
Band spreading, cattle slurry	Döhler 1990	ca. 30%.
Immediate incorporation by harrowing	Bless 1991	70–80%
Incorporation by harrowing after 8 h	Bless 1991	ca. 30%
Injection	Klarenbeek and Bruins 1990	at least 90%
Irrigation or rain (10 mm) after spreading	Klarenbeek and Bruins 1990	pig manure 70%, cattle manure 80%
Dilution (manure : water = 1 : 3)	Klarenbeek and Bruins 1990	pig manure 50%, cattle manure 70%
Dilution (manure : water = 1 : 1 or more)	Döhler 1990	25–50%
Broadcast spr. + ploughing within 6 h or harrowing within 3 h sis.	Klarenbeek and Bruins 1990	50%
Band spreading into growing crop	Bless 1991	at least 50%
Broadcast spreading + immediate incorporation by harrowing	Sommer and Christensen 1990	70%, cattle solid manure
Broadcast spreading + immediate incorporation by harrowing	Sipilä 1992	at lest 20%, cattle slurry
Cattle slurry, cut grassland, band spreading	Frost 1994	60%
Cattle slurry, cut grassland, shallow injection	Frost 1994	at least 90%
Cattle, pigs, poultry: low-emission application methods (injection, immediate incorporation by ploughing etc.)	Klaassen 1994	90%
Cattle slurry (pig slurry on one site), grassland	Misselbrook et al. 2002	Shallow injection 73%, Trailing shoe 57%, Band spreading 26%
Cattle slurry (pig slurry on one site), arable land	Misselbrook et al. 2002	Shallow injection 23%, Trailing shoe 38%, Band spreading 27%
Pig slurry, arable land	Malgeryd 1998	Shallow injection 90%, Band spreading 40%, Irrigation immediately after spreading 70%
Cattle slurry, arable land	Malgeryd 1998	Harrowing after 4 hours 60%
Cattle farmyard manure, arable land	Malgeryd 1998	Harrowing after 4 hours 90%

Appendix 4. Annual ammonia emissions by animal category in Finland 1990–2007 and emission projections for the years 2008–2050. The calculation of the emissions is reported in chapters 2.1. and 2.2.

Annual ammonia emissions (tonnes NH_3) of cattle and pigs in Finland 1990–2007 and emission projections for the years 2008–2050.

Year	Dairy cows	Suckler cows	Heifers >1 yr	Bulls >1 yr	Calves <1 yr	Sows (with piglets)	Fattening pigs (>50 kg)	Boars	Weaned pigs (20–50 kg)
1990	11 689	191	2 228	2 786	4 738	1 923	1 239	41.5	325
1991	10 709	285	2 208	2 735	4 804	1 823	1 218	39.8	314
1992	10 383	376	2 225	2 769	4 684	1 702	1 191	37.7	301
1993	10 432	447	2 327	2 737	4 522	1 612	1 182	36.2	293
1994	10 284	441	2 349	2 870	4 500	1 586	1 220	36.1	297
1995	9 852	395	2 073	2 193	4 484	1 509	1 340	42.0	308
1996	9 925	423	2 243	2 335	4 401	1 706	1 340	42.1	311
1997	10 120	443	2 230	2 487	4 432	1 780	1 437	44.7	370
1998	10 140	421	2 190	2 402	4 475	1 815	1 302	48.5	361
1999	10 075	409	2 190	2 506	4 337	1 775	1 352	35.7	300
2000	10 063	387	2 194	2 471	4 246	1 838	1 286	36.4	293
2001	10 140	380	2 174	2 429	4 262	1 637	1 239	33.8	296
2002	10 265	395	2 171	2 551	4 210	1 729	1 279	34.1	302
2003	10 168	398	2 172	2 590	4 133	1 794	1 399	33.1	304
2004	10 183	438	2 123	2 512	4 008	1 769	1 386	32.0	300
2005	10 306	494	2 088	2 486	4 031	1 792	1 440	30.7	319
2006	10 265	559	2 101	2 623	3 976	1 740	1 499	28.9	338
2007	10 050	624	2 113	2 589	3 940	1 803	1 642	29.1	357
2008	10 128	626	2 114	2 357	3 965	1 811	1 507	31.2	318
2009	10 153	639	2 073	2 311	3 888	1 733	1 441	29.8	304
2010	9 830	657	2 024	2 256	3 796	1 662	1 382	28.6	291
2011	9 996	676	2 027	2 258	3 799	1 614	1 331	27.8	281
2012	9 917	698	1 989	2 214	3 727	1 572	1 285	27.0	271
2013	9 815	723	1 951	2 170	3 654	1 538	1 246	26.5	263
2014	9 543	751	1 887	2 098	3 534	1 506	1 209	25.9	255
2015	9 103	796	1 835	2 040	3 436	1 493	1 199	25.7	253
2016	8 997	844	1 809	2 011	3 387	1 478	1 187	25.4	250
2017	9 030	894	1 808	2 010	3 385	1 470	1 181	25.3	249
2018	9 154	948	1 823	2 027	3 413	1 460	1 172	25.1	247
2019	9 345	990	1 843	2 049	3 451	1 456	1 169	25.0	247
2020	9 529	1 036	1 891	2 102	3 540	1 449	1 163	24.9	245
2030	9 648	1 016	1 900	2 113	3 558	1 449	1 163	24.9	245
2040	9 718	989	1 899	2 111	3 555	1 449	1 163	24.9	245
2050	9 836	965	1 906	2 119	3 568	1 449	1 163	24.9	245

Annual ammonia emissions (tonnes NH_3) of poultry, sheep and goats in Finland 1990–2007 and emission projections for the years 2008–2050.

Year	Laying hens	Broilers	Chickens	Cockerels	Broiler hens	Turkeys	Other poultry	Sheep with lambs	Goats with gilts
1990	1 959	417	336	28.9	33.1	19.4	7.5	176	10.0
1991	1 672	456	268	26.0	52.1	22.1	11.4	184	9.2
1992	1 603	497	328	23.2	71.1	25.4	15.4	191	8.4
1993	1 625	539	312	20.3	90.1	29.0	19.5	215	8.6
1994	1 651	581	291	17.5	109.1	32.7	23.5	221	10.4
1995	1 687	619	303	14.6	128.7	34.9	27.1	290	11.0
1996	1 691	589	255	14.3	149.5	43.4	19.6	277	12.1
1997	1 681	716	264	18.6	160.5	52.5	12.1	283	15.1
1998	1 541	806	243	17.1	186.2	70.5	12.5	245	15.5
1999	1 365	880	210	10.0	205.1	105.8	14.2	207	15.3
2000	1 265	1 166	187	10.2	195.0	111.7	11.5	196	16.9
2001	1 297	802	214	7.2	211.3	242.3	12.7	191	14.8
2002	1 297	860	158	5.5	215.4	288.4	14.9	193	13.3
2003	1 213	908	191	5.9	185.5	335.0	14.4	200	13.7
2004	1 229	841	187	6.0	154.1	303.4	6.5	223	14.9
2005	1 248	831	196	7.1	245.0	286.5	7.1	186	14.4
2006	1 214	810	174	7.8	216.8	273.2	5.2	244	13.9
2007	1 213	817	157	7.5	188.1	238.7	8.4	249	12.9
2008	1 222	881	199	7.1	244.8	274.5	10.4	228	15.3
2009	1 211	887	198	7.1	246.6	276.6	10.4	228	15.3
2010	1 199	894	196	7.1	248.6	278.8	10.4	228	15.3
2011	1 188	902	194	7.1	250.8	281.3	10.4	228	15.3
2012	1 177	892	193	7.1	248.1	278.2	10.4	228	15.3
2013	1 165	892	191	7.1	247.9	278.0	10.4	228	15.3
2014	1 155	891	189	7.1	247.8	277.9	10.4	228	15.3
2015	1 144	892	188	7.1	247.9	278.0	10.4	228	15.3
2016	1 134	891	186	7.1	247.8	277.9	10.4	228	15.3
2017	1 124	892	185	7.1	247.8	277.9	10.4	228	15.3
2018	1 114	891	183	7.1	247.8	277.9	10.4	228	15.3
2019	1 104	892	182	7.1	247.8	277.9	10.4	228	15.3
2020	1 094	891	180	7.1	247.8	277.9	10.4	228	15.3
2030	1 094	891	180	7.1	247.8	277.9	10.4	228	15.3
2040	1 094	891	180	7.1	247.8	277.9	10.4	228	15.3
2050	1 094	891	180	7.1	247.8	277.9	10.4	228	15.3

Annual ammonia emissions (tonnes NH_3) of horses, ponies, fur animals and reindeer in Finland 1990–2007 and emission projections for the years 2008–2050.

Year	Horses	Ponies	Minks and fitches	Foxes and racoons	Reindeer
1990	624	69	717	992	136
1991	649	73	601	740	147
1992	649	71	633	873	131
1993	633	69	670	848	122
1994	611	66	667	1 156	122
1995	631	66	792	1 270	118
1996	657	68	737	1 666	121
1997	689	71	751	1 789	115
1998	707	73	680	1 681	111
1999	712	70	719	1 441	111
2000	726	70	625	1 373	115
2001	766	72	624	1 507	105
2002	792	77	605	1 489	113
2003	827	82	587	1 477	112
2004	864	84	575	1 626	114
2005	926	90	565	1 603	117
2006	957	94	611	1 711	112
2007	981	100	593	1 493	110
2008	1 154	113	625	1 475	116
2009	1 171	114	625	1 475	116
2010	1 187	116	625	1 475	116
2011	1 204	117	625	1 475	116
2012	1 220	119	625	1 475	116
2013	1 237	121	625	1 475	116
2014	1 253	122	625	1 475	116
2015	1 270	124	625	1 475	116
2016	1 286	125	625	1 475	116
2017	1 303	127	625	1 475	116
2018	1 319	129	625	1 475	116
2019	1 336	130	625	1 475	116
2020	1 352	132	625	1 475	116
2030	1 352	132	625	1 475	116
2040	1 352	132	625	1 475	116
2050	1 352	132	625	1 475	116

Appendix 5. Annual nitrous oxide emissions (direct and indirect, excluding emissions deriving from leached nitrogen) by animal category in Finland 1990–2007 and emission projections for the years 2008–2050.

Annual nitrous oxide emissions (tonnes N_2O) of cattle and pigs in Finland 1990–2007 and emission projections for the years 2008–2050.

Year	Dairy cows	Suckler cows	Heifers >1 yr	Bulls >1 yr	Calves <1 yr	Sows (with piglets) (>50 kg)	Fattening pigs	Boars	Weaned pigs (20–50 kg)
1990	1392	32.4	302	271	503	195	103.3	4.2	29.8
1991	1351	39.7	297	258	492	187	101.4	4.2	28.1
1992	1300	48.9	290	242	478	176	99.0	4.2	26.1
1993	1249	58.0	283	226	463	165	96.7	4.2	24.0
1994	1198	67.2	276	210	449	155	94.3	4.2	22.0
1995	1187	69.0	274	207	446	153	93.8	4.2	21.6
1996	1181	67.8	277	212	442	159	93.1	4.1	21.4
1997	1174	66.6	281	217	437	166	92.4	4.0	21.2
1998	1168	65.3	284	222	432	173	91.7	3.9	21.0
1999	1161	64.1	287	227	427	179	91.0	3.8	20.8
2000	1155	62.9	290	233	422	186	90.3	3.7	20.6
2001	1139	66.1	287	233	418	184	91.4	3.6	20.7
2002	1124	69.3	284	233	413	182	92.5	3.4	20.8
2003	1108	72.5	281	233	409	180	93.5	3.3	21.0
2004	1093	75.7	278	233	405	177	94.6	3.1	21.1
2005	1077	78.8	275	234	400	175	95.7	3.0	21.2
2006	1073	89.1	277	247	395	170	99.6	2.8	22.4
2007	1050	99.6	279	243	391	176	109.1	2.8	23.7
2008	1040	102.3	273	228	384	169	100.6	2.8	21.6
2009	1030	105.0	267	212	377	163	92.1	2.8	19.4
2010	1030	105.0	267	212	377	163	92.1	2.8	19.4
2011	1016	110.9	262	208	370	159	90.3	2.7	19.0
2012	1003	116.8	257	204	362	156	88.4	2.7	18.6
2013	989	122.7	251	199	354	153	86.6	2.6	18.3
2014	975	128.6	246	195	347	149	84.8	2.6	17.9
2015	975	128.6	246	195	347	149	84.8	2.6	17.9
2016	987	138.3	247	197	349	148	84.1	2.5	17.7
2017	998	148.0	249	198	352	147	83.5	2.5	17.6
2018	1010	157.7	251	199	354	146	82.9	2.5	17.5
2019	1021	167.3	253	201	357	145	82.2	2.5	17.3
2020	1021	167.3	253	201	357	145	82.2	2.5	17.3
2030	1021	167.3	253	201	357	145	82.2	2.5	17.3
2040	1021	167.3	253	201	357	145	82.2	2.5	17.3
2050	1021	167.3	253	201	357	145	82.2	2.5	17.3

Annual nitrous oxide emissions (tonnes N_2O) of poultry, sheep and goats in Finland 1990–2007 and emission projections for the years 2008–2050.

	Laying hens	Broilers	Chickens	Cockerels	Broiler hens	Turkeys	Other poultry	Sheep with lambs and goats with gilts
1990	164	51	28.2	2.43	4.0	2.4	0.71	40.5
1991	160	56	27.6	2.18	6.4	2.7	1.08	45.1
1992	154	62	26.9	1.88	9.2	3.2	1.55	50.9
1993	148	68	26.2	1.58	12.1	3.7	2.01	56.7
1994	142	74	25.5	1.28	15.0	4.1	2.48	62.4
1995	141	75	25.3	1.22	15.6	4.2	2.57	63.6
1996	134	88	23.4	1.15	17.2	6.1	2.28	59.9
1997	127	102	21.4	1.07	18.8	8.0	1.98	56.2
1998	120	115	19.5	1.00	20.4	9.8	1.68	52.4
1999	112	128	17.6	0.93	22.0	11.7	1.39	48.7
2000	105	141	15.6	0.85	23.6	13.5	1.09	45.0
2001	105	133	15.8	0.80	24.9	17.8	1.01	44.5
2002	105	125	16.0	0.75	26.2	22.1	0.92	44.0
2003	105	117	16.1	0.70	27.4	26.4	0.84	43.4
2004	104	109	16.3	0.65	28.7	30.7	0.76	42.9
2005	104	101	16.5	0.60	29.9	35.0	0.67	42.4
2006	101	99	14.6	0.65	26.5	33.4	0.50	54.5
2007	101	100	13.2	0.63	23.0	29.1	0.80	55.4
2008	101	104	14.8	0.61	26.7	31.6	0.89	53.4
2009	100	109	16.4	0.60	30.4	34.0	0.98	51.4
2010	100	109	16.4	0.60	30.4	34.0	0.98	51.4
2011	99	109	16.3	0.60	30.3	34.0	0.98	51.4
2012	98	109	16.1	0.60	30.3	34.0	0.98	51.4
2013	97	109	15.9	0.60	30.3	34.0	0.98	51.4
2014	95	109	15.8	0.60	30.3	33.9	0.98	51.4
2015	95	109	15.8	0.60	30.3	33.9	0.98	51.4
2016	94	109	15.6	0.60	30.3	33.9	0.98	51.4
2017	93	109	15.5	0.60	30.3	33.9	0.98	51.4
2018	92	109	15.3	0.60	30.3	33.9	0.98	51.4
2019	91	109	15.1	0.60	30.3	33.9	0.98	51.4
2020	91	109	15.1	0.60	30.3	33.9	0.98	51.4
2030	91	109	15.1	0.60	30.3	33.9	0.98	51.4
2040	91	109	15.1	0.60	30.3	33.9	0.98	51.4
2050	91	109	15.1	0.60	30.3	33.9	0.98	51.4

Annual nitrous oxide emissions (tonnes N_2O) of horses, ponies, fur animals and reindeer in Finland 1990–2007 and emission projections for the years 2008–2050.

Year	Horses	Ponies	Minks and fitches	Foxes and racoons	Reindeer
1990	98	11.0	112.0	157	82.1
1991	102	11.2	114.4	166	80.0
1992	106	11.4	117.3	177	77.4
1993	110	11.7	120.2	188	74.7
1994	113	11.9	123.1	199	72.1
1995	114	12.0	123.6	201	71.5
1996	118	12.1	118.4	204	71.2
1997	121	12.3	113.2	207	70.9
1998	125	12.4	108.0	211	70.5
1999	128	12.6	102.8	214	70.2
2000	132	12.8	97.5	217	69.9
2001	135	13.1	95.7	225	70.2
2002	138	13.4	93.8	232	70.4
2003	141	13.8	92.0	239	70.7
2004	144	14.1	90.1	246	70.9
2005	147	14.4	88.2	254	71.2
2006	152	15.0	95.5	271	68.0
2007	156	15.9	92.6	236	66.4
2008	173	17.2	95.2	235	68.4
2009	189	18.4	97.7	233	70.4
2010	189	18.4	97.7	233	70.4
2011	192	18.8	97.7	233	70.4
2012	196	19.1	97.7	233	70.4
2013	199	19.4	97.7	233	70.4
2014	202	19.7	97.7	233	70.4
2015	202	19.7	97.7	233	70.4
2016	205	20.0	97.7	233	70.4
2017	209	20.4	97.7	233	70.4
2018	212	20.7	97.7	233	70.4
2019	215	21.0	97.7	233	70.4
2020	215	21.0	97.7	233	70.4
2030	215	21.0	97.7	233	70.4
2040	215	21.0	97.7	233	70.4
2050	215	21.0	97.7	233	70.4

Appendix 6. Examples of manure management data collection in Europe: Austria, Denmark and Sweden.

In Austria, national statistics on manure management systems are not available. Emission inventory is based on a comprehensive survey published in 1995. The results of this survey on manure management system distribution are used for the whole period of 1990–2006 (Umweltbundesamt 2008).

In Denmark, there is no statistical information on the types of animal buildings and manure management. Information on manure treatment for emission inventory is therefore based on estimate from the experts of the Danish Agricultural Advisory Centre. In the calculation of emissions from manure application, differentially weighed emission factors are used, which distinguish between solid manure and liquid manure (NERI 2008).

In Sweden, information about the type and amount of commercial fertilizers used, consumed quantity and handling of different types of manure (solid-, liquid- and semi-liquid manure, and deep litter), time and method of spreading manure, time for manure incorporation, and data on stabling periods of animals has been obtained from a special field investigation conducted by Statistics Sweden. This investigation is carried out every second year as a random sample survey. The field investigation includes telephone interviews with about 4 000 farmers and was performed by interviewers from Statistics Sweden. The latest reported results are from 2005. (Swedish environmental protection agency 2008).

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Title of publication	**Development of the ammonia emission inventory in Finland. Revised model for agriculture.**			
Publication series and number	The Finnish Environment 8/2009			
Theme of publication	Environmental protection			
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Abstract	Agriculture is the main source of ammonia (NH_3) emissions in Finland comprising ca. 90% of the total emissions annually. Agriculture is also an important source of nitrous oxide (N_2O), a greenhouse gas for which agriculture is responsible for ca. 50% of emissions. The main source for ammonia is livestock manure whereas for N_2O its importance is much smaller. However, the same activity data are needed to assess both NH_3 and direct N_2O emissions from animal husbandry. In addition to this, indirect emissions of N_2O are calculated based on NH_3 and NO emissions. NH_3 and N_2O emissions are annually reported according to international reporting classifications. The aims of the study were 1) to construct a calculation model for gaseous agricultural nitrogen emissions thereby developing and updating the emission calculation procedure to better reflect the development of these emissions in Finland, and 2) to improve correspondence of the emission inventory reporting with the reporting classifications. In 2007, the Finnish emissions of ammonia from agricultural sources totalled 30,686 tonnes, of which more than 60% originated from cattle manure. Time series for ammonia emissions from agriculture show that there have been no large changes in the total emissions during the last two decades. Despite the decreased number of cattle during that period the emissions have remained near the present level, mainly because of the increased nitrogen excretion of cattle. Emission projections for the years 2008–2050 show no significant changes in emissions in the future. As for ammonia, no significant changes for nitrous oxide emissions from animal husbandry have taken place, and no big changes can be expected in the future as long as there are no drastic alterations in animal production. Despite the development of emission modelling, the emission estimates still include significant sources of uncertainty, which is mainly related to information on the distribution of manure management systems and the use of different manure application methods as well as to information on ammonia evaporation in different manure management phases in Finland.			
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Julkaisun nimi	**Development of the ammonia emission inventory in Finland. Revised model for agriculture.** (Ammoniakkipäästöjen arvioinnin kehittäminen Suomessa. Uusittu maatalouden päästömalli.)	
Julkaisusarjan nimi ja numero	Suomen ympäristö 8/2009	
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Julkaisun osat/ muut saman projektin tuottamat julkaisut	Julkaisu on saatavana myös internetistä: www.environment.fi/publications	
Tiivistelmä	Maatalouden osuus Suomen ammoniakkipäästöistä (NH_3) on noin 90 %. Maatalous on myös tärkeä dityppioksidin (N_2O) päästölähde, vastaten noin puolesta Suomen N_2O-päästöistä. Ammoniakin pääasiallinen lähde on karjanlanta, kun taas dityppioksidin kannalta lanta ei ole päästölähteenä yhtä merkityksellinen. Molempien kaasujen päästöjen arvioimiseksi kotieläintaloudesta tarvitaan kuitenkin samoja lähtötietoja. Tämän lisäksi epäsuorien N_2O-päästöjen laskemista varten on oltava tiedot ammoniakki ja typpioksidin (NO) päästöistä. Ammoniakki- ja dityppioksidipäästöt on raportoitava vuosittain kansainvälisten raportointiohjeiden mukaisella tavalla. Tutkimuksen tavoitteena oli 1) rakentaa maatalouden kaasumaisille typpipäästöille laskentamalli päästöjen laskentamenetelmien kehittämiseksi ja edelleen aiempaa tarkempien päästöarvioiden saamiseksi, ja 2) parantaa kyseisten kaasujen päästöinventaarioraportointia vastaamaan paremmin kansainvälisiä raportointisääntöjä. Maataloudesta peräisin olevat ammoniakkipäästöt olivat vuonna 2007 yhteensä noin 30 686 tonnia, josta yli 60 % oli peräisin kotieläinten lannasta. Maatalouden ammoniakkipäästöissä ei ole tapahtunut suuria muutoksia viimeisten kahden vuosikymmenen aikana huolimatta siitä, että nautaeläinten määrä on merkittävästi vähentynyt, sillä samanaikaisesti eläinten lannassa eritetyn typen määrä on kasvanut tuotostasojen kohoamisen takia. Vuoteen 2050 asti ulottuvassa ennusteessa ei myöskään näy merkittäviä muutoksia päästöissä. Myös dityppioksidin päästöt ovat olleet pitkään melko muuttumattomat, eikä tulevaisuudessa ole odotettavissa merkittäviä muutoksia päästöissä, ellei kotieläintuotannossa tapahdu rajuja muutoksia. Huolimatta mallin kehittämisestä päästöarvioihin sisältyy edelleen huomattava määrä epävarmuuksia, jotka liittyvät lähinnä tietoon lannan käsittelyn jakaantumisesta eri käsittelytapojen kesken ja tietoon lannan levitysmenetelmistä Suomessa, ja toisaalta tietoihin ammoniakin haihtumisesta lannankäsittelyn eri vaiheissa suomalaisissa olosuhteissa.	
Asiasanat	ammoniakki, päästöt, inventointi, karjanlanta, typpi, maatalous, dityppioksidi, mallintaminen	
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PRESENTATIONSBLAD

Utgivare	Finlands miljöcentral (SYKE)	*Datum* Mars 2009
Författare	Juha Grönroos, Pasi Mattila, Kristiina Regina, Jouni Nousiainen, Paula Perälä, Kristina Saarinen och Johanna Mikkola-Pusa	
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Sammandrag	Jordbrukets andel av Finlands ammoniakutsläpp (NH_3) är cirka 90 %. Jordbruket är också en viktig källa för dikväveoxid (N_2O) och utgör cirka hälften av Finlands N_2O-utsläpp. Ammoniak härstammar huvudsakligen från boskapsgödsel, men när det gäller dikväveoxid är gödsel inte lika betydelsefull. För att uppskatta utsläppen av båda gasernas från boskapsskötsel behövs dock samma utgångsdata. Därtill behöver man uppgifter om utsläppen av kväveoksid (NO) för att räkna ut de indirekta utsläppen av N_2O. Data om båda måste meddelas varje år enligt internationella rapporteringsanvisningar. Undersökningens mål var att 1) konstruera en kalkyleringsmodell för jordbrukets gasformiga kväveutsläpp för att utveckla metoderna att räkna ut dem och vidare för att erhålla noggrannare beräkningar, och 2) att förbättra rapporteringen av ifrågavarande gasers utsläppsinventarier att bättre motsvara internationella rapporteringsregler. Ammoniakutsläppen från jordbruket var år 2007 totalt cirka 30 686 ton, av vilket över 60 % härstammade från husdjursgödsel. Under de två senaste årtiondena har det inte skett några betydelsefulla förändringar i jordbrukets ammoniakutsläpp trots att nötboskapen har blivit avsevärt mindre. Samtidigt har nämligen mängden utsöndrad kväve i djurgödsel vuxit tack vare nya produktionsnivåer. I en prognos som sträcker sig till år 2050 framkommer inte heller några anmärkningsvärda förändringar i utsläppen. Även utsläppen av dikväveoksid har varit länge oförändrade, och i framtiden väntas inga märkbara förändringar i dem, om inte det sker drastiska ändringar i boskapsproduktionen. Trots utvecklingen av en modell ingår det fortfarande en avsevärd mängd osäkerhetsfaktorer, som mest har att göra med uppgifterna om hur olika gödselhanteringsmetoder är fördelade i Finland och om metoderna att sprida gödsel, och å andra sidan med uppgifterna om hur ammoniak avdunstar i olika hanteringsskeden i finska förhållanden.	
Nyckelord	ammoniak, utsläpp, inventering, stallgödsel, kväve, jordbruk, dikväveoxid, modellering	
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This report presents the calculation model for gaseous agricultural nitrogen emissions (ammonia, nitrous oxide, nitric oxide). The model was constructed to better reflect the development of these emissions in Finland and to integrate the greenhouse gas and air pollutant inventories for nitrogen emissions. It also enables reporting on emissions at the level of detail required by the reporting guidelines.

DEVELOPMENT OF THE AMMONIA EMISSION INVENTORY IN FINLAND

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