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Abstract

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The National Emission Model for Agriculture (NEMA) is used to calculate emissions to air from agricultural activities in the Netherlands on a national scale. Emissions of ammonia (NH_3) and other N-compounds (NO_x and N_2O) are calculated from animal housing, manure storage, manure application and grazing using a Total Ammoniacal Nitrogen (TAN) flow model. Furthermore, emissions from application of inorganic N fertilizer, compost and sewage sludge, cultivation of organic soils, crop residues, and ripening of crops are calculated. NEMA is also used to estimate emissions of methane (CH_4) from enteric fermentation and manure management, particulate matter (PM) from manure management and agricultural soils and carbon dioxide (CO_2) from liming. Emissions are calculated in accordance with international guidance criteria and reported in an annual Informative Inventory Report (IIR; for air pollutants) and National Inventory Report (NIR; for greenhouse gases). This methodology report describes the outline and backgrounds of the emission calculations with NEMA.

Keywords: air pollutants, greenhouse gases, livestock, crops, animal housing, manure storage, manure application, inorganic N fertilizer, enteric fermentation, manure management, agricultural soils, liming, NIR, CRF, IIR, NFR

Authors:

J. Vonk, L.A. Lagerwerf & S.V. Oude Voshaar - National Institute for Public Health and the Environment (RIVM)
S.M. van der Sluis - Netherlands Environmental Assessment Agency (PBL)
A. Bannink & C.M. Groenestein - Wageningen Livestock Research
C. van Bruggen –Statistics Netherlands (CBS)
J.F.M. Huijsmans - Wageningen Plant Research
J.W.H. van der Kolk & G.L. Velthof - Wageningen Environmental Research
H.H. Luesink - Wageningen Economic Research

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National Institute for Public Health and the Environment (RIVM)
PO Box 1, 3720 BA Bilthoven
T: +31 (30) 274 91 11; e-mail: info@rivm.nl
PBL Netherlands Environmental Assessment Agency
PO Box 30314, 2500 GH Den Haag
T: +31 (70) 328 87 00; e-mail: info@pbl.nl
Wageningen Livestock Research
PO Box 65, 8200 AB Lelystad
T: +31 (320) 238 238; e-mail: info.livestockresearch@wur.nl
Statistics Netherlands (CBS)
PO Box 24500, 2490 HA Den Haag
T: +31 (70) 337 38 00; internet: www.cbs.nl
Wageningen Plant Research
PO Box 16, 6700 AA Wageningen
T: +31 (317) 48 60 01; e-mail: info.pri@wur.nl
Wageningen Environmental Research
PO Box 47, 6700 AA Wageningen
T: +31 (317) 48 07 00; e-mail: info.alterra@wur.nl
Wageningen Economic Research
PO Box 29703, 2502 LS Den Haag
T: +31 (70) 335 83 30; e-mail: informatie.lei@wur.nl

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Statutory Research Tasks Unit for Nature & the Environment, P.O. Box 47, NL-6700 AA Wageningen.
Phone: +31 317 48 54 71; e-mail: info.wnm@wur.nl; Internet: www.wur.nl/wotnatuurenmilieu

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Preface

This report describes the methodologies for estimating emissions to air from agricultural activities in the Netherlands reported in the Informative Inventory Report 2018 (IIR; air pollutants) and National Inventory Report 2018 (NIR; greenhouse gases), covering the 1990-2016 time series. The report is an update of Vonk *et al.* (2016). In turn mentioned report replaced the description of ammonia emission calculations by Velthof *et al.* (2009) and the protocols that previously accompanied the annual greenhouse gas reporting.

Calculations are performed with the National Emission Model for Agriculture (NEMA). Various institutes contribute to the annual calculations and maintenance of the model. The authors wish to thank the many colleagues at Statistics Netherlands, the Wageningen Research groups involved (Wageningen Environmental Research, Wageningen Economic Research, Wageningen Livestock Research and Wageningen Plant Research), PBL Netherlands Environmental Assessment Agency and RIVM for their contributions and support. The Netherlands Enterprise Agency (Peter Zijlema and Harry Vreuls) provided useful comments on previous versions of the report.

Jan Vonk
Sietske van der Sluis
André Bannink
Cor van Bruggen
Karin Groenestein
Jan Huijsmans
Jennie van der Kolk
Lotte Lagerwerf
Harry Luesink
Stephanie Oude Voshaar
Gerard Velthof

Contents

Summary

The National Emission Model for Agriculture (NEMA) is used to estimate emissions to air from agricultural activities in the Netherlands. Calculations include the emission of ammonia (NH_3), nitrogen oxides (NO_x), nitrous oxide (N_2O), methane (CH_4), particulate matter (PM_{10}, $PM_{2.5}$) and carbon dioxide (CO_2). These emissions originate from various processes within the agricultural production chain, grouped in the main categories enteric fermentation, manure management, crop production and agricultural soils, and lime application.

Enteric fermentation
During the digestion of feed, ruminal and/or intestinal fermentation processes take place. Especially in ruminants, considerable amounts of CH_4 are formed. In accordance to the key source analysis, a country-specific (IPCC Tier 3) method is used for dairy cattle which models the enteric fermentation processes. For other cattle categories, emissions are calculated from the feed rations on a yearly basis, using an IPCC Tier 2 approach. The emissions from small ruminants and intestinal fermentation by monogastric animals are calculated with IPCC 2006 default emission factors per head (Tier 1).

Manure management
This category includes emissions from manure stored in the animal house or outside, in manure storage facilities.

CH_4 emission results from fermentation of organic matter in stored livestock manure. The rate of emission depends on the chemical composition of the manure and on environmental factors like temperature and the availability of oxygen. Cattle, pigs and poultry are considered key sources, and are therefore assessed using an IPPC Tier 2 approach. The excretion of volatile solids is calculated from rations fed multiplied by the maximum methane production potential (B_o) and methane conversion factor (MCF). A distinction is made between slurry and solid manure, and manure excretion on pasture land. Emissions from other livestock categories, are calculated using the IPCC 2006 defaults (Tier 1).

NH_3 is produced from urinary nitrogen (N) and mineralized organic N in the faeces, the sum of which is called TAN (Total Ammoniacal Nitrogen). After bacterial conversion to ammonium gaseous NH_3 emits to the air, depending on physical and chemical conditions. TAN in manure is derived from the feed composition on a yearly basis. The NH_3 emission is calculated using NH_3-N emission factors expressed as percentage of TAN. These emission factors are derived from measurements of NH_3 emissions from animal houses, relative to the TAN excretion. When not measured, emission factors were deduced from measured factors, using ratios of TAN excretion as a scale factor. Separate calculations are performed for NH_3 emissions from manure storages outside the animal house. Because N-emissions are calculated using the TAN flow principle, the amount of TAN in storage is corrected for all the N losses in the housing system.

Emissions of N as NO_x and N_2O are also part of the TAN flow and originate from (de-)nitrification in manure during housing and in outside storage facilities. The NO_x and N_2O emissions are considered to be of equal size in terms of amount of N loss, and based on the IPCC default emission factors for N_2O. These emissions are converted into percentage of TAN when applied in the TAN flow model.

Particulate matter (PM_{10} and $PM_{2.5}$) emissions from manure management mainly depend on the housing systems. Information on housing systems in agricultural practice is derived from the Agricultural census, elaborated by provincial records on environmental permits. Emission factors are derived from measurements of PM. When not measured, emission factors were deduced from measured factors, using ratios of TAN excretion as a scale factor, or defaults have been used.

Crop production and agricultural soils

As part of the TAN flow, manure N available for application is calculated by subtracting N losses from the animal house and outside manure storages from the total N excreted by the animals. Besides emissions of NH_3-, N_2O- and NO_x-N, there are also losses from dinitrogen-N (N_2-N), the use of manure N outside agriculture, and the (net) export of manure N. The resulting application of animal manure N is then divided over grassland and cropland (cropped and uncropped), with a differentiation between manure application techniques and their respective NH_3 emission factors. For NH_3 from grazed grasslands, NH_3 emission factors based on TAN excreted during the time spent grazing are applied. The NH_3 emissions from application of inorganic N fertilizer, sewage sludge and compost, crop ripening and crop residues left on the field, are calculated using county-specific emission factors for these sources.

Emission of NO_x and N_2O occurs when N is supplied to agricultural soils. For N_2O a distinction is made between surface spreading and low-ammonia emission application, as incorporation of animal manure into the soil increases N_2O emission. The emission factors are country-specific (Tier 2), as well as those for inorganic N fertilizer, sewage sludge, compost, pasture manure, crop residues, and the cultivation of organic soils. Emissions of NO_x are calculated using the EMEP default emission factor for N supply to soil.

During the storage, handling, and transport of agricultural products, the cultivation of agricultural soils and crop harvesting particulate matter (PM) is emitted. A Tier 2 approach is used for PM_{10} and $PM_{2.5}$ emissions from the tillage of crops. Other sources of PM emissions (concentrates, inorganic fertilizers and pesticide use) have fixed estimates.

Liming

Application of lime to reduce soil acidity results in CO_2 emissions, because of the decomposition of carbonate. Emissions of CO_2 from lime are calculated from yearly statistics and the IPCC default emission factors (Tier 1).

Overview of methods and emission factors used

For the reporting of air pollutants within the Nomenclature For Reporting (NFR) format, the level of methods and emission factors used by NEMA are summarized in Table S.1.

Table S.1 *Methods and emission factors (EF) used in NEMA for air pollutants, towards level as distinguished by the 2016 EMEP Guidebook*

NFR source categories		NO_x		NH_3		$PM_{10}/PM_{2.5}$	
		Method	EF	Method	EF	Method	EF
3. Agriculture							
B.	Manure management	T3	CS	T3	CS	T2	CS
D.	Agricultural soils	T3	D	T3	CS	T2	CS,D
F.	Field burning of agricultural residues	NO	NO	N/A	N/A	NO	NO
I.	Other	NO	NO	NO	NO	NO	NO

Method: T2 = EMEP Tier 2; T3 = EMEP Tier 3; NO = not occurring; N/A = not applicable.

EF: D = EMEP default; CS = country-specific; NO = not occurring; N/A = not applicable.

The methods and emission factors used, fully comply with the requirements set by the 2016 EMEP Guidebook.

For the reporting of greenhouse gases within the Common Reporting Format (CRF), the level of methods and emission factors used by NEMA are summarized in Table S.2.

Table S.2 *Methods and emission factors (EF) used in NEMA for greenhouse gases, towards level as distinguished by the IPCC 2006 Guidelines*

CRF source categories		CO_2		CH_4		N_2O	
		Method	**EF**	**Method**	**EF**	**Method**	**EF**
3. Agriculture							
A.	Enteric fermentation	N/A	N/A	T1,T2,T3	CS,D	N/A	N/A
B.	Manure management	N/A	N/A	T1,T2	CS,D	T2	D
C.	Rice cultivation	N/A	N/A	NO	NO	N/A	N/A
D.	Agricultural soils	N/A	N/A	N/A	N/A	T1,T1b,T2	CS,D
E.	Prescribed burning of savannas	N/A	N/A	NO	NO	NO	NO
F.	Field burning of agricultural residues	N/A	N/A	NO	NO	NO	NO
G.	Liming	T2	D	N/A	N/A	N/A	N/A
H.	Urea application	NO	NO	N/A	N/A	N/A	N/A
I.	Other carbon-containing fertilizers	NO	NO	N/A	N/A	N/A	N/A
J.	Other	N/A	N/A	NO	NO	NO	NO

Method: T1 = IPCC Tier 1; T1a, T1b, T1c = IPCC Tier 1a, Tier 1b and Tier 1c, respectively; T2 = IPCC Tier 2; T3 = IPCC Tier 3; NO = not occurring; N/A = not applicable.

EF: D = IPCC default; CS = country-specific; NO = not occurring; N/A = not applicable.

The methods and emission factors used, fully comply with the requirements set by the 2006 IPCC Guidelines.

1 Introduction

In 2016, the agricultural sector was responsible for more than 85% of total ammonia (NH_3) emissions in the Netherlands. Agriculture also is a significant contributor towards the emissions of nitrogen oxides (NO_x). Deposition of NH_3 and NO_x can lead to adverse effects, in the form of eutrophication and acidification. For emissions of particulate matter agricultural activities form a considerable source as well, especially in the coarse fraction of up to 10 µm in size (PM_{10}). Particulate matter can cause detrimental health effects, and forms an uncertain factor in climate change.

With regards to the greenhouse gasses methane (CH_4) and nitrous oxide (N_2O), agriculture is the largest contributing source towards national total emissions. Combined and expressed as carbon dioxide equivalents (CO_2-eq), they amount to about 10% of Dutch greenhouse gas emissions. Stationary combustion (mainly by heating in horticulture) and use of mobile equipment are not included, because these are accounted for in the Energy sector. The only CO_2 emissions reported in the sector of Agriculture originate from calcareous fertilizers (liming).

Reporting requirements and institutional arrangements
Under the Kyoto Protocol, the Netherlands is required to set up and maintain a national system to monitor its greenhouse gas emissions. One of the elements of this system is a transparent and verifiable description of the methods and processes used in this monitoring system. These methods must meet international guideline criteria, which are defined by the United Nations (UN) and the European Union (EU) as described in the '2006 IPCC Guidelines'.

The Netherlands also reports emissions of other air pollutants. These are used to check if the Netherlands meets the National Emission Ceilings (NEC) and, as a party to the Convention on Long Range Transboundary Air Pollution (CLRTAP), the Gothenburg Protocol. Here too the methods must meet international guideline criteria, which are defined by the European Monitoring and Evaluation Programme (EMEP) of the European Environment Agency (EEA) as described in the 'EMEP Guidebook 2016'.

The Pollutant Release and Transfer Register (PRTR, or 'Emissieregistratie' (ER) in Dutch) collects and formally establishes the yearly emissions of pollutants to air, water and soil. The PRTR is a collaborative group that includes amongst others the institutions: Statistics Netherlands (CBS), Wageningen University & Research (WUR), the National Institute for Public Health and the Environment (RIVM), and PBL Netherlands Environmental Assessment Agency. It is coordinated by RIVM under supervision of Netherlands Enterprise Agency (RVO) acting as the National Inventory Entity (NIE) for greenhouse gas reporting. The Ministry of Economic Affairs and Climate Policy (EZK) and the Ministry of Infrastructure and Water Management (IenW) commission the PRTR.

Within the PRTR several teams work on respective sectors as defined by the guideline criteria, including the task force Agriculture and Land Use. Emissions from Land Use, Land Use Change and Forestry (LULUCF) form a separate reporting category, and therefore are not discussed here. This report deals with emissions to air originating from agricultural activities, for which the National Emission Model for Agriculture (NEMA) of the independent Dutch Scientific Committee of the Manure Act (CDM) is used. The model NEMA was developed in 2009 for NH_3 (Velthof *et al.*, 2009), and since then calculations for emissions of other compounds have been included (Van Bruggen *et al.*, 2014). The current report gives an overview of the methods applied in NEMA to estimate emissions of CH_4, NH_3, N_2O, NO_x, PM_{10}, $PM_{2.5}$ and CO_2 from the agricultural sector.

Emission data are available through the website www.prtr.nl and in yearly reports on greenhouse gas emissions (National Inventory Report, NIR) and other pollutants (Informative Inventory Report, IIR). Data from the PRTR are also used for the evaluation of national environmental policy and in many other environmental reports. For this reason, also yearly reports in Dutch are being published, with updated NEMA results.

Outline of the report
After an introductory chapter covering general aspects of emission and uncertainty calculations, following chapters describe the scope and definition, calculation method, emission factors, activity data, uncertainty and quality, for each combination of compound and source category distinguished. The categorization of the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines and the EMEP Guidebook 2016 is being followed here. For reporting the Common Reporting Format (CRF, to accompany the NIR) and the Nomenclature For Reporting (NFR, accompanying the IIR) are used.

Emissions from agriculture occur in the sectors 3A Enteric fermentation, 3B Manure management, 3D Agricultural soils and 3G Liming. Because of climatological conditions, activities related to sectors 3C Rice cultivation and 3E Prescribed burning of savannahs do not occur in the Netherlands. Also no emissions from sector 3F Field burning of agricultural residues take place, as this is prohibited by law for the entire time series (article 10.2 of the Environmental Management Act, or ‘Wet Milieubeheer’ in Dutch).

Figure 1.1 presents an overview of processes and emissions, indicating the chapters in which they are discussed in detail.

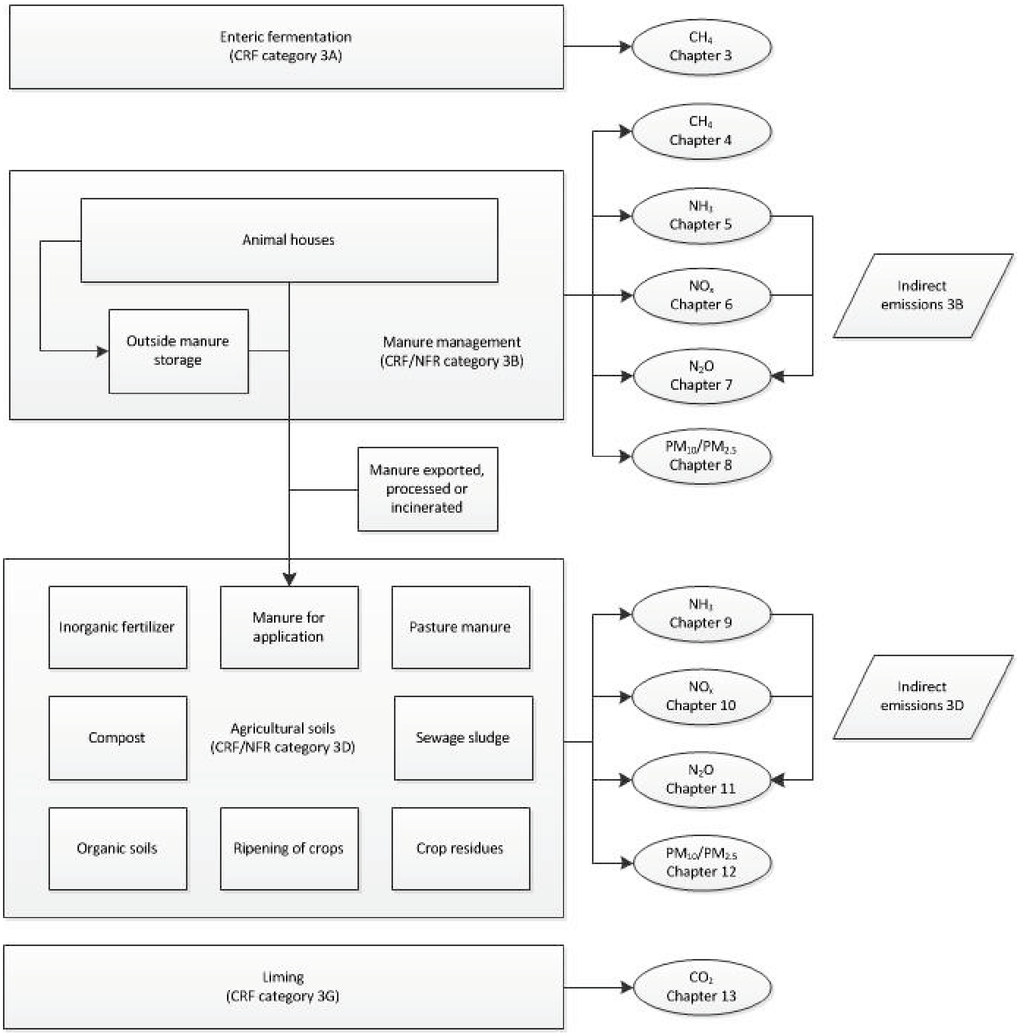

***Figure 1.1** Processes and emissions in agriculture with their allocation to CRF and NFR reporting categories*

By arranging chapters in a consecutive manner, starting at the animal level and then continuing to manure management (animal housing and outside manure storage), agricultural soils and liming the reader can get a full overview of emission calculations. Repetition of information was kept to a minimum, but as chapters are also intended to be read independently, some repetition could not be avoided. This also means that readers interested in given compound(s) should be able to skip the other chapters.

2 General aspects

2.1 Emission calculations

Dutch agriculture is a major source of NH_3, NO_x, N_2O, CH_4, PM_{10} and $PM_{2.5}$ emissions. NH_3 and NO_x contribute to eutrophication and acidification of soils. N_2O and CH_4 are greenhouse gases, and N_2O also damages the ozone layer. Particulate matter affects human health. In addition, N emissions reduce nitrogen use efficiency in agriculture.

Commissioned by the Ministry of EZK, the working group National Emission Model for Ammonia of the CDM developed a method to calculate NH_3 emissions in 2009. The method includes the emissions from animal housing and manure storage for livestock categories in the Dutch agricultural census, as well as from livestock grazing in pastures and applications of animal manure and fertilizers to the soil.

On request of the PRTR modules for the calculation of NO_x, N_2O, CH_4, PM_{10} and $PM_{2.5}$ were included in the model since the emission calculations of 2012. The name of the model thereon has been changed from National Emission Model for Ammonia into National Emission Model for Agriculture. With the implementation of the IPCC Guidelines 2006 in 2013 a module for the calculation of CO_2 from lime fertilizers was also added.

The results are used in reports to the EU, to test whether the Netherlands is in compliance with the NEC directive, and to the UNECE (Gothenburg Protocol). The results are also reported to the UNFCCC in the context of the Kyoto Protocol.

Reporting on higher level
The NEMA model calculates emissions using more subcategories than reported internationally. In addition, emission factors can be based on more factors than reported. To be able to report the activity data and emissions, these subcategories are aggregated. Resulting average emission factor is calculated by dividing emissions over the activity data. This calculated emission factor is called the implied emission factor.

2.2 Uncertainty calculations

Models are not an exact representation of real life and therefore their estimates are to a certain extent uncertain. In activity data the availability and representativeness of data is the main source of uncertainty. When applying emission factors uncertainties come from possible measurement errors, statistical random sampling errors or missing data. Other causes of uncertainty are lack of completeness due to unrecognized emission sources or lack of measurement methods; these aspects are not taken into account in the current uncertainty analysis. For more details on causes of uncertainty see Chapter 3 of the 2006 IPCC Guidebook (IPCC, 2006).

Following the guidance documents, uncertainty estimates are essential for a complete emission inventory. The Netherlands are obliged to estimate uncertainties for national level and trend in emissions as well as for separate components: activity data, emission factors and other parameters used in estimating emissions. Estimates of uncertainties for separate components as well as for the calculation methods should be used to prioritise efforts to further improve emission calculations. Emissions sources in NEMA with relatively high uncertainty that are responsible for relatively large emissions should get more attention.

A Tier 1 uncertainty analysis is implemented every year before the NIR is submitted by the PRTR, based on the greenhouse gas inventory and in compliance with IPCC Guidelines. The assumptions used and the results thereof are described in an annex to the NIR. In addition to this, where included in the QA/QC-programme for the relevant period, extra analyses are implemented regularly in specific situations, which include any updating of the Tier 2 uncertainty analyses.

Based on the 2017 inventory (1990-2015 time series) new estimates of uncertainties were calculated using the propagation of error approach. Uncertainties were estimated based on literature and expert judgements. Previous estimates were reconsidered and when needed revised, based on new insights or changed methods. The previous full Tier 2 uncertainty assessment was conducted in 2009 (Olivier *et al.*, 2009), with partial updates in Vonk *et al.* (2016). This assessment showed that a Tier 1 uncertainty assessment is sufficiently reliable and that Tier 2 uncertainty assessments need only be implemented at periodic intervals of around five years, unless a major change in an important source is sufficient to require a reassessment. Data from this uncertainty analysis was also used as input for the Monte Carlo analysis of uncertainties carried out on the 2017 emission inventory of the Netherlands.

A detailed overview of quality assurance and quality control is given in Annex 11. In this annex also some outlines on the verification of data are presented.

Methods for emission estimation are periodically improved to new availability of data or new scientific insights. This should be reflected in a new estimate of uncertainty for the relevant emission sources. An updated method does not automatically mean uncertainty decreases; it is also possible the uncertainty was previously estimated too low.

Calculation method
For each emission source reported in the NIR and the IIR the uncertainty is estimated, using the propagation of error method. The uncertainty per emission source is calculated as the square root of the sum of squared uncertainties of the activity data (U AD) and the implied emission factor (U IEF), see formula 2.1. The extent of the total uncertainty is primarily determined by the largest uncertainty.

$$\text{Uncertainty estimate}_{\text{total}} = \sqrt{([\text{U AD}]^2 + [\text{U IEF}]^2)} \qquad (2.1)$$

The uncertainty over all emission sources is calculated by aggregating the subcategories and is simulated using the Monte Carlo method.

Activity data
In most emission sources from the agricultural sector the activity data consists of livestock numbers. This can either be a total number of animals in a category (i.e. dairy cows; ducks; goats) or an aggregate of subcategories within an livestock category (i.e. 'young stock for milk production' consists of five subcategories divided in age and gender; 'laying hens' consists of four subcategories divided in age and production goal (eggs or broiler parent)). A few emission sources are not (directly) related to livestock numbers. Activity data for emissions from crop production or agricultural soils consist of acreage. Emissions from application of fertilizer, compost and sewage sludge are based on input in kilograms.

The build-up of activity data for an emission source may differ between pollutants. A distinction between subcategories can be relevant for one pollutant, but irrelevant for another pollutant. Distinctions between subcategories are made when scientifically important, and omitted when scientifically irrelevant for simplification of the calculations.

Emission factor
For emission sources where a Tier 1 method is used the default uncertainty from the IPCC Guidelines or EMEP Guidebook is used. When a range of uncertainties is given, the uncertainty used is decided on by expert judgement of the NEMA working group.

A Tier 2 or Tier 3 method is used to better approximate the emission. The uncertainties are preferably calculated with use of literature and expert judgements. Annex 11 gives the list of experts consulted. As these methods give a better representation of the system, the uncertainty would be lower than when a Tier 1 method is applied. Tier 2 and 3 methods generally use more parameters for emission calculations which increases the uncertainty. Less complicated methods could give a lower uncertainty, while higher Tier methods (with possible higher uncertainties) give a better approximation of the complexity of the model and the availability of scientific data.

In case the emission factor is calculated using several parameters the uncertainty in the implied emission factor is calculated using the propagation of error method.

Levels of calculation and reporting
The emission calculation is performed on a level with more livestock categories than the reporting of the emissions. Therefore, uncertainty reporting has to be aggregated. Because uncertainties are estimated on the lowest level, reported uncertainties on the higher level show many significant figures. Aggregation of uncertainties leads in the case of independent categories to lower uncertainties. The propagation of error method can calculate uncertainties with dependencies but only for 100% dependent and 100% independent uncertainties there are simplified formulas. To reduce calculation time only those two formulas are used. In case of dependencies being between 0 and 100% it is possible to aggregate during the calculation of the uncertainty. This method is used to not underestimate uncertainties.

(Dis-)aggregation of uncertainties in livestock numbers
Table 2.1 presents the uncertainties of the livestock subcategories. Because aggregated categories are reported, uncertainties have to be aggregated using the following formula:

$$\text{Combined uncertainty} = \sqrt{(\Sigma(\text{U livestock category x animals})^2)}/\Sigma \text{ animals} \qquad (2.2)$$

This formula assumes 100% independent categories.

The same formula can also be used to disaggregate uncertainties. An assumption has to be made whether absolute or relative uncertainties are the same for the underlying categories. This is sometimes necessary when literature gives uncertainty on a higher level.

2.3 Activity data

In the agricultural emission calculation livestock numbers and N excretion rates are used in several categories. Because of this livestock numbers and N excretion rates are described in this chapter, and in the description of the emission calculation there will be references to this chapter.

Livestock numbers
Activity data on number of animals originates from the Agricultural census held yearly. Under this Agricultural census, all agricultural businesses are taken into account which have their main office in the Netherlands and which are larger than three Dutch so-called ‘size units’ (grootte-eenheden; until 2009) or 3,000 Standard Output (from 2010 onwards). For more details on population statistics the reader is referred to CBS (www.cbs.nl), and Van Bruggen *et al.* (2015). Livestock categories are presented in Figure 2.1.

Should there be an outbreak of an animal disease, and for this reason a deviating number of animals is kept throughout the year, the Working group on Uniformity of calculations of Manure and mineral data (in Dutch: ‘Werkgroep Uniformering berekening Mest- en mineralencijfers', WUM) modifies the number of animals. These updated numbers are used for the emission calculations. The calculations by the WUM are reported by Statistics Netherlands.

The Agricultural census distinguishes a considerable number of livestock (sub-)categories. This categorization is also used within the NEMA calculations, and results are then grouped towards reporting categories as indicated for the NFR and CRF.

The number of privately owned horses and ponies is not estimated in the Agricultural census. The former product Boards for Livestock, Meat and Eggs estimated the number of privately owned horses and ponies at 300,000 (PVE, 2005). Emissions which are related to these animals are calculated within NEMA, but strictly speaking these are not part of agriculture. Therefore resulting emissions of ammonia, nitrogen oxides and particulate matter are attributed to NFR category 6 Other. However as the Netherlands chose not to report greenhouse gas emissions under the CRF category Other, methane and nitrous oxide emissions have been included within sector 3 Agriculture.

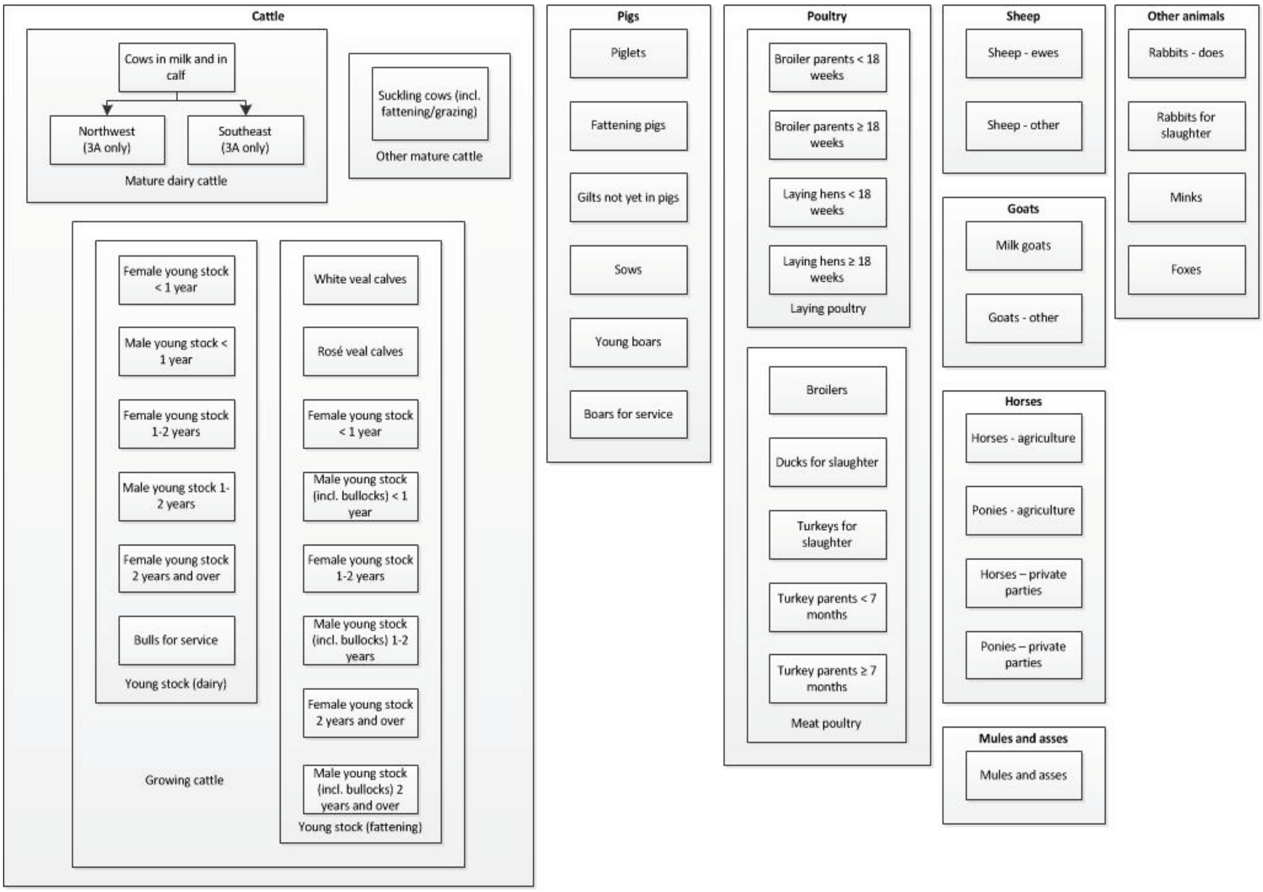

Figure 2.1 *Livestock categories in the Agricultural census*

Uncertainty in livestock numbers

Uncertainties in livestock numbers are described in CBS (2012b) and presented in Table 2.1. A few additional uncertainties had to be included using expert judgement, since these are not part of the methodology of the Working group on Uniformity of calculations of the WUM. This concerns usually young animals, for which the excretion is considered together with the mother animal. The uncertainty for number of piglets is assumed to be 10%, for the total number of sheep 10% and for the total number of goats 10% based on expert judgement. The uncertainty for number of privately owned horses and ponies is assumed to be 50%.

***Table 2.1** Uncertainty in livestock numbers*

Livestock category	Uncertainty
Cattle for breeding	
Female young stock < 1 year	2%
Male young stock < 1 year	2%
Female young stock, ≥ 1 yrs	2%
Male young stock, ≥ 1 yrs	2%
Dairy cows	2%
Cattle for fattening	
Fattening calves, for white veal production	2%
Fattening calves, for rosé veal production	2%
Female young stock < 1 year	2%
Male young stock (incl. young bullocks) < 1 year	2%
Female young stock, ≥ 1 yrs	2%
Male young stock (incl. young bullocks), ≥ 1 yrs	2%
Suckling cows	2%
Other grazing animals	
Sheep (Ewes)	5%
Sheep (All)	10%1)
Dairy goats (≥ 1 year)	5%
Goats (All)	10%1)
Horses (agriculture)	5%
Ponies (agriculture)	5%
Mules and asses	5%1)
Horses and ponies (not agriculture)	50%2)
Pigs	
Piglets	10%1)
Fattening pigs	10%
Sows	5%
Breeding pigs	5%
Boars	5%
Poultry	
Parent animals of broilers, under 18 weeks	10%
Parent animals of broilers, 18 weeks and over	5%
Laying hens, under 18 weeks	10%
Laying hens, 18 weeks and over	5%
Broilers	10%
Ducks	10%
Turkeys	10%
Other animals	
Rabbits (does)	5%
Other rabbits	10%1)
Mink	5%

Source: CBS, 2012b.

1) Expert judgement; 10% of piglets is estimated using the following calculation. In 2012 there were 2.37 litters per sow (Agrovision). The number of full grown piglets was 27.8 per sow. If the assumption is made that piglets die mostly in the beginning than there are 11.7 (27.8/2.37) piglets per litter. After 78 days piglets become fatteners, while the next litter comes after 154 days (365/2.37). Average number of piglets per sow during a year is then 78/154*11.7 = 5.93. With 938,000 sows in 2012 there are 5.93*938,000 = 5.6 million piglets. Agricultural census counted 5.2 million piglets.

2) Expert judgement.

N excretion

For the N excretion in the animal house (taking into account the excretion on pasture land during grazing) the data of the WUM are used. These data have been published for the 1990-2008 time-series by CBS (2012) and for consecutive years in the publication series Animal manure and minerals (in Dutch; Van Bruggen, 2011 to 2017) available on the CBS website, www.cbs.nl.

Starting points for N emission calculations are the N excretion figures derived by the WUM. The uncertainties for both parameters were estimated previously (WUM, 2012), and are summarized in Table 2.2 below. For emission calculation the age category ≥ 1 year for cattle is split in the age category 1-2 and > 2 years, with the same N excretions per animal. For the uncertainty calculation, they are therefore not assessed separately, but combined.

Although WUM reports the split for excretions over the housing and grazing period, only an uncertainty on totals is given. In order to do a propagation of error-analysis on both animal housing and grazing emissions, uncertainties were calculated for the shares:

$$\text{U animal house} = \sqrt{(\text{total excretion x total uncertainty})^2/(\text{total uncertainty}^2 + \text{excretion animal house}^2)} \quad (2.3a)$$

$$\text{U pasture} = \sqrt{(\text{total excretion x total uncertainty})^2/(\text{total uncertainty}^2 + \text{excretion pasture}^2)} \quad (2.3b)$$

In the model, it is assumed that only female cattle is grazed along with sheep, horses, ponies, mules and asses. Male cattle and dairy goats are usually kept indoors in the Netherlands, as well as pigs and poultry (some free range does occur in the latter, but is accounted for in the emission factor for animal housing).

Table 2.2 *Uncertainties (U, %) in total N excretion (CBS, 2012b) and N excretions in the animal house or on pasture*

Livestock category	U total N excretion per head	U animal house N excretion per head	U pasture N excretion per head
Cattle for breeding			
Female young stock < 1 year	4.9%	4.0%	24.5%
Male young stock < 1 year	5.5%	-	-
Female young stock, ≥ 1 yrs	4.1%	4.0%	10.3%
Male young stock, ≥ 1 yrs	5.3%	-	-
Dairy cows	5.8%	4.7%	31.3%
Cattle for fattening			
Fattening calves, for white veal production	14.8%	-	-
Fattening calves, for rosé veal production	9.5%	-	-
Female young stock < 1 year	4.9%	4.0%	25.1%
Male young stock (incl. young bullocks) < 1 year	11.3%	-	-
Female young stock, ≥ 1 yrs	4.1%	4.1%	10.2%
Male young stock (incl. young bullocks), ≥ 1 yrs	8.9%	-	-
Suckling cows	5.3%	7.7%	7.3%
Other grazing animals			
Sheep (Ewes, including young animals and males)	6.0%	42.4%	4.7%
Dairy goats (≥ 1 year, including young animals and males)	14.5%	-	-
Horses (agriculture)	21.4%	29.2%	31.4%
Ponies (agriculture)	21.4%	36.8%	25.7%
Mules and asses[1)]	21.4%	36.8%	25.7%
Horses and Ponies (not agriculture)			

Livestock category	U total N excretion per head	U animal house N excretion per head	U pasture N excretion per head
Pigs			
Fattening pigs	9.9%		
Sows (including piglets)	11.4%		
Breeding pigs	9.8%		
Boars	7.9%		
Poultry			
Broiler parents, under 18 weeks	10.7%		
Broiler parents, 18 weeks and over	6.8%		
Laying hens, under 18 weeks	10.8%		
Laying hens, 18 weeks and over	8.3%		
Broilers	21.6%		
Ducks	14.6%		
Turkeys	13.1%		
Other animals			
Rabbits (does, including young animals and males)	9.4%		
Mink (females, including young animals and males)	11.8%		

1) Mules and asses are not part of the calculations performed by WUM, and were set equal to ponies.

3 CH_4 emissions from enteric fermentation (CRF sector 3A)

3.1 Scope and definition

This chapter describes the methods and working processes used to determine the emission of CH_4 from ruminal and intestinal (enteric) fermentation. In the CRF the following source categories are distinguished:

- 3A1a Mature dairy cattle (ruminal and intestinal fermentation)
- 3A1b Other mature cattle (ruminal and intestinal fermentation)
- 3A1c Growing cattle (ruminal and intestinal fermentation)
- 3A2 Sheep (ruminal and intestinal fermentation)
- 3A3 Swine (intestinal fermentation only)
- 3A4 Other livestock
  a) Goats (ruminal and intestinal fermentation)
  b) Horses (intestinal fermentation only)
  c) Mules and asses (intestinal fermentation only)
  d) Poultry
  e) Other

In category 3A4d Poultry emissions are reported as Not Estimated (NE), since the anatomy of the gastro-intestinal tract of poultry (i.e. high passage rate of feed) and the composition of poultry feed (relatively high energy value) result in a negligible contribution of fermentation processes to feed digestion. The 2006 IPCC Guidelines do not provide a default emission factor for poultry either. Under category 3A4e Other, no emissions are being reported as the same applies to the livestock categories fur-bearing animals and rabbits or the respective species are not kept commercially in the Netherlands (llamas, alpacas and deer).

The feed consumed by an animal is digested in the gastro-intestinal tract, to provide the energy and nutrients needed for maintenance and production. Part of the (nearly anaerobic) gastro-intestinal tract accommodates a particularly large microbial population, fermenting the feed in which methane is formed as a by-product. In monogastric animals (pigs, horses, mules and asses) this only involves the large intestine and therefore CH_4 production remains relatively low. The gastro-intestinal tract of polygastric animals (cattle, sheep and goats) is specialized to digest fibrous material, especially in the rumen. With intensive microbial fermentation taking place, the rumen gives rise to a considerably larger CH_4 production in ruminants than in monogastric animals.

In addition to the microbial matter synthesized through fermentation of organic matter, volatile fatty acids and hydrogen gas are produced. Just a small fraction of the hydrogen gas is utilized with microbial growth, or with the production of propionic acid and branched chain volatile fatty acids. The surplus of hydrogen is released into the rumen environment, either in rumen fluid or in the gaseous head space. Together with CO_2, which is available in excess in the rumen, the released hydrogen gas is almost completely converted into CH_4 and water by methanogens. Under Dutch feeding conditions of cattle less than 0.5% of enteric hydrogen production was observed to be exhaled in dairy cattle, indicating the remainder of hydrogen production ends up in CH_4 (Van Zijderveld *et al.*, 2011). This fairly complete conversion of hydrogen into CH_4 keeps the partial gas pressure of hydrogen in the rumen environment very low.

Although it was generally accepted that a relatively small increase of the partial gas pressure could have a detrimental effect on the fermentative degradation of feed in the rumen as a result of the inhibition of microbial activity (fibre degradation in particular), more recent findings contradict this. Feeding the methanogen inhibiting feed additive nitro-oxypropanolol caused about 30% reduction in CH_4 emissions and significant increases in partial hydrogen pressure in the rumen. Nevertheless, digestibility seemed to rather improve instead of decline (Hristov *et al.*, 2015). Also Van Lingen *et al.* (2016) clearly demonstrated the flexibility of the rumen microbiota in handling variation in hydrogen pressure by shifting their fermentation pathways from a hydrogen yielding acetate-oriented pathway towards a hydrogen consuming propionate-oriented pathway. Although there are two enteric compartments where CH_4 is produced (the rumen and the hindgut) almost all CH_4 (99%) formed will leave the ruminant via the mouth, via respiration (transport from the rumen to blood and lungs) and by frequent eructations of rumen gases and rumination (Berends *et al.*, 2014).

The amount of CH_4 produced by ruminants depends on the amount of feed consumed by the animal and the characteristics and composition of this feed (Veen, 2000; Smink *et al.*, 2003; Tamminga *et al.*, 2007). The amount of feed ingested strongly determines the amount of organic matter fermented, and with this, the amount of hydrogen gas converted into CH_4. The feed characteristics (degradability, rate of degradation and outflow to the intestine) determine which fraction of individual feed components ferments in the rumen and which fraction escapes rumen fermentation and flows out to the small intestine (Dijkstra *et al.*, 1992). The chemical composition of the fermented part of the feed determines the amount and type of volatile fatty acids produced (Bannink *et al.*, 2008; Kebreab *et al.*, 2009), and is thereby an important determinant of the surplus of hydrogen in the rumen that becomes converted into CH_4 (Mills *et al.*, 2001; Ellis *et al.*, 2008; Bannink *et al.*, 2011).

In conclusion, the amount and type of ingested feed determines the emission factor for CH_4 (i.e. the amount of CH_4 in kg CH_4/year that is produced by an animal), partly through its effect on the so-called methane conversion factor (Y_m, i.e. the fraction of gross energy in ingested feed that is converted into CH_4).

3.2 Source-specific aspects

3.2.1 Calculation method

The emission of CH_4 as a result of ruminal and intestinal fermentation in cattle is calculated by multiplying the number of animals per livestock category by a country-specific emission factor for that livestock category. For the other livestock categories, default EFs are used according to the IPCC 2006 Guidelines. The total emission of CH_4 of all animals is calculated by summing the emissions per livestock category.

$$CH_4 \text{ emissions 3A} = \sum_i [\text{ number of animals in livestock category (i) }] \times \text{EF } CH_4 \text{ 3A}_i \qquad (3.1)$$

In which

CH_4 emissions 3A	: Methane emission (kg CH_4/year) for all defined livestock categories (i) within the CFR source category 3A enteric fermentation
EF CH_4 $3A_i$	: Emission factor (kg CH_4/animal/year) for enteric fermentation of livestock category (i)

Comparison to IPCC methodology
For all livestock categories, excluding cattle, Tier 1 default IPCC emission factors are applied. For cattle, excluding mature dairy cattle, the Tier 2 approach is applied, with intake of gross energy being calculated according to a country-specific method. In this method the EF is calculated using the Y_m and the gross energy (GE; MJ/kg dry matter) intake from feed (GE_i; MJ/animal/day). The default IPCC value of 0.065 is used as Y_m, except for white veal calves since these are mainly fed milk products and therefore do not show full rumen development (Gerrits *et al.*, 2014).

For mature dairy cattle, a country-specific Tier 3 approach is applied by using a dynamic simulation model which describes the mechanisms of the fermentation processes in the gastrointestinal tract (Bannink *et al.*, 2011). The model predicts the consequences of nutrition on microbial fermentation and the accompanying production of CH_4 in the rumen and the large intestine. The simulation model predicts GE_i and the production of CH_4 in the rumen and large intestine from feed intake and dietary characteristics (dry matter intake, chemical composition and rumen degradation characteristics). Subsequently, the model calculates the Y_m from predicted CH_4 emission and GE_i. Therefore, the model predicts Y_m instead of assuming a constant Y_m value as a model input, as is the case with the Tier 2 approach.

3.2.2 Activity data

Livestock numbers are the activity data for this emission source. Livestock numbers and their uncertainty are described in section 2.3.

3.2.3 Emission factors

Emission factors used for the calculation of enteric fermentation, are detailed in following sections dealing with all livestock categories, excluding cattle (Tier 1), cattle excluding mature dairy cattle (Tier 2) and mature dairy cattle (Tier 3).

Emission factors all livestock categories, excluding cattle
For all livestock categories excluding cattle, a Tier 1 approach is applied with default emission factors as described in the IPCC Guidelines (2006; p. 10.28). Table 3.1 gives an overview of the EFs used.

Table 3.1 *Emission factors (EF) for all livestock categories, excluding cattle*

Livestock category	EF in kg CH_4/animal/year
Sheep	8.00
Goats	5.00
Horses	18.00
Mules and asses	10.00
Pigs	1.50

Source: IPCC (2006).

Uncertainties in emission factors all livestock categories, excluding cattle
The IPCC Guidelines give default uncertainties of 30-50%. Using expert judgement an uncertainty of 40% is used in the calculations.

Emission factors cattle excluding mature dairy cattle
Cattle is considered a key source (Coenen *et al.*, 2017) and therefore, for all cattle categories excluding mature dairy cattle, a Tier 2 approach is followed to calculate country- and year-specific emission factors. White veal calves have different characteristics, and therefore parameters used in the calculations are modified for this group. The general emission factor is expressed by the following equation:

$$EF\ CH_4\ 3A_i = (Y_{mi} \times GE_i) / 55.65 \qquad (3.2)$$

In which

Y_{mi}	: Methane conversion factor for livestock category (i) (fraction of gross energy intake (GE) that is converted into CH_4)
GE_i	: Gross energy intake (MJ/animal/year) for livestock category (i)

A default value of 0.065 is used for the Y_m as described in the Guidelines (IPCC, 2006), with the exception of white veal calves. It is assumed that 1 kg CH_4 has a standard energy content of 55.65 MJ (IPCC, 2006).

The GE_i is calculated according to the following equation:

$$GE_i = DM_i \times 18.45 \qquad (3.3)$$

In which

DM_i : Dry matter intake (kg dry matter/animal/year) for livestock category (i)

It is assumed that 1 kg dietary dry matter has a gross energy content of 18.45 MJ/kg dry matter (IPCC, 2006), with the exception of milk products fed to white veal calves (21.00 MJ/kg DM; Gerrits *et al.*, 2014).

Feed intake and rations of cattle, excluding mature dairy cattle

Dry matter intake (DM_i; kg dry matter/animal/day) is derived from calculations by the WUM. The intake of various components in the ration (milk(-products), grass, grass silage, maize silage, standard concentrates, protein-rich concentrates and wet by-products) is calculated yearly per cattle category based on national statistics on the amounts of these products that have been traded or produced. These statistics on dietary components cover part of the total energy requirement that is calculated yearly according to a country-specific method for the various cattle categories.

Subsequently, it is assumed that the remainder of the energy requirement for the recorded production level is covered by the intake of grass from grazing. From 1990 onwards, the WUM calculates the DM intake and ration yearly, which is also input for the method used to calculate manure production and mineral excretion by livestock (Van Bruggen, 2003 through 2017). The first release appeared in 1994 (WUM, 1994) and a revised calculation of the rations (from 1990 to 2008) appeared in 2009 (CBS, 2012). The DM intake of cattle, excluding mature dairy cattle, is given in the report written by Smink (2005) and in Van Bruggen *et al.* (2015).

Emission factors white veal calves

The production of white veal forms a considerable sector in the Netherlands. Rations consist largely or entirely out of milk products, with low associated Y_m as milk products are not fermented in the rumen. In order to improve animal welfare, over time rations have been supplemented with increasing amounts of concentrates and roughages. As the rumen will still not be fully developed in white veal calves, Y_m for these ration components was observed to be lower than the default value of 0.065. Specific Y_m values of 0.003 for milk products and 0.055 for other ration components are assumed, and a GE of 21.00 MJ/kg DM for milk products is used (Gerrits *et al.*, 2014):

$$EF\ CH_4\ 3A_{\text{white veal}} = (Y_{m,\text{milk products}} \times GE_{\text{milk products}} + Y_{m,\text{other ration components}} \times GE_{\text{other ration components}}) / 55.65 \quad (3.4)$$

In which

$EF\ CH_4\ 3A_{\text{white veal}}$	: Emission factor (kg CH_4/animal/year) for enteric fermentation of white veal calves
$Y_{m,\text{milk products}}$	: Methane conversion factor for milk products (fraction of gross energy intake (GE) that is converted into CH_4)
$GE_{\text{milk products}}$	: Gross energy intake (MJ/animal/year) with milk products
$Y_{m,\text{other ration components}}$	: Methane conversion factor for other ration components (fraction of gross energy intake (GE) that is converted into CH_4)
$GE_{\text{other ration components}}$	: Gross energy intake (MJ/animal/year) with other ration components

Uncertainties in emission factors cattle excluding mature dairy cattle

Feed intake depends on the total energy requirement and the variety of rations fed to fulfill this requirement. Uncertainty in total energy requirement is considered to be 2%. Because of extra uncertainty in how to fulfill this requirement the uncertainty in dry matter feed intake is considered to be 5% in female young stock and 10% in male young stock categories. Since rations can be better predicted, 2% is used for veal calves. As the various feed components are mutually dependent, only the uncertainty on the total DM uptake is considered.

Energy content of the feed is estimated to have an uncertainty of 2.5%. The uncertainty depends on the uncertainties in fat, crude protein and carbohydrates. Especially fat has a large influence in energy content, but fat is also the smallest part in the total feed intake and because of this the uncertainty is low. The parts crude protein and carbohydrates are more important in the uncertainty for dry matter intake.

Uncertainty in Y_m is set at 20%, because of its dependence from roughage quality (Bannink *et al.*, 2011). Since veal calves diets contain less or no roughage, therefore the uncertainty of the Y_m is put at 10% instead of the 20% for other cattle diets.

As a physical quantity, energy content of CH_4 is considered to bear no uncertainty.

Table 3.2 summarizes the starting points for the uncertainty calculations for cattle excluding mature dairy cattle.

Table 3.2 *Starting points uncertainty calculation methane emissions from enteric fermentation for cattle except mature dairy cattle, calculated by a Tier 2 approach*

Livestock category	U livestock numbers	U DM feed intake	U feed energy content	U Y_m	U energy content CH_4
Young cattle					
Female young stock for breeding < 1 yr	2%	5%	2.5%	20%	0%
Male young stock for breeding < 1 yr	2%	10%	2.5%	20%	0%
Female young stock for breeding, ≥ 1 yrs	2%	5%	2.5%	20%	0%
Male young stock for breeding, ≥ 1 yrs	2%	10%	2.5%	20%	0%
Meat calves, for white veal production	2%	2%	2.5%	10%	0%
Meat calves, for rosé veal production	2%	2%	2.5%	10%	0%
Female young stock for fattening < 1 yr	2%	5%	2.5%	20%	0%
Male young stock (incl. young bullocks) for fattening < 1 yr	2%	10%	2.5%	20%	0%
Female young stock for fattening, ≥ 1 yrs	2%	5%	2.5%	20%	0%
Male young stock (incl. young bullocks) for fattening, ≥ 1 yrs	2%	10%	2.5%	20%	0%
Suckling cows (incl. fattening/grazing ≥ 2 yrs)	2%	5%	2.5%	20%	0%

Mature dairy cattle

For mature dairy cattle a Tier 3 approach is applied to calculate country-specific emission factors, split in the regions Northwest and Southeast of the Netherlands. Because both regions have different ration compositions, emissions are also different. The most important difference with the Tier 2 approach is that the simulation model predicts the emission factor from feed intake and dietary characteristics as model inputs, without using GE_i or Y_m values. Another important difference with the Tier 2 approach is that the simulation model takes into account several dietary characteristics to predict the fermentation processes in the rumen and large intestine, instead of using only the net energy value for milk production and maintenance as a dietary characteristic. A final difference with the Tier 2 approach is that the simulation model calculates GE_i from dry matter intake and dietary composition instead of adopting a GE value for feed DM. The EF, GE_i and Y_m of mature dairy cattle are calculated yearly (Bannink, 2011). The Tier 3 approach does not account for effects of feed additives supposed to reduce enteric CH_4 emission.

The simulation model describes CH_4 production as a result of microbial fermentation processes in the gastro-intestinal tract of mature dairy cattle. The simulation model is developed by Dijkstra *et al.* (1992), Mills *et al.* (2001) and Bannink *et al.* (2005; 2008; 2011) and is described in scientific (peer-reviewed) journals. Mills *et al.* (2001) added a representation of CH_4 production to the model of rumen fermentation processes developed by Dijkstra *et al.* (1992), including a representation of the fermentation processes in the large intestine. This model extension calculates the production of volatile fatty acids and hydrogen (the latter converted into CH_4) according to Bannink *et al.* (2006). More recently, an improved representation was included of the production of volatile fatty acids and hydrogen by making this dependent on the acidity of rumen contents (Bannink *et al.*, 2005; 2008; 2011). This version of the simulation model is applied since 2005 as a Tier 3 approach to calculate CH_4 emissions in mature dairy cattle. Although the model can also be used for other cattle categories, it is currently not applied for this purpose because of budget constraints and lack of model evaluation results for other categories.

Based on predicted values of emission factor and GE_i the simulation model calculates an Y_m value. The Y_m is hence not part of the assumptions made in the model representation but is a predicted outcome of the model in the same unit as used for Y_m with other categories. From the predicted values of the emission factor and the GE per year, the Y_m is calculated as follows:

$$Y_m = EF \times 55.65 / (GE \times 365) \quad (3.5)$$

In which

Y_m	: Methane conversion factor (fraction of GE intake converted into CH_4)
EF	: Emission factor (kg CH_4/animal/year) calculated with the simulation model
GE	: Gross energy intake (MJ/animal/day) calculated with the simulation model

It is assumed that 1 kg CH_4 has a standard energy content of 55.65 MJ (IPCC, 2006), and the factor 365 was used to calculate GE_i on a yearly basis.

Should the results from the simulation model not be available in a particular year, a secondary (simplified) approach is used to calculate the emission factor, where the Y_m and GE/DM from the three preceding years will be used (as a back-up option). The following equation is then used to calculate the emission factor:

$$EF = (DM \times 365 \times GE / DM \text{ (gross energy content in dry matter; average of year n-1 to year n-3)} \times Y_m \text{ (average year n-1 to year n-3)) } / 55.65 \quad (3.6)$$

In which

EF	: Emission factor (kg CH_4/animal/year)
DM	: Dry matter intake (kg dry matter/animal/day)
GE	: Gross energy intake (MJ/animal/day)
Y_m	: Methane conversion factor (fraction of GE converted into CH_4)

It is assumed that 1 kg CH_4 has a standard energy content of 55.65 MJ (IPCC, 2006), and the factor 365 is used to calculate DM on a yearly basis.

The emission factor is calculated more accurately with equation 3.6 since estimates are based on dietary characteristics of three consecutive previous years instead of using characteristics of only one single year. The Y_m depends on all input data to the simulation model: 1) the level of feed intake, 2) the chemical composition of ingested feed and 3) the degradation characteristics in the rumen. The origin of this data is described in the next section.

Feed intake of mature dairy cattle

Important input data for the simulation model are:

1. Feed intake levels, DM, as calculated by WUM (CBS, 2012) for the regions Northwest and Southeast, according to the same method as described above for cattle, excluding mature dairy cattle.
2. The chemical composition of DM in the various dietary components (grass herbage, grass silage, maize silage, low-protein concentrates, protein-rich concentrates and wet by-products). A distinction is made between soluble carbohydrates (including sugars), starch, cell walls (hemi-cellulose, cellulose, lignin), crude protein (including a distinction of the ammonia fraction), crude fat and crude ash. Data on the composition is derived from information from the laboratory Eurofins Agro (formerly Blgg and AgroXpertus) in Wageningen (eurofins-agro.com), which analyses roughages, and from producers of compound feed. The data used have been previously described by Smink *et al.* (2005). With a recent revision of the WUM rations from 1990 to 2008 by CBS (CBS, 2012) new calculations have been conducted and data of chemical composition is attached to the report of Bannink (2011). Part of the ensiled roughage is not fed to dairy cattle in the same year as the roughage analysis was performed. Therefore, in the annual ration calculations a correction on ensiled roughage is made (CBS, 2012).
3. Rumen intrinsic degradation characteristics of starch, crude protein and fibre. The report by Bannink (2011) also gives the assumptions on these degradation characteristics (soluble/washable fraction, fraction that is potentially degradable, undegradable fraction and the fractional degradation rate of the fraction that is potentially degradable).

Data varies with annual changes in the proportion of individual dietary components (grass herbage, grass silage, maize silage, low-protein concentrates, protein-rich concentrates, wet by-products) and with changes in chemical composition and intrinsic degradation characteristics of these chemical fractions. The fractional passage rate of fermentable matter and acidity of contents in the rumen and the large intestine are also important model parameters that have a considerable influence on predicted CH_4 production. However, this concerns internal model parameters which do not need to be given as an input to the model. Within the current method the simulation model predicts the fractional passage rate as a function of DM, and acidity as a function of predicted concentration of volatile fatty acids according to Mills *et al.* (2001). Sensitivity of model predictions for the parameter values and the effect on uncertainty have been described (Bannink, 2011).

Uncertainties in emission factors mature dairy cattle

CBS (2012b) reported an uncertainty of 2% in total number of mature dairy cattle, and Bannink (2011) an uncertainty of 15% in the emission factor based on an analysis of the effect of input uncertainty on predicted emission factor and Y_m. Disaggregating to Northwest and Southeast Netherlands, the uncertainty for the two subcategories is calculated with the following formula:

$$\text{U dairy cows NW} = \sqrt{(\text{total dairy cows x total uncertainty})^2 / (\text{total uncertainty}^2 + \text{dairy cows NW}^2)} \quad (3.7a)$$

$$\text{U dairy cows ZO} = \sqrt{(\text{total dairy cows x total uncertainty})^2 / (\text{total uncertainty}^2 + \text{dairy cows ZO}^2)} \quad (3.7b)$$

This yields the uncertainties shown in Table 3.3.

***Table 3.3** Uncertainty for enteric fermentation of mature dairy cattle*

Livestock category	U AD	U EF	U emission
Dairy cows Northwest Netherlands	3.4%	21%	21%
Dairy cows Southeast Netherlands	2.4%	21%	21%
Dairy cows implied factors	2%	15%	15%

3.2.4 Uncertainty

The uncertainty estimates concerning the data sources and emission factors used and the total uncertainty estimate for CH_4 from enteric fermentation are listed in Table 3.4.

***Table 3.4** Uncertainty estimates (% of value) for CH_4 emissions, activity data (AD) and implied emission factors (IEF) from CRF sector 3A Enteric fermentation*

IPCC	Livestock category	U AD	U IEF	U emission
3A1a	Mature dairy cattle	2%	15%	15%
3A1b	Other mature cattle	2%	21%	21%
3A1c	Growing cattle	1%	11%	11%
3A2	Sheep	10%	40%	41%
3A3	Swine	6%	40%	41%
3A4a	Goats	10%	40%	41%
3A4b	Horses	36%	40%	56%
3A4c	Mules and Asses	5%	40%	40%
	Total			10%

4 CH_4 emissions from manure management (CRF sector 3B)

4.1 Scope and definition

This chapter describes the methodology and working processes for determining CH_4 emissions from manure in animal housings and outside storages, or produced on pasture land during grazing. In the CRF the following source categories are distinguished:

- 3B1a Mature dairy cattle
- 3B1b Other mature cattle
- 3B1c Growing cattle
- 3B2 Sheep
- 3B3 Swine
- 3B4 Other livestock
  - a) Goats
  - b) Horses
  - c) Mules and asses
  - d) Poultry
  - e) Other

Under category 3B4e Other, rabbits and fur-bearing animals are being reported. Llamas, alpacas, and deer are not kept commercially in the Netherlands.

Methane emissions from animal manure are caused by fermentation of organic matter in an anaerobic environment. It takes some time for methanogenic bacteria to develop and produce methane. This implies that when manure is stored for shorter than a month methane production will remain very low. To what extent organic matter is converted in methane also depends on the (chemical) composition of the manure and environmental factors like temperature. Webb *et al.* (2012) present an overview of key factors affecting methane emission.

Animal manure can be slurry or solid, depending on the livestock category and manure management system (like the use of straw). It is called slurry when it is flowing under gravity and pumpable, solid manure is stackable and can be packed in heaps (RAMIRAN Glossary, 2011). Slurry is anaerobic, solid manure, when not packed or compressed, is more aerated, resulting in lower CH_4 emissions.

- Cattle manure in the Netherlands is mainly stored as slurry, but can also be solid, possibly with a share of urine and faeces excreted during grazing. In general female young stock, dairy and suckling cows are kept on pasture land during the summer months. All dairy cows spend part of the day inside the animal house depending on the applied grazing system, particularly at night and during milking times. With an increase of the number of animals per farm, more animals are kept inside the animal house all the time. This implies that also during the summer months all of the manure (and CH_4) is produced in the animal house.
- Pig manure in the Netherlands is mainly slurry. A minor part is solid, produced when bedding material is used (for instance straw).
- Poultry includes laying hens, broilers, ducks and turkeys. Because of the high dry matter content of poultry excreta and the management systems used, currently all poultry manure is considered solid. In earlier years of the time series, battery cage systems, in which slurry is produced, are also taken into consideration.
- Goats in the Netherlands are kept inside the animal house throughout the year and produce solid manure.
- Sheep are grazing animals kept outside except during the lambing season. During this housing period they produce solid manure.
- Horses, mules and asses produce manure in the animal house and during grazing. Solid manure is produced in the period inside the animal house.
- Rabbits and fur-bearing animals (minks, foxes) are kept indoors year-round, and can produce either solid manure or slurry depending on the housing system.

Slurry of pigs and cattle is often stored underneath the slatted floors of animal houses in slurry pits, and manure storage facilities outside the animal house. Solid manure is stored in the animal house and stacked outdoors, in most cases with a roof to avoid rainwater. In both cases anaerobic conditions can occur, resulting in the production and emission of CH_4.

The slurry pit is a so-called accumulation system: there is a constant input of manure and the volume increases until it is removed. The CH_4 emission in such a system increases as the manure temperature rises and the manure is stored for longer periods (Zeeman, 1994). Additionally, when older manure with high methanogenic activity is already present (inoculation) CH_4 emission also increases.

Methane emission from manure excreted during grazing is low, because of the aerobic conditions and fast drying of manure.

4.2 Source-specific aspects

4.2.1 Calculation method

Cattle, pigs and poultry are considered to be key-sources (Coenen *et al.*, 2017) and therefore emission factors are calculated with a Tier 2 approach. In this approach, distinction is made between slurry manure management systems, solid manure management systems and pasture manure.

CH_4 emissions in livestock category (i) = Σ [number of animals in livestock category (i)] x [fraction manure management system (j)] x EF CH_4 $3B_{ij}$ (4.1)

In which

EF CH_4 $3B_{ij}$: Emission factor (kg CH_4/animal) for the manure management of livestock category (i) and manure management system (j)

With respect to the other livestock categories, default Tier 1 emission factors are used (IPCC, 2006).

CH_4 emissions in livestock category (i) = [number of animals in livestock category (i)] x EF CH_4 $3B_i$ (4.2)

In which

EF CH_4 $3B_i$: Emission factor (kg CH_4/animal) for the manure management of livestock category (i)

4.2.2 Activity data

Livestock numbers
Livestock numbers are the activity data for this emission source. Livestock numbers and their uncertainty are described in section 2.3.

Distribution between the manure management systems
The proportion of slurry and solid manure depends on how manure is managed in the housing systems. Data on these are derived from the Agricultural census. The length of the grazing period in days per year and hours per day indicate the fraction of manure excreted on pasture land as indicated by the WUM.

According to the IPCC method, slurry is divided into two groups: storage in slurry pits lasting less than one month, and storage lasting longer than one month.

Uncertainties in activity data for CH_4 from manure management
The uncertainty in livestock numbers, including (dis-)aggregation of subcategories, is given in section 2.3.

Uncertainties in the fraction of manure management systems pasture and animal house manure are included in the volatile solids (VS) uncertainty for these two categories. Animal house manure in the

Netherlands again is split in two categories, solid and slurry manure. An uncertainty of 10% is used for the smallest fraction. The uncertainty of the other fraction is calculated as the absolute uncertainty in the small fraction divided by the large management system fraction. Because emissions are reported per livestock category, uncertainties of distribution between manure management systems is eventually included in the emission factor uncertainty.

4.2.3 Emission factors

For all other livestock categories, the Tier 1 default emission factors from Table 4.1 are used (IPCC, 2006).

Table 4.1 *Emission factors for all livestock categories (excluding cattle, pigs and poultry)*

Livestock category	EF in kg CH_4/animal/year
Sheep	0.19
Goats	0.13
Horses	1.56
Mules and asses	0.76
Rabbits	0.08
Fur-bearing animals (minks and foxes)	0.68

Source: IPCC (2006).

For the key livestock categories cattle, pigs and poultry a country-specific emission factor is calculated for each manure management system using the following formula:

$$EF\ CH_4\ 3B_{ij} = VS_i \times B_{oi} \times MCF_{ij} \times \text{methane density} \quad (4.3)$$

In which
VS_i : Volatile solids (kg VS/year) excreted by livestock category (i)
B_{oi} : Maximum methane production potential (m^3 CH_4/kg VS) for the manure produced by livestock category (i)
MCF_{ij} : Methane conversion factor for livestock category (i) and manure management system (j)
Methane density: 0.67 kg/m^3 CH_4

Volatile solids (VS)
The amount of excreted VS is calculated for the key categories cattle, pigs and poultry (Zom and Groenestein, 2015). The amount of VS excreted by livestock depends on the digestibility of the organic matter and protein of the feed components. VS excretion in urine is calculated as the amount of urea (CH_4N_2O) or uric acid ($C_5H_4O_3N_4$) from the digestibility of crude protein, which is also used in the calculation of TAN. In faeces VS depends on DM uptake, ash content therein and digestibility of the VS (Zom and Groenestein, 2015).

Maximum methane production potential (B_o)
The B_o depends on the degradability of the organic components in the manure. B_o is expressed in m^3 CH_4/kg VS and is 0.22 for cattle manure, 0.31 for pig manure, and 0.34 for poultry manure (Groenestein *et al.*, 2016).

Methane Conversion Factor (MCF)
The MCF indicates which part of B_o will actually be converted into methane depending on environmental conditions. The most important factors are storage time, inoculation, availability of oxygen, dry matter content and manure coverage (hard cover, floating, crust or otherwise). In the Netherlands, farmers need to store the manure for six or seven months, because it is forbidden to apply manure from September to February (obligation related to implementation of Nitrates Directive). Therefore long-term measurements are needed to estimate the yearly CH_4 emission from which MCF can be deduced while environmental factors need to be representative for the Dutch situation. Additionally, in analysing the measuring data of storage in housing systems, correction for enteric methane production is necessary. Considering the above Groenestein *et al.* (2016) made

estimations of the mean MCF for cattle and pig slurry based on literature (Table 4.2). Not enough data were available for solid poultry manure, so here IPCC defaults were used. In earlier years of the time series also slurry manure of poultry is considered, MCF of which was set equal to pig slurry. For solid manure of cattle and pigs and manure on pasture land, the default IPCC MCF values of respectively 0.02 and 0.01 are used.

Table 4.2 *MCF values used per livestock category*

Livestock category	MCF
Slurry	
Cattle	0.17
Pigs	0.36
Laying hens	0.36
Solid manure	
Cattle	0.02
Pigs	0.02
Poultry	0.015
Pasture manure	
Cattle	0.01

Uncertainties in emission factors for CH_4 from manure management
IPCC gives an uncertainty of 30% for the Tier 1 emission factor.

The uncertainties of the estimations of the excretion of VS are assumed to be 10% for housing conditions and 20% for grazing animals.

The uncertainties of the estimation of the mean B_o, defined as 2 x (stdev/√(n-1)) depend on the livestock category (Table 4.3) and are 11% for cattle and 14% for pigs based on the data in Groenestein *et al.* (2016). For poultry manure, the uncertainty is assumed to be the same as for pig manure.

Based on the data of Groenestein *et al.* (2016) an uncertainty (defined as 2 x (stdev/√n)) could be calculated for the estimation of MCF of slurry pig manure of 35%. For cattle and poultry the assumption is made that MCF uncertainties will be the same. For solid manure the uncertainty is assumed to be twice the uncertainty of slurry (Table 4.3).

Table 4.3 presents an overview of all uncertainties.

Table 4.3 *Uncertainties in basic data for the calculation of methane emission from manure management*

Livestock category	MMS[1)]	U livestock numbers	U MCF	U B_o	U VS	Fraction solid/slurry
Cows in milk and in calf	Slurry	2%	35%	11%	10%	0.31%
	Solid	2%	71%	11%	10%	14.21%
	Pasture	2%	35%	11%	20%	
Female young stock < 1 yr	Slurry	2%	35%	11%	10%	6.95%
	Solid	2%	71%	11%	10%	10%
	Pasture	2%	35%	11%	20%	
Male young stock < 1 yr	Slurry	2%	35%	11%	10%	6.95%
	Solid	2%	71%	11%	10%	10%
Female young stock, ≥ 1 yrs	Slurry	2%	35%	11%	10%	0.42%
	Solid	2%	71%	11%	10%	10%
	Pasture	2%	35%	11%	20%	
Male young stock, ≥ 1 yrs	Slurry	2%	35%	11%	10%	0.91%
	Solid	2%	71%	11%	10%	10%
Meat calves, for white veal production	Slurry	2%	35%	11%	10%	
Meat calves, for rosé veal production	Slurry	2%	35%	11%	10%	
Female young stock < 1 yr	Slurry	2%	35%	11%	10%	7.86%

Livestock category	MMS[1]	U livestock numbers	U MCF	U B_o	U VS	Fraction solid/slurry
	Solid	2%	71%	11%	10%	10%
	Pasture	2%	35%	11%	20%	
Male young stock (incl. young bullocks) < 1 yr	Slurry	2%	35%	11%	10%	8.18%
	Solid	2%	71%	11%	10%	10%
Female young stock, ≥ 1 yrs	Slurry	2%	35%	11%	10%	7.86%
	Solid	2%	71%	11%	10%	10%
	Pasture	2%	35%	11%	20%	
Male young stock (incl. young bullocks) ≥ 1 yrs	Slurry	2%	35%	11%	10%	8.38%
	Solid	2%	71%	11%	10%	10%
Suckling cows (incl. fattening/grazing ≥ 2 yrs)	Slurry	2%	35%	11%	10%	5.15%
	Solid	2%	71%	11%	10%	10%
	Pasture	2%	35%	11%	20%	
Fattening pigs	Slurry	10%	35%	14%	10%	
Rearing pigs	Slurry	5%	35%	14%	10%	
Sows	Slurry	5%	35%	14%	10%	0.31%
	Solid	5%	71%	14%	10%	10%
Boars for service	Slurry	5%	35%	14%	10%	2.35%
	Solid	5%	71%	14%	10%	10%
Broilers	Solid	10%	71%	14%	10%	
Ducks for slaughter	Solid	10%	71%	14%	10%	
Turkeys for slaughter	Solid	10%	71%	14%	10%	
Broilers parents under 18 weeks	Solid	10%	71%	14%	10%	
Broilers parents 18 weeks and over	Solid	5%	71%	14%	10%	
Laying hens < 18 weeks, solid manure	Solid	10%	71%	14%	10%	
Laying hens ≥ 18 weeks, solid manure	Solid	5%	71%	14%	10%	

[1] Manure management system

For the density of CH_4 an uncertainty of 0% is assumed because it is a physical property.

4.2.4 Uncertainty

The uncertainty estimates concerning the data sources and emission factors used and the total uncertainty estimate for CH_4 from manure management are listed in Table 4.4.

Table 4.4 *Uncertainty total CH_4 emission, activity data (AD) and implied emission factors (IEF) from manure management*

IPCC	Livestock category	U AD	U IEF	U emission
3A1a	Mature dairy cattle	2%	38%	38%
3A1b	Other mature cattle	2%	34%	34%
3A1c	Growing cattle	1%	21%	21%
3A2	Sheep	10%	44%	45%
3A3	Swine	7%	29%	30%
3A4a	Goats	10%	30%	32%
3A4b	Horses	36%	58%	68%
3A4c	Mules and asses	5%	43%	43%
3A4d	Poultry	5%	44%	44%
3A4e	Other	5%	29%	29%
	Total			20%

5 NH_3 emissions from manure management (NFR category 3B)

5.1 Scope and definition

This chapter describes the methods and working processes for determining NH_3 emissions from manure management, using the following NFR categories:

- 3B1a Dairy cattle
- 3B1b Non-dairy cattle
- 3B2 Sheep
- 3B3 Swine
- 3B4d Goats
- 3B4e Horses
- 3B4f Mules and asses
- 3B4gi Laying hens
- 3B4gii Broilers
- 3B4giii Turkeys
- 3B4giv Other poultry
- 3B4h Other animals

Buffalo (3B4a) are reported as Not Occurring (NO), because these animals are not kept commercially in the Netherlands. The Other animals (3B4h) category consists of fur-bearing animals and rabbits.

NH_3 emissions from manure management are the sum of emissions from animal housing (including inside manure storage) and outside manure storages. These emissions originate mainly from nitrogen excreted in the urine and to a small extent from mineralized organically bound N in faeces. In mammals this N is excreted as urea (CH_4N_2O) and in birds as uric acid ($C_5H_4O_3N_4$). Both urea and uric acid are converted by bacterial enzymes (urease and uricase) into ammonium (NH_4^+). For urea this process generally takes less than 24 hours (Elzing and Monteny, 1997), while uric acid breaks down less quickly (Groot Koerkamp, 1998). At high pH, NH_4^+ is converted to NH_3 which emits in a process affected by physical (air speed, area and temperature) and chemical (NH_4^+ concentration, pH and ion strength) factors.

The sum of the amount of NH_3 and NH_4^+ is called total ammoniacal N (TAN). The N-flow method described in this methodology report and its predecessors (Vonk *et al.*, 2016; Velthof *et al.*, 2009) calculates the gaseous N emissions based on TAN. This is a change with respect to methodologies used earlier in the Netherlands, which used emission factors based on total N excretion (Oenema *et al.*, 2000; Van der Hoek, 2002). The excretion of TAN is calculated as the sum of excretion of urine N and net mineralized organically bound N in faeces. The net mineralized organically bound N is used since TAN can also be immobilized and become organic N.

There is international consensus about the advantages of a methodology to calculate NH_3 emissions on the basis of TAN instead of total N:

- Gaseous N components are formed from NH_4^+ in the manure and research under controlled conditions shows that the NH_3 emission is better related to the NH_4^+ content than the content of total N in manure (e.g. Velthof *et al.*, 2005).
- A measure that does not change the total amount of N in the manure, but does change the amount of TAN, does affect NH_3 emission as well. With an emission factor based on total N this effect cannot be calculated. Rations do not only have an effect on total N excretion, but also on the share TAN of the excretion (Annexes 1, 2 and 3). The effects of ration composition on NH_3 emission can be quantified better with a methodology based on TAN.
- The emission factor for application of manure is based on TAN (section 9.2.3). In the former methodology used in the Netherlands the emission after application is calculated based on standard TAN contents in the manure from literature. These data are not influenced by changes in rations or

housing systems. If the NH_3 emission after application of manure can be based on the calculated TAN contents in the manure, effects of rations and housing systems on TAN also become visible in the emissions after application.

- With the methodology on basis of TAN, connection is made to internationally accepted concepts of NH_3 calculation methods (Reidy *et al.*, 2008), and also to the Emission Inventory Guidebook of EMEP/EEA that is being used in the European and UNECE context (www.eea.europa.eu/publications/emep-eea-guidebook-2016).

In the methodology it is assumed that the relation between the TAN contents and the NH_3 emission progresses linearly, so that a linear emission factor is applied as percentage of the excreted TAN in manure. This assumption was also made in the former methodology based on total N (Oenema *et al.*, 2000) and has been found in experimental research (Velthof *et al.*, 2005).

The calculation method for NH_3 emissions based on TAN excretion rate also takes into account the net mineralization of organic N that occurs in the manure (Annex 4). Methods to calculate the animal excretion rate of TAN is based on ration data and animal productivity as drafted in Annexes 1, 2 and 3. Recently, the calculation method for dairy cattle as described in Annex 1 has been replaced by a new method based on the Tier 3 approach to estimate enteric CH_4 in dairy cattle (Bannink *et al.*, 2011). These calculations are performed yearly by the WUM to quantify dietary effects in estimates on TAN excretion and NH_3 emission (such as changes in roughage production and composition, and consequent changes in ration composition and feeding quality). The actual ration compositions and N digestibility of the separate components are taken as the starting point for the TAN calculations instead of fixed TAN values or empirically averaged digestion values (Velthof *et al.*, 2012).

For dairy cattle, a new approach has been developed recently which aligns with the Tier 3 approach to estimate enteric CH_4 emissions (Bannink *et al.*, 2011; see 3.1.2), because the previous method appeared to result in an overestimation of N fecal N digestibility by 8 percent units (Bannink *et al.*, 2016). The new approach allows the simultaneous simulation of enteric CH_4 and fecal N digestibility. Some minor modifications (representation of the fate and digestibility of endogenous and of microbial N synthesized in the rumen) were introduced in the representation of digestion in the small intestine and fermentation in the large intestine to achieve an appropriate estimation of fecal N digestibility (Bannink *et al.*, 2017; Bannink *et al.*, in prep). With these modifications the change in predicted enteric CH_4 emission factors for the time series of 1990 till 2016 compared to the non-modified Tier 3 approach was negligible (-0.03% ± 0.056%; -0.04 kg/cow/year), while largely preventing the systemic overprediction of fecal N digestibility.

In poultry TAN is mainly composed of uric acid instead of urea. It is however known that part of the uric acid in the animal house and outside manure storage may not have been converted to NH_4^+, especially in dried manures. The amount of uric acid in the applied manure is uncertain, and as a result no correction is made for it. In subsequent sections uniform calculation rules are given based on TAN for all livestock categories.

For all livestock categories, over time, part of the TAN in manure is lost as gaseous N compounds. It is assumed that net mineralization takes place directly after excretion in the housing. The calculations are performed as follows:

1. The TAN excretion by the animal is calculated as the excretion of N in urine;
2. The amount of TAN produced by net mineralization is calculated from the excretion of organic N in faeces;
3. The total amount of TAN in manure equals the sum of TAN excretion from step 1 and 2;
4. The emissions of NH_3 and other N compounds (N_2, N_2O and NO_x) is calculated relative to the total amount of TAN in the manure;
5. After deduction of N losses in the animal house from the total TAN in manure, part of the manure is stored in outside storages and here too N losses occur;
6. The amount of TAN remaining after deduction of N losses in the animal house and/or outside storage, is applied to land (Chapters 9, 10 and 11).

In the next section the calculation steps are described in detail.

5.2 Source-specific aspects for NH_3 emissions from animal houses

5.2.1 Calculation method

The total NH_3 emission from animal houses is calculated from:

- Number of animals per livestock category;
- Total N excretion in the animal house per livestock category and manure management system (slurry or solid manure);
- Share of TAN (urine fraction) in the excretion per livestock category (slurry or solid manure);
- Net mineralization of organically bound N in manure stored in the animal house (slurry or solid manure);
- Average emission factors for NH_3 from animal housing per livestock category. This emission factor is weighted for the share of the different housing systems.

The NH_3 emission from animal houses for livestock category (i) is calculated as:

$$NH_3 \text{ animal houses}_i = \sum \text{TAN input}_{ij} \times \text{EF } NH_3\text{-N animal house}_{ij} \times 17/14 \qquad (5.1)$$

In which

NH_3 animal houses$_i$: Total NH_3 emission (kg NH_3/year) from animal housing for livestock category (i)

TAN input$_{ij}$: Sum of urine excretion and net N mineralization in the animal house (TAN; kg N/year) for livestock category (i) and manure management system (j)

EF NH_3-N animal house$_{ij}$: NH_3 emission factor (% of TAN) for animal housings of livestock category (i) and manure management system (j)

17/14 : Conversion factor from NH_3-N to NH_3 based on molecular weight

The TAN input is calculated differently depending on manure management type. For slurry a part of the fraction of organically bound N mineralizes while in solid manure a part of the urine N immobilizes. In poultry manure no mineralisation or immobilisation takes place.

The TAN input for a given livestock category (i) with slurry manure management system (j) is calculated as follows:

$$\text{TAN input}_{ij} = [\text{ number of animals in livestock category (i) }] \times [\text{ fraction slurry manure management system (j) }] \times \text{N excretion}_i \times (\text{TAN}_u \text{ fraction}_i + (1 - \text{TAN}_u \text{ fraction}_i) \times \text{N mineralization}_j) \qquad (5.2a)$$

The TAN input for a given livestock category (i) with solid manure management system (j) is calculated as follows:

$$\text{TAN input}_{ij} = [\text{ number of animals in livestock category (i) }] \times [\text{ fraction solid manure management system (j) }] \times \text{N excretion}_i \times (\text{TAN}_u \text{ fraction}_i \times (1 + \text{N mineralization}_j)) \qquad (5.2b)$$

In which

N excretion$_i$: N excretion (kg N/animal) in the animal house for livestock category (i)

TAN$_u$ fraction$_i$: Fraction urine N in the total N excretion in the animal house for livestock category (i)

N mineralization$_j$: net N mineralization in % of the organic N excretion for manure management system (j)

In the case of slurry net N mineralisation is mineralisation of the faeces into TAN. In the case of solid manure net N mineralisation is immobilisation of TAN into organically bound N.

5.2.2 Activity data

Livestock numbers are the activity data for this emission source. Livestock numbers and their uncertainty are described in section 2.3.

Uncertainties in activity data for NH_3 from manure management
The uncertainty in livestock numbers, including (dis-)aggregation of subcategories, is given in section 2.3.

5.2.3 Emission factors

N excretion per livestock category in the considered year
N excretion and uncertainties are described in section 2.4.

Fraction of TAN of the total N excretion
The excretion of urine N (TAN) is calculated yearly, based on data on ration composition and N digestibilities of the feed components in the ration and production parameters (Tamminga *et al.*, 2000, 2004; Bannink *et al.*, 2016; Bannink *et al.*, 2017; Bannink *et al.*, in prep). In Annexes 1, 2 and 3 the calculation method of urine N excretion for, respectively, cattle, pigs and poultry is described for historic years (before 2009). For other grazing animals (horses, ponies, sheep and goats), the same methodology is used as for cattle. For rabbits and fur-bearing animals no data were available to calculate the TAN fraction in the N excretion. The share of these animals in the total NH_3 emission is limited and data on ration composition are difficult to obtain. The TAN fractions for these livestock categories are therefore estimated to be 70% (expert judgement) of the excreted N (Velthof *et al.*, 2009). A more detailed explanation of TAN is given in Annex 1, 2 and 3.

Mineralization/immobilization of organic N
It is assumed that the N mineralization during storage of slurry in the animal house amounts to 10% of the organic N, based on research of Beline *et al.* (1998), see also Annex 4. For solid manure, an N immobilization of 25% (or -25% mineralization) is assumed. In poultry and slurry manure of fur-bearing animals no mineralization/immobilization is assumed.

Manure management system
The proportion of slurry and solid manure depends on how manure is managed in the housing systems. Data on these are derived from the Agricultural census. The length of the grazing period in days per year and hours per day indicate the fraction of manure excreted on pasture land. This is indicated by the WUM.

NH_3 emission factor per livestock category and housing system
One manure management system the Netherlands can have several different housing systems. The shares of housing systems per livestock category are based on the Agricultural census. Until 2015, if for certain livestock categories not enough information was available, other sources were used like environmental permit files for housing systems of local authorities. NH_3 emission factors of these housing systems are often derived from measurements, resulting from the measurement protocol for emission factors within the legislation 'Regeling ammoniak en veehouderij' (Regulation ammonia and animal husbandry, Rav). The data of the most recent NH_3 emission factors in the Rav are used where possible. If new information about a certain livestock category or housing system is available, the emission factor can however prelude the one in the Rav. The NH_3 emission factors derived from the measurements are expressed per animal place. For the TAN flow, these are converted into an emission factor as a percentage of TAN present taking into account the TAN excretion of the housed animals and the vacancy in housing. For all animal housing systems (k) per livestock category (i) the following calculation is performed.

$$\text{EF } NH_3\text{-N animal house}_{ik} = \Sigma\ (\text{EF } NH_3 \text{ animal house}_{ik} \times (14/17) / (1 - \text{fraction occ}_{ik})) / \text{TAN input}_{ik} \times 100 \qquad (5.3)$$

In which

EF NH_3–N animal house$_{ik}$: NH_3 emission factor (% of TAN excretion) for livestock category (i) and housing system (k)
EF NH_3 animal house$_{ik}$: NH_3 emission factor (kg NH_3/animal place/year) for livestock category (i) and housing system (k)
fraction occ$_{ik}$: Fraction lack of occupancy per animal place for livestock category (i) and housing system (k), during the housing period
TAN input$_{ik}$: TAN input (kg N/animal/year) for livestock category (i) and housing system (k)
14/17 : Conversion factor from NH_3 to NH_3-N based on molecular weight

Research by an enforcement agency (Handhavingsamenwerking Noord-Brabant (2010, 2013)) showed that many of the air scrubbers were not properly used. Implementation grades were therefore corrected: in the years up and including 2009 it was assumed that 40% of the scrubbers did not function, decreasing by 8% a year to 16% in 2012. From then on a decrease of 4% per year was assumed until in 2016 all scrubbers were assumed to operate properly, because at that point it was compulsory to have electronic monitoring on all equipment.

Lack of occupancy
The lack of occupancy is given in Annex 8, based on Van Bruggen *et al.* (2015). With lack of occupancy the period in which the animal house is unoccupied between production rounds is meant. Through loss of animals, earlier selection of animals or other reasons for vacancies during a period of growth and rearing as described in Stichting Groen Label (1996) and Ogink *et al.* (2008) are not considered.

Uncertainties in emission factors for NH_3 from manure management
Uncertainties in total excretion per livestock category are estimated by WUM (CBS, 2012b). These uncertainties were split between uncertainties for excretion during housing and excretion during grazing. The uncertainties and calculation method are described in Chapter 2.

Uncertainties in TAN excretion are estimated to be 10% (expert judgement).

Uncertainties in mineralization/immobilization are estimated at 150% (expert judgement).

Uncertainties in manure management systems are described in section 4.2.2 and shown in Table 4.3.

Uncertainty in emission factor of the animal house is 40% (expert judgement). This estimate is for an emission factor of one housing system in kg NH_3 per animal. This estimate is used for the average emission factor over all housing systems based on TAN. This aggregation method is used to include dependencies as described in section 2.2. Some housing systems are based on the same emission measurement.

5.2.4 Uncertainty

For the calculation of the overall uncertainty the uncertainty in TAN excretion per aggregated livestock category per manure type is calculated first. Then these uncertainties are multiplied by the uncertainty of the NH_3 emission factor of the animal house. This method is chosen because emission factors of housing systems of the different livestock subcategories are the same and as such dependent.

Table 5.1 presents an overview of the uncertainties in the calculation of NH_3 from manure management.

***Table 5.1** Uncertainties (U, %) in TAN excretion, implied emission factors (IEF) and emissions*

Livestock category	U livestock numbers	U total TAN excretion slurry	U total TAN excretion solid	U IEF	U emission
Dairy cows	2%	10%	42%	41%	41%
Young stock for breeding	1%	8%	26%	36%	36%
Fattening calves	1%	9%		41%	41%

Livestock category	U livestock numbers	U total TAN excretion slurry	U total TAN excretion solid	U IEF	U emission
Young stock for meat production	1%	7%	17%	30%	30%
Suckling cows	2%	15%	35%	35%	35%
Sheep (ewes)	5%		73%	88%	88%
Dairy goats (> 1 year)	5%		42%	60%	60%
Horses and ponies (agriculture)	4%		40%	58%	59%
Mules and asses	5%		55%	71%	72%
Fattening pigs	10%	18%		43%	44%
Breeding pigs	4%	15%	37%	42%	42%
Laying hens	4%		10%	41%	42%
Broilers	10%		26%	48%	49%
Ducks	10%		20%	45%	46%
Turkeys	10%		19%	44%	45%
Rabbits and minks	5%	16%	29%	33%	33%
Total					19%

5.3 Source-specific aspects for NH_3 emissions from outside manure storages

5.3.1 Calculation method

Part of the manure is stored in outside manure storages on the farm. From the initial TAN excreted by livestock (including mineralization), total gaseous N losses in the animal house are subtracted. These losses occur as NH_3, NO_x, N_2O and N_2. After multiplication by the fraction of manure stored, the TAN input into outside storages is established.

The total NH_3 emission from outside manure storages in a given year is calculated from:

- TAN input (urine N excretion and net N mineralization in the animal house, minus total N losses in the animal house);
- Emission factors for NH_3 for outside manure storages per livestock category and manure management system (slurry or solid), expressed in percentage of the TAN input. In this emission factor the transfer of manure from the animal house to the outside storage is accounted for.

The NH_3 emission from outside manure storages for livestock category (i) is calculated as:

$$NH_3 \text{ manure storage}_i = \Sigma \text{ (TAN input}_{ij} \text{ - N losses animal house}_{ij}) \text{ x fraction storage}_{ij} \text{ x EF } NH_3\text{-N storage}_{ij} \text{ x } 17/14 \qquad (5.4)$$

In which

NH_3 manure storage$_i$: NH_3 emission (kg NH_3/year) from outside manure storages for livestock category (i)

N losses animal house$_{ij}$: Sum of NH_3-N, N_2O-N, NO_x-N and N_2-N losses (kg N/year) from animal houses for livestock category (i) and manure management system (j)

fraction storage$_{ij}$: Fraction of manure stored outside for livestock category (i) and manure management system (j)

EF NH_3-N storage$_{ij}$: NH_3 emission factor (% of TAN) for outside storages of livestock category (i) and manure management system (j)

17/14 : Conversion factor from NH_3-N to NH_3 based on molecular weight

Total N losses from animal houses for livestock category (i) and manure management system (j) are calculated as:

$$\text{N losses animal house}_{ij} = NH_3\text{-N animal house}_{ij} + N_2O\text{-N animal house}_{ij} + NO_x\text{-N animal house}_{ij} + N_2\text{-N animal house}_{ij}) \qquad (5.5)$$

In which
N_2O-N/NO_x-N/N_2-N animal house$_{ij}$: Nitrous oxide/nitrogen oxides/nitrogen gas emission factor (% of TAN) for animal housing of livestock category (i) and manure management system (j)

For the calculation of these emissions, see Chapters 6 (NO_x) and 7 (N_2O). Losses as N_2 are not reported, but only calculated for calculation of the TAN flow.

5.3.2 Activity data

For the calculation of the manure storage emissions, the TAN excretion as described in section 5.2 is used. However, for reporting livestock numbers are the activity data (section 5.3).

Uncertainty in activity data for NH_3 outside manure storage
Uncertainties in TAN excretion are described in the previous section.

Livestock numbers and their uncertainty are described in section 2.3.

5.3.3 Emission factors

Emissions for N_2O, NO_x, and N_2
The calculation method of the emissions of N_2O and NO_x are described in Chapters 6 and 7. N_2 emissions are 10 times larger than N_2O-N emission for slurry manure and 5 times larger for solid manure (Oenema *et al.*, 2000).

Fraction of the manure stored outside
Information on the fractions of manure stored outside the animal house, are taken from the Agricultural census complemented with data taken from literature. Annex 9 gives an overview of the percentages and sources.

Emission factor
The emission factors used for the calculation of ammonia emissions are described in Annex 9 (Table A9.3).

Uncertainty in NH_3 emission factor outside manure storage
Uncertainties in total N losses is estimated and assumed to be 100% (expert judgement). The total uncertainty is estimated because only uncertainties in N_2O, NO_x and NH_3 animal house emissions are calculated but not the N_2 uncertainties.

Outside storage of slurry depends on storage capacity in relation to manure production. Storage capacity is asked in the Agricultural census. Uncertainties in storage fraction depend on manure production, the response of farmers on the question in the Agricultural census and the use of this outside storage. Uncertainty is estimated to be 25% for slurry (expert judgement). For all solid manures that are exported or burned, the uncertainty for outside storage is estimated at 50%.

The uncertainty in emission factor of the outside storage of slurry is estimated to be 200%. The emission factor is based on a limited amount of old data (expert judgement). From data in Koerkamp and Kroodsma (2000) the uncertainty for outside storage of solid manure of broilers can be calculated to be 35%. Assumption is made that other solid poultry manure has the same uncertainty (expert judgement).

5.3.4 Uncertainty

The uncertainty estimates concerning the data sources and emission factors used and the total uncertainty estimate for NH_3 from manure management are listed in Table 5.2.

Table 5.2 *Uncertainties in livestock numbers (AD), implied emission factors (IEF) and emissions from manure storage*

Livestock category	U AD	U IEF	U emission
Dairy cows	2%	181%	181%
Young stock for breeding	1%	169%	169%
Young stock for meat production	1%	206%	206%
Suckling cows	2%	201%	202%
Sheep (ewes)	5%	269%	269%
Dairy goats (> 1 year)	5%	245%	245%
Horses and ponies (agriculture)	4%	244%	244%
Mules and asses	5%	254%	254%
Fattening pigs	10%	208%	210%
Breeding pigs	4%	186%	186%
Laying hens	4%	65%	65%
Broilers	10%	69%	69%
Ducks	10%	67%	67%
Turkeys	10%	67%	67%
Rabbits and minks	5%	176%	176%
Total			50%

5.4 Combined emissions and uncertainties

NEMA calculates emissions from animal houses and outside manure storages separately, to account for the differences in circumstances and thus emissions therein. Output of the model is at the level of detail shown in Tables 5.1 and 5.2, available through www.prtr.nl.

Aggregation of emissions for reporting
For the respective livestock categories distinguished in the NFR, emissions from animal housing and outside storage are added up to arrive at total NH_3 emission from manure management.

Aggregation of uncertainties for NH_3 animal houses and outside manure storage
Uncertainties calculated for emissions from animal houses and outside manure storages, are aggregated up to the NFR categories as shown in Table 5.3.

Table 5.3 *Uncertainties in NH_3 emission from manure management, activity data (livestock numbers) and implied emission factors*

EMEP	Livestock category	U AD	U IEF	U emission
3B1a	Dairy cattle	2%	45%	45%
3B1b	Non-dairy cattle	1%	29%	29%
3B2	Sheep	5%	106%	106%
3B3	Swine	8%	37%	38%
3B4d	Goats	5%	89%	89%
3B4e	Horses	4%	83%	83%
3B4f	Mules and asses	5%	88%	88%
3B4gi	Laying hens	4%	46%	46%
3B4gii	Broilers	10%	49%	50%
3B4giii	Turkeys	10%	44%	45%
3B4giv	Other poultry	10%	46%	47%
3B4h	Other animals	5%	47%	47%
	Total			20%

6 NO_x emissions from manure management (NFR category 3B)

6.1 Scope and definition

This chapter describes the methods and working processes for determining NO_x emissions from manure management, using the following NFR categories:

- 3B1a Dairy cattle
- 3B1b Non-dairy cattle
- 3B2 Sheep
- 3B3 Swine
- 3B4d Goats
- 3B4e Horses
- 3B4f Mules and asses
- 3B4gi Laying hens
- 3B4gii Broilers
- 3B4giii Turkeys
- 3B4giv Other poultry
- 3B4h Other animals

The category 3B4a (Buffalo) is reported as Not Occurring (NO), because these animals are not kept commercially in the Netherlands. Category 3B4h Other animals consists of fur-bearing animals and rabbits. Emissions reported under category 3B concern only the NO_x emissions from manure produced in animal houses, and then stored temporarily and/or processed before being transported elsewhere. The NO_x emissions resulting from manure production on pasture land are reported under category 3D (NO_x emissions from soil).

NO_x emissions from livestock manure management depend on the nitrogen and carbon content of the manure, the amount of time the manure is stored and the treatment method used. During storage the manure often becomes low-oxygen, which slows the nitrification process and therefore denitrification remains low.

Nitrification is the process whereby, under high-oxygen circumstances, ammonia (NH_4^+) is converted into nitrate by bacteria. NO_x can be formed as a by-product, particularly if the nitrification is limited through lack of oxygen. Nitrification does not require any organic substances (volatile solids) to be present. Straw-rich solid manure and poultry manure can possess a relatively open and loose structure, where O_2 can diffuse far more easily than in slurry, enabling nitrification.

Denitrification is the process whereby, under low-oxygen circumstances, bacteria can convert nitrate (NO_3^-) into the gaseous nitrogen compound N_2, with NO_x as a by-product. Organic substances (volatile solids) are used as an energy source. Denitrification in animal houses and manure storages is fully depending on the nitrification process, which has to supply the oxidized nitrogen compounds.

Although emissions are reported as NO (nitrogen monoxide) by NEMA, it is referred to as NO_x in this report to prevent confusion with the notation key NO (not occurring).

6.2 Source-specific aspects

6.2.1 Calculation method

NO_x emissions from animal manure are calculated as follows:

$$NO_x \text{ emissions 3B} = \sum [\text{ number of animals in livestock category (i) }] \times [\text{ fraction manure management system (j) }] \times \text{N excretion}_i \times \text{EF } NO_x \text{ 3B}_{ij} \times 30/14 \quad (6.1)$$

In which

NO_x emissions 3B	: NO_x emissions (kg NO_x, expressed as nitrogen monoxide) for all livestock categories (i) within NFR category 3B manure management
N excretion$_i$	: N excretion (kg N/animal) for livestock category (i)
EF NO_x 3B$_{ij}$	: Emission factor (kg NO_x-N/kg N excreted in the animal house) for livestock category (i) and manure management system (j)
30/14	: Conversion factor from kg NO_x-N to kg NO_x, expressed as nitrogen monoxide

Contrary to NH_3 from animal housing and outside manure storage, emissions of NO_x are calculated for animal housings and outside manure storages combined.

6.2.2 Activity data

Livestock numbers are the activity data for this emission source. Livestock numbers and their uncertainty are described in section 2.3.

Uncertainties in activity data for NO_x from manure management
The uncertainty in livestock numbers, including (dis-)aggregation of subcategories, is given in section 2.3.

6.2.3 Emission factors

Nitrogen excretion per animal and manure management system
N excretion and uncertainties are described in section 2.4.

Emission factors
The NEMA model uses the emission factors in following Table 6.1, NO_x emission factors are the same as N_2O emission factors (Oenema *et al.,* 2000).

Table 6.1 *Emission factors for NO_x from manure management*

Manure management system	Emission factors in kg NO_x-N/kg N manure excreted in the animal house
Slurry	0.002
Solid manure	0.005
Poultry slurry	0.001
Solid poultry manure	0.001
Goats deep bedding	0.01

Sources: Oenema *et al.* (2000) based on IPCC (2006).

Uncertainty in emission factor for NO_x manure management
Uncertainties in nitrogen excretion are described in Chapter 2. Uncertainties in manure management system are described in Chapter 4.

Uncertainties in emission factors are estimated to be 200%.

6.2.4 Uncertainty

The uncertainty estimates concerning the data sources and emission factors used and the total uncertainty estimate for NO_x from manure management are listed in Table 6.2.

Table 6.2 *Uncertainties NO_x manure management*

EMEP	Livestock category	U AD	U IEF	U emission
3B1a	Dairy cows	2%	200%	200%
3B1b	Non-dairy cattle	1%	140%	140%
3B2	Sheep	5%	222%	222%
3B3	Swine	7%	151%	151%
3B4d	Goats	5%	203%	203%
3B4e	Horses	36%	222%	225%
3B4f	Mules and asses	5%	200%	200%
3B4gi	Laying hens	4%	201%	201%
3B4gii	Broilers	10%	200%	200%
3B4giii	Turkeys	10%	203%	203%
3B4giv	Other poultry	10%	204%	204%
3B4h	Other animals	5%	201%	202%
	Total			92%

7 N_2O emissions from manure management (CRF sector 3B)

7.1 Scope and definition

This chapter describes the methods and working processes for determining N_2O emissions from manure management. In the CRF the following source categories are distinguished:

- Direct emissions
  - 3B1a Mature dairy cattle
  - 3B1b Other mature cattle
  - 3B1c Growing cattle
  - 3B2 Sheep
  - 3B3 Swine
  - 3B4 Other livestock
- Indirect emissions
  - 3B5 Indirect N_2O emissions

The source categories 3B4 Other livestock consists of poultry, goats, horses, mules and asses, fur-bearing animals and rabbits.

Emissions reported under category 3B concern only the N_2O emissions from manure produced in animal houses, and then stored temporarily and/or processed before being transported elsewhere. The nitrous oxide resulting from manure production on pasture land is reported under category 3D (Chapter 11; N_2O emissions from crop production and agricultural soils).

Nitrous oxide emissions from livestock manure management depend on the nitrogen and carbon content of the manure, the amount of time the manure is stored and the treatment method used. During storage the manure often becomes low-oxygen, which slows the nitrification process and therefore denitrification remains low.

Nitrification is the process whereby, under high-oxygen circumstances, ammonia (NH_4^+) is converted by bacteria into nitrate. Nitrous oxide can be formed as a by-product, particularly if the nitrification is limited through lack of oxygen. Nitrification does not require any organic substances (volatile solids) to be present. Straw-rich solid manure and poultry manure can possess a relatively open and loose structure, where O_2 can diffuse far more easily than in slurry, enabling nitrification.

Denitrification is the process whereby, under low-oxygen circumstances, bacteria can convert nitrate (NO_3^-) into the gaseous nitrogen compound N_2, with N_2O as a by-product. Organic substances (volatile solids) are used as an energy source. Denitrification in animal houses and manure storages is fully depending on the nitrification process, which has to supply the oxidized nitrogen compounds.

N_2O emissions from solid manure are higher than those from slurry, because there is very little nitrification in the latter due to the lack of oxygen.

7.2 Source-specific aspects for direct N_2O emissions from manure management

7.2.1 Calculation method

Direct N_2O emissions from animal manure are calculated as follows:

$$N_2O \text{ emission direct} = \sum [\text{ number of animals in livestock category (i) }] \times \text{N excretion}_i \times [\text{ fraction manure management system (j) }] \times \text{EF } N_2O \text{ direct } 3B_j \times 44/28 \quad (7.1)$$

In which

N excretion$_i$	: N excretion (kg N/animal) of livestock category (i)
EF N_2O direct 3B$_j$	: Emission factor for manure management system (j) in kg N_2O-N/kg N excreted manure
44/28	: Conversion factor from kg N_2O-N to kg N_2O

Comparison to IPCC methodology

The aforementioned method complies with that described by the IPCC (IPCC, 2006; p. 10.52). Therefore the total amount of manure produced is multiplied by an emission factor, without subtracting NH_3 and NO_x emissions.

Default (Tier 1) values are used for the emission factors.

7.2.2 Activity data

Livestock numbers and N excretion are the activity data for this emission source. Livestock numbers and their uncertainty are described in section 2.3. N excretion and uncertainties are described in section 2.4.

Uncertainties in activity data for N_2O from manure management

The uncertainty in livestock numbers, including (dis-)aggregation of subcategories, is given in section 2.3.

7.2.3 Emission factors direct N_2O emissions from manure management

The NEMA model uses the default IPCC 2006 emission factors, in following Table 7.1. It has been examined whether better emission factors for N_2O from manure management are available in the Netherlands. Based on this study it is concluded that only few data is available on emissions of N_2O, NO_x and N_2 from animal houses and outside manure storages, and that as a result the uncertainties on emission factors for N_2O, NO_x and N_2 are large. Because of the large uncertainties, it was decided to maintain the current methodology based on the IPCC Guidelines and Oenema *et al.* (2000), however the measurements indicated that for slurry in the Dutch situation (largely without litter) the IPCC 2006 default values are rather high.

Table 7.1 *Emission factors for N_2O from manure management*

Manure management system	Emission factors in kg N_2O-N/kg N manure excreted in the animal house
Slurry	0.002
Solid manure	0.005
Poultry slurry	0.001
Solid poultry manure	0.001
Goats deep bedding	0.01

Source: IPCC (2006).

Uncertainty in emission factors for direct N_2O emissions from manure management

The uncertainty in the emission factors is 200% (IPCC, 2006).

7.2.4 Uncertainty

Because there are several livestock categories to add up to the total emissions from slurry and solid manure, the uncertainty becomes 153% for slurry and 101% for solid manure.

Table 7.2 *Uncertainties in direct N_2O emissions from manure management*

CRF	Manure type	U N excretion	U IEF	U emission
3B1-4	Slurry	3%	153%	153%
3B1-4	Solid	8%	101%	101%
	Total			115%

7.3 Source-specific aspects for indirect N_2O emissions from manure management

7.3.1 Calculation method

Indirect nitrous oxide emission from manure management are calculated by multiplying total NH_3 and NO_x emissions from animal housing and NH_3 from manure storage with an emission factor:

$$N_2O \text{ emission indirect} = (NH_3 \text{ emissions 3B} \times 14/17 + NO_x \text{ emissions 3B} \times 14/30) \times EF\ N_2O \text{ indirect 3B} \times 44/28 \qquad (7.2)$$

In which

N_2O emission indirect	: Indirect nitrous oxide emission (kg N_2O-N/year) following atmospheric deposition of NH_3 and NO_x from manure management
NH_3 emissions 3B	: NH_3 emission (kg NH_3/year) for all defined livestock categories (i) within NFR category 3B manure management
14/17	: Conversion factor from NH_3 to NH_3-N
NO_x emissions 3B	: NO_x emissions (kg NO_x/year, expressed as nitrogen monoxide) for all defined livestock categories (i) within NFR category 3B manure management
14/30	: Conversion factor from NO_x (expressed as nitrogen monoxide) to NO_x-N
EF N_2O indirect 3B	: Nitrous oxide emission factor for indirect emission following atmospheric deposition of NH_3 and NO_x
44/28	: Conversion factor from kg N_2O-N to kg N_2O

Comparison to IPCC methodology
For indirect emissions only atmospheric deposition is mentioned. The IPCC Guidelines also calculate leaching and runoff. In the Netherlands all slurry manure is stored underneath animal houses or in fully closed outside storage tanks (this is an obligation of the EU Nitrates Directive). Solid manure has to be stored on concrete plates with runoff directed into a slurry pit or separate tank.

7.3.2 Activity data

Calculation of NH_3 and NO_x emissions are described in Chapters 5 and 6.

Uncertainty in activity data for indirect N_2O emissions from manure management
Uncertainty in total NH_3 and NO_x emission from manure management is 34%. This is based on uncertainties calculated in Chapter 5 and 6.

7.3.3 Emission factors

The IPCC 2006 default EF of 0.01 kg N_2O-N/kg N emitted as NH_3 and NO_x from animal houses and outside manure storages is used.

Uncertainty in emission factor for indirect N_2O emissions from manure management
The uncertainty in this emission factor is 400% (IPCC, 2006).

7.3.4 Uncertainty

The uncertainty estimates concerning the data sources and emission factors used and the total uncertainty estimate for indirect N_2O emissions from manure management are listed in Table 7.3.

Table 7.3 *Uncertainty in indirect N_2O emissions from manure management*

CRF	Category	U AD	U IEF	U emission
3B5	NH_3 and NO_x emissions animal house and storage	34%	400%	424%

7.4 Combined emissions and uncertainties

Aggregation of uncertainties for direct and indirect N_2O emissions from manure management

Uncertainties calculated for direct and indirect emissions are aggregated up to the total uncertainty in N_2O emissions from manure management of 159%.

8 $PM_{10/2.5}$ emissions from animal housing (NFR category 3B)

8.1 Scope and definition

This chapter describes the methods and working processes for determining PM_{10} and $PM_{2.5}$ (particulate matter smaller than 10 μm and smaller than 2.5 μm) emissions from animal housing, using the following NFR categories:

- 3B1a Dairy cattle
- 3B1b Non-dairy cattle
- 3B2 Sheep
- 3B3 Swine
- 3B4d Goats
- 3B4e Horses
- 3B4f Mules and asses
- 3B4gi Laying hens
- 3B4gii Broilers
- 3B4giii Turkeys
- 3B4giv Other poultry
- 3B4h Other animals

The category 3B4a (Buffalo) is reported as Not Occurring (NO), because these animals are not kept commercially in the Netherlands. Categories 3B4h Other animals consists of fur-bearing animals and rabbits.

Particulate matter emissions from agriculture mainly originate from animal houses, and consist of skin, manure, feed, and bedding particles. Poultry is the main source category of PM_{10} and $PM_{2.5}$ in agriculture. Slurry-based housing systems for laying hens have been replaced by systems that produce solid manure, which leads to higher emissions of PM. Pigs and cattle also contribute to the production of PM but to a smaller extent. With more housing systems for pigs using air scrubbers, the emission of PM decreases.

8.2 Source-specific aspects

8.2.1 Calculation method

Shares of housing systems are derived from the Agricultural census. The emissions are calculated as the product of the number of animals per housing system with corresponding emission factors for PM_{10} and $PM_{2.5}$ in grams per animal per year.

$$\text{PM emissions 3B} = \sum [\text{ number of animals per livestock category (i) }] \times [\text{ fraction animal housing system (k) }] \times \text{EF PM 3B}_{ik} / 1{,}000 \quad (8.1)$$

In which

PM emissions 3B	: PM emissions (kg PM_{10} or $PM_{2.5}$/year) for all livestock categories (i) and housing systems (k) within NFR category 3B manure management
EF PM $3B_{ik}$	: Emission factor (g PM_{10} or $PM_{2.5}$/year) for livestock category (i) and animal housing system (k)
1,000	: Conversion factor from grams to kilograms

8.2.2 Activity data

Livestock numbers are the activity data for this emission source. Livestock numbers and their uncertainty are described in section 2.3.

The shares of housing systems per livestock category
The shares of housing systems per livestock category are based on the Agricultural census. If for certain categories not enough information is available, other sources can be used like permit files of local authorities.

Research by an enforcement agency (Handhavingsamenwerking Noord-Brabant (2010, 2013)) showed that many of the air scrubbers were not properly used, implementation grades were therefore corrected: in the years up and including 2009 it was assumed that 40% of the scrubbers did not function, decreasing by 8% a year to 16% in 2012. From then on a decrease of 4% per year was assumed until in 2016 all scrubbers were assumed to operate properly because then equipment with electronic monitoring was compulsory.

Uncertainty in activity data for PM emissions from manure management
The uncertainty in livestock numbers, including (dis-)aggregation of subcategories, is given in section 2.3.

Uncertainty in the shares of housing systems is estimated to be 10%.

8.2.3 Emission factors

The emission factors are based on a measurement program conducted by Wageningen UR Livestock Research between 2007 and 2009 (publication series ‘Particulate matter emission from animal houses’, in Dutch; Mosquera *et al.*, 2009a, 2009b, 2009c, 2010a, 2010b, 2010c and 2011 and Winkel *et al.*, 2009a, 2009b, 2010 and 2011).

Not of all livestock categories PM emissions from housing were measured. When not measured, EFs were deduced from measured factors of similar livestock categories, using ratios of fixed P excretion (Chardon and Van der Hoek, 2002) as a scale factor.

Table 8.1 gives an overview of traditional housing systems and emission factors of PM_{10} and $PM_{2.5}$.

Several techniques have been developed to reduce PM emissions. Air scrubbers are the most common. Air scrubbers cause the following reductions of emissions of $PM_{2.5}$ as well as PM_{10} based on measurements (Mosquera *et al.*, 2011):

- Chemical air scrubber: 35%
- Biological air scrubber with short retention time: 60%
- Biological air scrubber with long retention time: 75%
- Combined air scrubber: 80%

Table 8.1 *Emission factors for PM_{10} and $PM_{2.5}$ from animal housing (g/animal/year; Traditional systems do not have PM emission reduction but can have emission reduction for other substances. Calculated emission factors for air scrubbers per livestock category are not mentioned)*

Livestock category	Housing system	PM_{10}	$PM_{2.5}$
Dairy cattle			
Female young stock under 1 year	Traditional	37.7	10.4
Male young stock under 1 year	Traditional	170.1	46.8
Female young stock, 1-2 years	Traditional	37.7	10.4
Male young stock, 1-2 years	Traditional	170.1	46.8
Female young stock, 2 years and over	Traditional	117.8	32.5
Cows in milk and in calf	Tie-stall system	80.8	22.3
	Cubicle system, grazing$^{1)}$	117.8	32.5
	Cubicle system, no grazing$^{1)}$	147.5	40.6
Bulls for service 2 years and over	Traditional	170.1	46.8

Livestock category	Housing system	PM_{10}	$PM_{2.5}$
Cattle for fattening			
Calves, for white veal production	Traditional[2)]	35.7	9.8
Calves, for rosé veal production	Traditional[2)]	35.7	9.8
Female young stock under 1 year	Traditional	37.7	10.4
Male young stock (incl. young bullocks) under 1 year	Traditional	170.1	46.8
Female young stock, 1-2 years	Traditional	37.7	10.4
Male young stock (incl. young bullocks), 1-2 years	Traditional	170.1	46.8
Female young stock, 2 years and over	Traditional	86.2	23.8
Male young stock (incl. young bullocks), 2 years and over	Traditional	170.1	46.8
Suckling cows (incl. fattening/grazing), 2 years and over	Traditional	86.2	23.8
Pigs			
Piglets	Traditional partially raster[1), 2)]	81.2	2.0
	Traditional fully raster[1), 2)]	62.0	2.1
Fattening pigs and growing pigs	Traditional[1), 2)]	157.3	7.4
Sows, pregnant and dry	Traditional, individual[1), 2)]	186.3	16.0
	Traditional, group[1), 2)]	173.7	12.1
Sows with piglets	Traditional[2)]	164.9	14.2
Boars for service	Traditional[2)]	185.6	15.9
Poultry			
Broilers	Traditional[1), 2), 4)]	26.8	2.0
Broilers parents under 18 weeks	Floor housing[3)]	17.0	1.3
Broilers parents 18 weeks and over	Cage housing	8.7	1.8
	Floor housing + aviary[1), 2), 4)]	49.1	3.8
Laying hens under 18 weeks	Battery[3), 5)]	2.2	0.4
	Colony housing	9.6	0.9
	Floor housing[2), 4)]	34.8	1.7
	Aviary housing	26.9	1.6
Laying hens 18 weeks and over	Battery[3), 5)]	5.4	1.1
	Enriched cage/colony housing	24.0	2.3
	Floor housing[1), 2), 4)]	87.1	4.2
	Aviary housing[1)]	67.3	4.0
Ducks for slaughter	Traditional	104.5	5.0
Turkeys for slaughter	Traditional[1)]	95.1	44.6
Turkeys parents under 7 months	Traditional	177.0	83.0
Turkeys parents 7 months and over	Traditional	240.8	112.9
Rabbits (mother animals)	Traditional	10.7	2.1
Minks (mother animals)	Traditional[1)]	8.1	4.2
Foxes (mother animals)	Traditional		
Goats	Traditional	19.0	5.7
Horses[6)]	Traditional	220.0	140.0
Ponies[6)]	Traditional	220.0	140.0
Mules and asses[6)]	Traditional	160.0	100.0

[1)] Source: Wageningen UR Livestock Research measurements.
[2)] Air scrubbers available.
[3)] Chemical air scrubbers available.
[4)] Additional emission reducing techniques available, see Table 8.2.
[5)] Prohibited since 2013.
[6)] Default emission factors from the EMEP Guidebook (EEA, 2016).

Source: Wageningen UR Livestock Research.

For poultry also additional emission reducing techniques have been developed. Table 8.2 gives the average emission factors calculated with the specific reduction percentages of the different techniques and the implementation of the technique.

Table 8.2 *Emission factors for PM_{10} and $PM_{2.5}$ for poultry housing with additional emission reducing techniques (g/animal/year)*

Poultry		2011-2014	2015	2016
Broilers	PM_{10}	23.1	20.9	19.6
	$PM_{2.5}$	1.7	1.6	1.5
Broilers parents 18 weeks and over	PM_{10}		38.0	33.9
	$PM_{2.5}$		2.9	2,6
Laying hens under 18 weeks	PM_{10}		19.8	20.2
	$PM_{2.5}$		1.2	1.2
Laying hens 18 weeks and over	PM_{10}		50.5	50.8
	$PM_{2.5}$		3.0	3.0

Uncertainty in emission factors for PM from manure management

Uncertainties of the measured emission factors are also published in publication series 'Particulate matter emission from animal houses' and shown in Table 8.3.

Table 8.3 *Uncertainty estimation emission factors PM_{10} and $PM_{2.5}$ manure management*

Livestock category	Uncertainty PM_{10}	Uncertainty $PM_{2.5}$	Source
Dairy cows	32%	35%	Largest uncertainty[1] in Particulate matter emission from animal houses: dairy cows (Mosquera *et al.*, 2010c) (47.4 x 100% / 147.5 = 32%)
Other cattle	32%	35%	Equal to dairy cows
Goats	32%	35%	Equal to dairy cows
Fattening pigs	45%	55%	Largest uncertainty in Particulate matter emission from animal houses: fattening pigs (Mosquera *et al.*, 2010a) (65.4 x 100% / 144.0 = 45%)
Sows	48%	52%	Largest uncertainty in Particulate matter emission from animal houses: gestating sows (Mosquera *et al.*, 2010b and Winkel *et al.*, 2010) (82.6 x 100% / 173.7 = 48%)
Laying hens	44%	100%	Largest uncertainty in Particulate matter emission from animal houses: laying hens in animal houses with a drying tunnel (Winkel *et al.*, 2009b and 2011 and Mosquera *et al.*, 2009a and 2009c) (1.7 x 100% / 3.9 = 44%)
Broilers	33%	45%	Largest uncertainty in Particulate matter emission from animal houses: broilers (Winkel *et al.*, 2009a) (8.8 x 100% / 26.8 = 33%)
Ducks	33%	45%	Equal to broilers
Turkeys	33%	45%	Equal to broilers
Rabbits	49%	100%	Largest uncertainty in Gaseous emissions and particulate matter from rabbit animal houses with manure storage under the welfare cages (Huis in 't Veld *et al.*, 2011) and report minks (Mosquera *et al.*, 2011) (5.21 x 100% / 10.7 = 49%)
Fur-bearing animals	49%	1000%	Used rabbit uncertainty

[1] In line with EMEP (2006) the largest uncertainty is chosen.

8.2.4 Uncertainty

Uncertainties in activity data, implied emission factors and resulting emissions of PM_{10} and $PM_{2.5}$ are shown in Table 8.4.

For the calculation of the emissions more livestock categories than shown in Table 8.4 and several housing systems (Table 8.1 and 8.2) are used. These livestock categories (for instance female young cattle < 1 yr and 1-2 yrs) have been aggregated in the uncertainty analysis so that associated uncertainty is considered only once. The same applies for the uncertainty in emission factor of the housing systems. Air scrubbers have emission factors dependent on the traditional system. Uncertainty is calculated with only one category instead of two.

The uncertainty in share of housing system is included in the implied emission factor. Multiplying these uncertainties and the chosen aggregation (based on expert judgement) implied emission factors as shown in Table 8.4 are calculated.

Table 8.4 *Uncertainty in PM_{10} and $PM_{2.5}$ emissions, activity data and implied emission factors (IEF) from animal houses*

NFR	Livestock category	U AD	U IEF PM_{10}	U emission PM_{10}	U IEF $PM_{2.5}$	U emission $PM_{2.5}$
3B1a	Dairy cows	2%	24%	24%	26%	26%
3B1b	Non-dairy cattle	1%	15%	15%	17%	17%
3B3	Swine	7%	26%	27%	30%	31%
3B4d	Goats	5%	32%	32%	35%	35%
3B4e	Horses	4%	40%	40%	40%	40%
3B4f	Mules and asses	5%	40%	40%	40%	40%
3B4gi	Laying hens	4%	36%	37%	79%	79%
3B4gii	Broilers	10%	32%	34%	43%	44%
3B4giii	Turkeys	10%	33%	35%	45%	46%
3B4giv	Other poultry	10%	33%	35%	45%	46%
3B4h	Other animals	5%	46%	47%	98%	98%
	Total			21%		31%

9 NH_3 emissions from crop production and agricultural soils (NFR category 3D)

9.1 Scope and definition

This chapter describes the method and working processes for determining NH_3 emissions from crop production and agricultural soils, using the following NFR categories:

- 3Da1 Inorganic N fertilizers (includes also urea application)
- 3Da2a Livestock manure applied to soils
- 3Da2b Sewage sludge applied to soils
- 3Da2c Other organic fertilizers applied to soils (including compost)
- 3Da3 Urine and dung deposited by grazing animals
- 3Da4 Crop residues left behind on soils
- 3De Cultivated crops

NH_3 emissions occur in all subcategories describing N inputs to the soil (i.e. 3Da1 up to 3Da4), and during crop cultivation (3De). Category 3Da2a Livestock manure applied to soils is referred to as animal manure applied to soil, because the IPCC Guidelines use the term animal manure. One term has been chosen to be consistent in this report. The Subcategory 3F Field burning of agricultural residues is reported as Not Occurring (NO) since field burning is prohibited in the Netherlands during the whole time series (article 10.2 of the Environmental Management Act, or 'Wet Milieubeheer' in Dutch). In the categories 3Df Use of pesticides and 3I Agriculture other, no NH_3 emissions occur either.

For all distinguished source categories, a calculation method is available within the National Emission Model for Agriculture (NEMA). The amount of TAN in animal manure available for application, follows from the TAN excretion minus N emissions, in animal houses and during manure storage, and minus exported N, using a balance method to model N flows in agriculture. Also TAN excreted on pasture land during grazing is part of this scheme. The other N supply sources (e.g. inorganic N fertilizer, sewage sludge, compost and crop residues) are in the flow model as well.

The amount of TAN and organic N that remains in manure from animal houses and after outside storage, is applied to the soil. It is assumed that manure stocks in storage remain equal, so no correction is made for manure stored longer than 1 year. The amount of TAN in manure applied to soil is calculated from:

- Total N (urine N and fecal N) excretion in the animal house;
- Mineralization/immobilization of organic N in storage;
- Losses of NH_3, N_2O, NO_x and N_2 inside the animal house and during outside storage;
- Amount of manure that is incinerated, exported or processed and subsequently used outside agriculture;
- Manure used outside agriculture but in the Netherlands (hobby farming and application on nature areas).

Manure can also be applied to soils directly via grazing animals. Emissions during grazing are calculated directly from TAN. Besides manure application and grazing, the application of inorganic N fertilizer (including rinsing liquid of air scrubbers) to agricultural soils is a source of emission of NH_3. NH_3 emission from fertilizer occurs only if the fertilizer contains urea, or when ammonium (NH_4^+) is applied to calcareous soils.

9.2 Source-specific aspects for NH_3 emission from inorganic N fertilizer application

9.2.1 Calculation method

Inorganic N fertilizer includes synthetic fertilizer, urea and rinsing liquid. The NH_3 emission from inorganic N fertilizer is calculated from:
- Amount of N applied per type of inorganic N fertilizer;
- Amount of N applied from rinsing liquid;
- Emission factor per type and application technique of inorganic N fertilizer (section 9.2.3);
- Emission factor rinsing liquid.

NH_3 emissions from inorganic N fertilizer application are calculated as follows.

$$NH_3\ fertilizer = \sum EF\ NH_3\ fertilizer_l \times N\ fertilizer_l \times 17/14 \qquad (9.1)$$

In which
NH_3 fertilizer : NH_3 emission (kg NH_3/year) from inorganic N fertilizers
EF NH_3 $fertilizer_l$: NH_3 emission factor of inorganic N fertilizer (l) in % of the applied N
N $fertilizer_l$: Total amount applied inorganic N fertilizer (l) in kg N
17/14 : Conversion factor from NH_3-N to NH_3

9.2.2 Activity data

The usage of the different types of inorganic N fertilizers is taken from the synthetic fertilizer statistics of Wageningen Economic Research. Amount of rinsing liquid produced by air scrubbers, as calculated by NEMA, is also taken into consideration.

Uncertainty in activity data for NH_3 emission from inorganic N fertilizer application
For the uncertainty analyses only the total amount of fertilizer is used. This is decided because every separate category will have a higher uncertainty, but aggregating several categories gives a lower uncertainty. Estimating the uncertainty on a higher level is more robust and will give the same uncertainty as when estimating for every separate category. Only rinsing liquid is estimated separately. Uncertainties in total amount of applied inorganic fertilizer, excluding rinsing liquid, is estimated to be 25%. The Netherlands has two different statistics and the largest difference in the two statistics was 25%, differing over the years. A small part of the fertilizer is used outside agriculture. Disaggregating uncertainties in use of inorganic fertilizer for agriculture and private use gives an uncertainty for the use of inorganic fertilizer in agriculture of 27%. The uncertainty in use of rinsing liquid is 40%.

9.2.3 Emission factors

NH_3 emission factors for inorganic N fertilizer are based on Bouwman *et al.* (2002). In this review paper the results of 148 studies (1,667 NH_3 measurements) from all over the world are used to quantify the effect of fertilizer type, crop, N addition, application method, temperature, soil characteristics (cation exchange capacity (CEC), pH, organic matter content) and location on NH_3 emission. A regression analysis has been performed (R^2 = 28%) and based on this analysis a calculation model has been developed. For the Netherlands the following data are being used.

Crop
In the calculation model a distinction is made between 'grassland' and 'upland crops'. The areas of grassland, cropland and maize are determined based on soil use maps. Grassland has a factor class value of -0.045 and cropland and maize are considered to be 'upland crops' (factor class value -0.158).

Fertilizer type

Calculation has been performed for the fertilizer types in Bouwman *et al.* (2002), but not all inorganic N fertilizer types used are mentioned. The emission factors have been calculated as follows:

- Ammonium sulphate nitrate; this fertilizer type contains both ammonium nitrate and ammonium sulphate. The emission factor is equal to the average emission factor of ammonium nitrate and ammonium sulphate;
- Nitrogen magnesium; this fertilizer type resembles calcium ammonium nitrate, but contains $MgCO_3$ besides $CaCO_3$ which however does not lead to a different emission factor;
- Chilean nitrate, calcium nitrate and potassium nitrate; these are fertilizer types that only contain nitrate N and no ammonium. As a result no NH_3 emission from the soil can occur, and the emission factor is set to 0%;
- Mixed nitrogen fertilizer; this can be all kinds of fertilizer. The emission factor is set equal to that of the most used fertilizer types in the Netherlands;
- Nitrogen phosphate potassium magnesium fertilizers; these fertilizer types are comparable to nitrogen phosphate potassium fertilizer and emission factor is set to 2%;
- Ammonia water; this fertilizer type is comparable to liquid ammonia;
- Sulphur coated urea; the coating of this fertilizer type leads to lower emission than urea without coating (Oenema and Velthof, 1993). The emission factor is set to half that of urea.

Application method

It is assumed that all inorganic N fertilizers are surface applied, except for a small amount of liquid injected urea and fertilizer applied in greenhouse horticulture.

Soil pH

Bouwman *et al.* (2002) considers four pH-classes, where in the calculation for the Netherlands a distinction is made in lime containing soils and other soils. It is assumed that other soils have a pH < 7.3 and lime containing soils a pH > 7.3. For soils with a pH < 7.3 half is considered to have a pH lower than 5.5 and the other half a pH of 5.5-7.3 (factor class value becoming (-1.072 – 0.9333) / 2 = -1.002). For calcium rich soils pH is considered to be in the 7.3-8.5 range (factor class value = -0.608).

Soil CEC

The cation exchange capacity (CEC) of soil types in the Netherlands varies strongly (from 60 for sea sand to more than 300 for peat and clayish peat; data of Blgg (nowadays Eurofins Agro) in Wageningen, the Netherlands for 2007-2008; Arjan Reijneveld, Blgg personal communication). Average CEC is 70 $mmol_c/kg^{-1}$ for sand, 180 $mmol_c/kg^{-1}$ for clay and loess, and 300 $mmol_c/kg^{-1}$ for peat and reclaimed peat soils. Based on the areas used it is calculated that the average CEC for grassland is 146 $mmol_c/kg^{-1}$ and for cropland 134 $mmol_c/kg^{-1}$. Both for grassland and cropland a factor class value of 0.088 is therefore used.

Climate

The climate in the Netherlands is temperate: factor class value = -0.408.

In Table 9.1 the resulting emission factors used to calculate NH_3 emission from inorganic N fertilizers are given.

Table 9.1 *Emission factors (in % of N) for inorganic N fertilizer, derived using Bouwman et al., 2002*

Fertilizer type	EF used (in % of N)
Ammonium nitrate	5.2
Ammonium sulphate	11.3
Ammonium sulphate nitrate	8.2
Chilean nitrate	0.0
Diammonium phosphate	7.4
Mixed nitrogen fertilizer	2.5
Potassium nitrate	0.0
Calcium ammonium nitrate	2.5
Calcium nitrate	0.0

Fertilizer type	EF used (in % of N)
Monoammonium phosphate	7.4
Other nitrogen, phosphate and potassium fertilizers[1]	4.5
Nitrogen phosphate potassium magnesium fertilizers	2.5
Nitrogen magnesium	2.5
Urea – granular incl. urea with nitrification inhibiter	14.3
Urea – granular with urease inhibitor	5.9
Urea – liquid, surface applied	7.5
Urea – liquid, injected	1.5
Urea – liquid with urease inhibitor or acid, surface applied	3.1
Urea – greenhouse horticulture	0.0
Liquid ammonia	2.3
Sulphur coated urea	7.1

[1] Including nitrogen phosphate and nitrogen potassium fertilizers.

Rinsing liquid

There are no results of ammonia emission from rinsing liquid available. Being a solution of ammonium sulphate, the EF derived for (granular) ammonium sulphate fertilizer derived in Velthof *et al.* (2009) is taken as starting point for the EF of rinsing liquid. On non-calcareous soils, application of ammonium sulphate does not result in ammonia emission because the pH is too low. On calcareous soils the EF is 15%. It is assumed that the emission of rinsing liquid is half of that of granular ammonium sulphate, since it will penetrate the soil and, in addition, is partly applied with low ammonia emission techniques. Taking into account that 76% of agricultural soils in the Netherlands are non-calcareous (Velthof *et al.*, 2009) and assuming a homogeneous distribution of rinsing liquid over soil types, the emission factor becomes 0.76 x 0 + 0.24 x 7.5 = 1.8%.

Uncertainty in emission factors for NH_3 emission from inorganic N fertilizer application

The uncertainty for the fertilizer emission factor is estimated on the average emission factor of the total because this estimate will be more robust. Uncertainty is 25%.

Uncertainty in rinsing liquid EF is estimated to be 100%, like the uncertainties of compost and sewage sludge. The emission factor is not measured for rinsing liquid but deducted, thus an uncertainty of 100% is assumed.

9.2.4 Uncertainty

Table 9.2 presents the uncertainty in inorganic N fertilizer application, implied emission factors and resulting NH_3 emission.

Table 9.2 *Uncertainty in NH_3 emissions, implied emission factors (IEF) and activity data (AD) from inorganic N fertilizer application*

NFR	Source category	U AD	U IEF	U emission
	Inorganic N fertilizer	27%	25%	37%
	Rinsing liquid	40%	100%	115%
3Da1	Total	26%	26%	37%

9.3 Source-specific aspects for NH_3 emission from animal manure applied to soils

9.3.1 Calculation method

The amount of TAN applied with manure is calculated from:

- TAN input in the animal house (the sum of the urine N excretion and the TAN released through mineralization during storage);
- Losses in NH_3 and other N compounds in animal houses and manure storages;
- Amount N in the manure that is processed and marketed outside agriculture (NH_3 emission are calculated separately and reported under sector 6 Other);
- Amount N that is exported or imported through manure (net export);
- It is assumed that the N stock in manure storages does not change from year to year.

The NH_3 emission from manure application is calculated as:

$$NH_3 \text{ manure application} = \sum (\text{TAN applied on grassland}_{ij} \times \text{fraction application technique on grassland}_j \times \text{EF application technique on grassland}_j + \text{TAN applied on uncropped land}_{ij} \times \text{fraction application technique on uncropped land}_j \times \text{EF application technique on uncropped land}_j + \text{TAN applied on cropped land}_{ij} \times \text{fraction application technique on cropped land}_j \times \text{EF application technique on cropped land}_j) \times 17/14 \qquad (9.2)$$

In which

NH_3 manure application: NH_3 emission from manure applied to agricultural soils (kg NH_3/year)

TAN applied on grassland$_{ij}$: Amount of TAN in manure (kg N/year) of livestock category (i) and manure management system (j) applied to grassland

fraction application technique on grassland$_j$: Fractions of manure application techniques for manure management system (j) used on grassland

EF application technique on grassland$_j$: NH_3-N emission factor (% of TAN) for manure application techniques for manure management system (j) used on grassland

TAN applied on uncropped land$_{ij}$: Amount of TAN in manure (kg N/year) of livestock category (i) and manure management system (j) applied to uncropped land

fraction application technique on uncropped land$_j$: Fractions of manure application techniques for manure management system (j) used on uncropped land

EF application technique on uncropped land$_j$: NH_3-N emission factor (% of TAN) for manure application techniques for manure management system (j) used on uncropped land

TAN applied on cropped land$_{ij}$: Amount of TAN in manure (kg N/year) of livestock category (i) and manure management system (j) applied to cropped land

fraction application technique on cropped land$_j$: Fractions of manure application techniques for manure management system (j) used on cropped land

EF application technique on cropped land$_j$: NH_3-N emission factor (% of TAN) for manure application techniques for manure management system (j) used on cropped land

17/14 : Conversion factor from NH_3-N to NH_3

The NH_3 emission is calculated for different manure application techniques. For grassland the following application techniques are distinguished (section 9.3.2): surface spreading, shallow injection, trailing shoe and slit coulter application. For uncropped land: surface spreading, injection/full coverage, shallow injection, trailing shoe, incorporation in 1 track and incorporation in 2 tracks are distinguished. On cropped land, shallow injection and trailing shoe are considered.

The amount of TAN available per livestock category/manure type, is calculated by subtracting N emissions in animal houses and during manure storage from the TAN excretion in the animal house. Part of the manure is used outside agriculture, processed or exported. The amount of manure per livestock category (i) and manure management system (j) that is available for application is found by subtracting these amounts from the initial TAN excretion:

$$\text{TAN for application}_{ij} = \text{TAN input}_i \times [\text{ fraction manure management system (j) }] - \text{N losses animal housing}_{ij} - NH_3 \text{ storage}_{ij} - \text{N processed}_{ij} - \text{N export}_{ij} \qquad (9.3)$$

In which

TAN for application$_{ij}$: Amount of manure (kg N) that per livestock category (i) and manure management system (j) is applied to agricultural soils

TAN input$_{i}$: TAN excretion (kg N) in the animal house for livestock category (i)

N losses animal housing$_{ij}$: Sum of NH_3, N_2O, NO_x and N_2 losses (kg N) from animal houses for livestock category (i) and manure management system (j)

NH_3 storage$_{ij}$: NH_3 emission from outside manure storages for livestock category (i) and manure management system (j) in kg N

N processed$_{ij}$: Amount of manure that per livestock category (i) and manure management system (j) is processed in kg N

N export$_{ij}$: Amount of manure that per livestock category (i) and manure management system (j) is exported in kg N, with import denoted as negative export

It is assumed that the imported manure has the same TAN fraction in total N as the manure coming from the animal house and storage.

The total amounts of slurry and solid manure are then divided over grassland, uncropped land and cropped land, see section 9.3.2. The NH_3 emission from application of manure to grassland, uncropped land and cropped land is calculated from, first the amount of TAN that is applied to grassland, uncropped land, and cropped land through manure and second the emission factors for NH_3 emission for application by different techniques on grassland, uncropped land and cropped land and the fraction of the application techniques used (section 9.3.3).

9.3.2 Activity data

For reporting livestock numbers are the activity data. The amount of TAN in manure applied to the soil is calculated from the urine N excretion, mineralization and immobilization of organic N in animal houses and the gaseous N losses occurring in animal houses and during manure storage (as described in Chapter 5, 6, and 7). Based on CBS statistics, data from the Netherlands Enterprise Agency (RVO) and calculations of the manure market, the amount of TAN is corrected for manure processing, export of manure and import of manure.

The amounts of manure applied to grassland, uncropped land and cropped land are based on the results of the calculations performed in the perspective of monitoring the manure market (Luesink *et al.*, 2008; De Koeijer *et al.*, 2012 and De Koeijer *et al.*, 2014; based on the Farm Accountancy Data Network (FADN; or BIN in Dutch) of Wageningen Economic Research and on the data about manure transport of the Netherlands Enterprise Agency).

A small part of the manure is produced or used outside agriculture. Companies smaller than 3,000 Standard Output (SO) with the label ‘agricultural company’ bringing in animal manure are given the label ‘hobby farm’. Import of less than 425 kg nitrogen by companies with the label ‘agricultural company’ that do not appear in the Agricultural census are relabelled hobby farm (Standard Output of 3,000 SO equals 2.5 ha grassland and this corresponds with 2.5 x 170 kg N/ha = 425 kg N). Suppliers with the label ‘agricultural company’ not appearing in the Agricultural census, dispose of relatively much more horse manure than companies that do appear in the Agricultural census, these companies are relabeled to hobby farm. Suppliers with the label ‘agricultural company’ not appearing in the Agricultural census with a disposal of less than 350 kg nitrogen are relabeled to hobby farm. Emissions outside agriculture are reported in NFR category 6A Other.

For the implementation grade of manure application techniques the results of the Agricultural census are used. In the Agricultural census of 2016 the kind of manure application techniques on grassland, uncropped land and cropped land were questioned for the last time (Van Bruggen *et al.*, 2017).

Livestock numbers
Livestock numbers are the activity data for this emission source. Livestock numbers and their uncertainty are described in section 2.3.

Uncertainty in activity data for NH_3 emission from manure application
Uncertainty in amount of manure exported out of the Dutch agriculture is estimated to be 20%. The information is mostly based on registered manure transports, but there are a few types of transport that are not mandatory to be registered. Also measurement of N and P in manure samples can have an error. For the mineral content of the export of solid manure, not the mineral content of the transportation documents animal manure (VDM's) are used as it is concluded that the samples are not representative for the whole batch (Luesink *et al.*, 2011). For solid poultry manure Dutch averages calculated by the WUM/NEMA working groups are used (Van Bruggen, in press). For products from manure separation the mineral content of the separated slurry from WUM/NEMA is the starting point (Van Bruggen, 2017) and for separation results from the average situation of WUR research from separation machines (Van Bruggen, in press).

Uncertainty in amount of manure going to grassland, uncropped land or cropped land is estimated to be 20%.

Information gathered in the Agricultural census usually gives a small uncertainty, but for the application techniques an uncertainty of 25% is assumed. It is estimated that farmers tend to fill in the lower emission techniques. Also, contractors usually apply the manure and not the farmer.

9.3.3 Emission factors

Emission factors for manure application are based on measurements. The average emission figures based on all available observations per method including minimum and maximum values, and number of observations and uncertainties are presented in Table 9.3 (Huijsmans and Schils, 2009). The total emission per observation was estimated as the maximum of the emission curve, fitted by the measured emission figures in the period of 96 hours after application.

Table 9.3 *Average total emission (% of TAN applied) per application method of manure on grassland and cropland, based on all available observations (n)*

Method	Average total emission (% of TAN)	Minimum	Maximum	n	Uncertainty
Grassland					
Surface spreading	74	28	100	81	6%
Narrow-band (trailing shoe)	26	9	52	29	17%
Shallow injection	16	1	63	89	19%
Uncropped land					
Surface spreading	69	30	100	26	
Incorporation (direct)	22	3	45	25	17%
Full coverage[1]	2	1	3	7	25%

[1] Full coverage: direct injection (one pass) or direct incorporation with the plow.

Source: Huijsmans and Schils (2009).

Statistical analysis of possible trends in time for the NH_3 emission on grassland
Huijsmans and Schils (2009) assessed whether the NH_3 emission on grassland systematically changed over the years since the measurements were performed (since 1988). Per technique a regression analysis was conducted, and it was analysed whether observed trends can be explained by the circumstances under which measurements took place (manure and environmental variables). A factor "time since 1988" was added to the existing statistical models for influence of the circumstances, and analysed for significance on emission after application.

The trend analysis revealed that measured emission rates after shallow injection on grassland had increased significantly since 1989 when experiments started. Because 1999 was the last year with many observations of the emission for shallow injection, the NH_3 emission for this year and the following years was estimated to be 19%. For the reference (broadcast surface manure application) and narrow band application no effect of time since 1989 on the total NH_3 emission was found.

Emission factors for other techniques

The CBS figures include a manure application technique called slit coulter for manure application on grassland. No emission data are available for this technique. As the slit coulter results in a manure placement intermediate between shallow injection and narrow band application, the EF for this technique is assessed as 22%, being the average of the EFs for shallow injection and narrow band application.

Depending on the method of manure incorporation, a certain reduction of NH_3 volatilization can be achieved on arable land. However, the reduction achieved by incorporation in a second pass highly depends on the time-lag between surface spreading and incorporation (Huijsmans and De Mol, 1999). The incorporation of the manure in a second pass always leads to a certain time lag. For this reason, the emission factors for surface incorporation in two passes and ploughing in were estimated as 46% and 35%, respectively, being the average emission for surface spreading and direct incorporation. Presently, the application and incorporation of slurry in two passes is not allowed anymore in the Netherlands. Therefore, the emission factors for arable land as shown in Table 9.4 are representative for current application methods i.e. spreading and incorporation in one operation.

***Table 9.4** Emission factors for NH_3 (% of TAN applied) per application technique on grassland and on cropland, including increasing trend for shallow injection*

Land type/application technique	EF (% of TAN)					
	1990	1991	1992-1993	1994-1998	1999-2003	From 2004 on
Grassland						
Surface spreading	67	71[4)]	71	71	71	71
Narrow-band (trailing shoe)	30.5	30.5	30.5	30.5	30.5	30.5
Slit coulter[1)]	20.3	20.3	20.3	22.8	24.8	24.8
Shallow injection	10	10	10	15	19	19
Cropland (uncropped)						
Surface spreading	64	64	69	69	69	69
Incorporation in two passes[2)]	46	46	46	46	46	46
Narrow-band (trailing shoe)	36	36	36	36	36	36
Slit coulter[1)]	24.5	24.5	24.5	27.5	30	30
Shallow injection	13	13	13	19	24	24
Incorporation (direct)	22	22	22	22	22	22
Full coverage	2	2	2	2	2	2
Cropland (cropped)						
Narrow-band (trailing shoe)	N/A	N/A	N/A	N/A	N/A	36[3)]
Shallow injection	N/A	N/A	N/A	N/A	N/A	24[3)]

[1)] For the emission factor for slit coulter the average of the emission factors for narrow-band and shallow injection is taken.

[2)] For the emission factor for incorporation in two passes the average of the emission factors for surface spreading and direct incorporation is taken.

Source: Huijsmans and Schils (2009), except [3)] Huijsmans and Hol (2012) and [4)] Huijsmans and Goedhart (in prep).

Uncertainty in emission factors for NH_3 from manure application

Uncertainties per application technique are taken from Huijsmans and Schils (2009).

9.3.4 Source-specific uncertainty

Implied emission factor uncertainties are calculated and include all uncertainties from excretion until emission factor uncertainties.

Table 9.5 *Uncertainty in NH_3 emissions, implied emission factor (IEF) and activity data (AD, livestock numbers) from manure application*

NFR	Livestock category	U AD	U IEF	U emission
	Cattle for breeding			
	Young stock	1%	41%	41%
	Dairy cows	2%	67%	67%
	Cattle for fattening			
	Meat calves	1%	92%	93%
	Young stock	1%	33%	33%
	Suckling cows	2%	39%	39%
	Other grazing animals			
	Sheep (Ewes)	5%	83%	83%
	Dairy goats, ≥ 1 year	5%	61%	61%
	Horses and ponies	4%	57%	57%
	Mules and asses	5%	70%	71%
	Pigs			
	Fattening pigs	10%	76%	76%
	Breeding pigs	4%	54%	54%
	Poultry			
	Laying hens	4%	0%$^{1)}$	0%$^{1)}$
	Broilers	10%	110%	111%
	Ducks	10%	107%	107%
	Turkeys	10%	106%	107%
	Other animals			
	Rabbits and minks	5%	72%	72%
3Da2a	Total			38%$^{2)}$

$^{1)}$ Uncertainty is probably the same as uncertainty for broilers, except that all manure is incinerated and absolute manure application is zero. It is not possible to calculate uncertainties in this case.

$^{2)}$ Calculated with the Monte Carlo method.

9.4 Source-specific aspects for NH_3 emission from sewage sludge applied to soils

9.4.1 Calculation method

In the calculation of NH_3 emission from sewage sludge application a distinction is made between liquid and solid sludge, with different TAN fractions:

$$NH_3 \text{ sewage sludge} = (N \text{ sewage sludge} \times \text{liquid fraction} \times TAN \text{ liquid} \times EF\ NH_3 \text{ liquid} + N \text{ sewage sludge} \times \text{solid fraction} \times TAN \text{ solid} \times EF\ NH_3 \text{ solid}) \times 17/14 \qquad (9.4)$$

In which

NH_3 sewage sludge	: NH_3 emission (kg NH_3/year) from sewage sludge
N sewage sludge	: Amount of sewage sludge (kg N) applied to agricultural soils
liquid fraction	: Fraction sewage sludge in liquid form
TAN liquid	: Fraction TAN in liquid sewage sludge
EF NH_3 liquid	: NH_3 emission factor (kg NH_3-N/kg N applied) for liquid sewage sludge
solid fraction	: Fraction sewage sludge in solid form
TAN solid	: Fraction TAN in solid sewage sludge

EF NH_3 solid : NH_3 emission factor (kg NH_3-N/kg N applied) for solid sewage sludge
17/14 : Conversion factor from NH_3-N to NH_3

9.4.2 Activity data

Amounts of sewage sludge applied to agricultural soils are available from CBS.

Uncertainty in activity data for sewage sludge application
Uncertainty on total sewage sludge use is estimated to be 25%. Disaggregated uncertainties for the liquid and solid fractions are calculated.

9.4.3 Emission factors

The percentage TAN in the sludge is calculated from German data on N and TAN contents of liquid and solid sewage sludge (Landwirtschaftliches Wochenblatt, 2007). All sewage sludge is assumed to be applied to cropland, using shallow injection for the liquid part and incorporation in two passes for the solid part. The corresponding emission factors for manure application (Table 9.4) are used.

An exception is made for the first two years of the time series (1990 and 1991), where the emission factor for surface spreading is used for both liquid and solid sewage sludge. Reason is that before 1992 there was no obligation to directly incorporate sewage sludge into the soil, but within a few days of application. Using this technique NH_3 emission already has taken place.

Uncertainty in emission factors for NH_3 from sewage sludge application
Uncertainty for both emission factors is estimated to be 100%. This is different from the uncertainty of the manure application emission factor because the emission factors are measured for manure and not for sewage sludge application.

9.4.4 Source-specific uncertainty

Only total sludge emissions are reported and so are the uncertainties. Because of this the uncertainties of the liquid fraction and the solid fraction are aggregated. The reported uncertainty in implied emission factors also includes the uncertainty in TAN. Combining TAN uncertainty and emission factor uncertainty and aggregating the two categories leads to an IEF uncertainty of 84%.

Table 9.6 *Uncertainty for NH_3 emissions, activity data and implied emission factors from sewage sludge application*

NFR	Source category	U AD	U IEF	U emission
3Da2b	Sewage sludge	25%	84%	88%

9.5 Source-specific aspects for NH_3 emission from other organic fertilizers applied to soils (including compost)

9.5.1 Calculation method

Two sources of compost are considered (from organic waste or green refuse), however it is assumed that the fraction of TAN in both is equal. All compost is surface applied on uncropped land:

$$NH_3\ compost = (N\ organic\ waste\ compost + N\ green\ refuse\ compost) \times TAN\ compost \times EF\ NH_3\ compost \times 17/14 \quad (9.5)$$

In which
NH_3 compost : NH_3 emission (kg NH_3/year) from compost
N organic waste compost : Amount of organic waste compost (kg N) applied to agricultural soils

N green refuse compost : Amount of green refuse compost (kg N) applied to agricultural soils in kg N
TAN compost : Fraction TAN in compost
EF NH_3 compost : NH_3 emission factor (kg NH_3-N/kg N applied) for compost
17/14 : Conversion factor from NH_3-N to NH_3

NEMA also calculates the NH_3 emissions for compost use outside agriculture, but these are allocated to NFR sector 6A Other.

9.5.2 Activity data

Amounts N in of organic (household) waste and green refuse compost are available from CBS.

Uncertainty in activity data for compost use
Uncertainty for total compost use is estimated to be 25%. Part of the compost is used outside agriculture, so uncertainty for the part of the compost used in agriculture is 23%.

9.5.3 Emission factors

The percentage TAN is taken from the Arable fertilization advice (De Haan and Van Geel, 2013; Bemestingsadvies akkerbouw, www.kennisakker.nl). Uncertainty in TAN is 25%.

All compost is assumed to be applied to uncropped land, using surface spreading. The corresponding emission factor for manure application (Table 9.4) is used.

An exception is made for the first two years of the time series (1990 and 1991), where the emission factor is kept equal to that of later years. Reason is that in these years there was an obligation to incorporate surface spread manure into the soil on uncropped lands. As a result the emission factor is set lower for 1990 and 1991, but this requirement did not apply to compost. From 1992 onwards it is no longer allowed to surface spread slurry, and the obligation was lifted for other (solid) manures.

Uncertainty in emission factors for NH_3 from compost use
Uncertainty is estimated to be 100%. This is different from the uncertainty of the manure application emission factor, because the emission factors are measured for manure and not for compost application.

9.5.4 Uncertainty

Table 9.7 presents the uncertainty in compost use, implied emission factor and resulting NH_3 emission.

Table 9.7 Uncertainty for NH_3 emissions, activity data and implied emission factors from compost application

NFR	Source category	U AD	U IEF	U emission
3Da2c	Compost	23%	106%	111%

9.6 Source-specific aspects for NH_3 emission from urine and dung deposited by grazing animals

9.6.1 Calculation method

The NH_3 emission from urine and dung deposited by grazing animals is calculated from:
- N excretion on pasture land per grazing livestock category, in kg N calculated on a yearly basis by the WUM;
- Share TAN in the N excretion during grazing, % of total N excretion (Annex 1);
- Emission factors for grazing, in % of TAN on pasture land (section 9.6.3).

The total NH_3 emission from grazing for all livestock categories (i) is calculated as:

$$NH_3 \text{ pasture} = \Sigma ([\text{ number of animals in livestock category (i) }] \times \text{TAN pasture}_i - \text{TAN excreted in nature areas}) \times \text{EF } NH_3 \text{ grazing} \times 17/14 \quad (9.6)$$

In which

NH_3 pasture	: NH_3 emissions (kg NH_3/year) from grazing
TAN pasture_i	: TAN excretion on pasture land (kg N/year) for livestock category (i) calculated by multiplying N excretion and TAN percentage
EF NH_3 grazing	: Emission factor for grazing in % of TAN excretion
17/14	: Conversion factor from NH_3-N to NH_3

The TAN excretion on pasture land is calculated as:

$$\text{TAN excretion pasture}_i = \text{N excretion pasture}_i \times \text{TAN fraction pasture}_i \quad (9.7)$$

In which

TAN excretion pasture_i	: TAN excretion (kg N/animal/year) on pasture land for livestock category (i)
N excretion pasture_i	: Total N excretion (kg N/animal/year) on pasture land for livestock category (i)
TAN fraction pasture_i	: Fraction TAN in the total N excretion on pasture land for livestock category (i)

TAN excreted in nature areas: Amount of TAN produced by farm animals grazing in nature areas

The emission factor for grazing is calculated yearly, based on grass composition (year-specific emission factor).

9.6.2 Activity data

Livestock numbers are the activity data for this emission source. Livestock numbers and their uncertainty are described in section 2.3.

Uncertainty in activity data for NH_3 emissions from grazing
The uncertainty in livestock numbers, including (dis-)aggregation of subcategories, is given in section 2.3.

9.6.3 Emission factors

N excretion on pasture land
N excretion and uncertainties are described in section 2.4.

Percentage TAN in pasture manure
The percentage of the N excretion that is TAN, is determined on a yearly basis by the WUM for each grazing livestock category.

TAN excretion in nature areas
Nature terrain is ground with nature as the main function and is not considered to be agricultural land. Also when an agricultural company hires or owns nature terrain, it is not part of the company in the manure legislation. The disposal on nature terrain has always to be answered for by means of transportation documents animal manure (VDM's) also if it concerns pasture manure. Agricultural firms with natural grassland therefore have to declare by a VDM how much manure was applied on it. Because the manure remains on the own company likely part of the companies will not declare this form of disposal through a VDM.

If animals of agricultural companies are grazed on nature terrain of nature protection organizations these organizations are obliged to answer for the manure disposal on nature terrain as the owner of the ground with transportation documents animal manure. The expectation is that this usually does not happen. The disposal of pasture manure on nature terrain of nature protection organizations is estimated to be 0.7 million kg P_2O_5 (Luesink *et al.*, 2011). This disposal of pasture manure is divided over the livestock categories based on the phosphate production in pasture manure. The disposal of nitrogen is calculated from the disposal of phosphate and the N/P_2O_5 ratio of the pasture manure. Besides production of pasture manure on nature terrain the disposal of stored animal manure to nature terrain has to be answered for by means of transportation documents. The registered disposal through transportation documents is counted as disposal to natural grassland with the manure being applied above ground.

Emission factor
There are no recent measurements for NH_3 emission during grazing. From research of Bussink (1992, 1994) an emission factor in % of total N excretion was derived. From this work also an emission factor based on TAN can be derived since urine N excretion is reported next to total N excretion. Several adjustments to the dataset of Bussink (1992, 1994) were made and the emission factor for grazing (EFgrazN) was corrected for:

- Inorganic N fertilizer applied during the research of Bussink (1992, 1994);
- Changes over time in grazing systems used;
- Soil type.

Following each of these corrections is discussed briefly.

Inorganic N fertilizer application
The emission factor for the inorganic N fertilizer in the study of Bussink was 2% (calcium ammonium saltpetre on calcium rich clay). However there are reasons to assume that emissions at this specific study site would normally be lower:

- NH_3 emission from inorganic N fertilizer is inhibited by the higher NH_3 concentration in the air from grazing (application took place around three days after grazing);
- Emission factors for inorganic N fertilizers are derived from experiments where grass height was low compared to the research of Bussink (1992, 1994);
- Emission from inorganic N fertilizer is slow and only a part of total NH_3 emission will have occurred during the measuring days;
- Measured NH_3 emission from calcium ammonium saltpetre at the same location in another year was 0.1% at 50 kg N/ha and 1% at 400 kg N/ha (Bussink, personal communication).

Also application of inorganic N fertilizer took place in periods without grazing or NH_3 measurements. It is estimated that around 75% was applied when measurements were performed (Bussink, personal communication). The correction for inorganic N fertilizer based on that amount, and an emission factor of 1% yields a corrected NH_3 emission for grazing between 6 and 38 kg N/ha.

Grazing system
The grazing systems in the Netherlands have shifted strongly towards systems with limited grazing in recent years (Aarts *et al.*, 2008; Van Bruggen and Faqiri, 2015). Bussink derived an emission factor in a situation with unlimited (day and night) grazing. Higher temperature, wind speed and global radiation during the day can lead to on average higher NH_3 emission from fresh urine patches. Furthermore during the night the grass is wet from dew and background concentrations of NH_3 are relatively high (little dilution).

This effect is also clearly seen in the measurements of Bussink. The average NH_3-N flux over 24 hours was 38 g NH_3-N per hour and 46 g NH_3-N per hour in the period between 07:00 and 21:30h in case of restricted grazing (Bussink, 1992). Emission during the day is therefore a factor 1.20 higher, and this factor is used to derive the emission factor for systems with limited grazing from the emissions of Bussink (1992, 1994).

Soil type
The NH_3 emission also depends on the cation exchange capacity (CEC) of the soil (Bussink, 1994; Whitehead and Raistrick, 1993). With higher CEC, the soil can bind NH_4^+ more strongly and the risk of NH_3 emission reduces. The CEC correction calculated by Bussink (1996) is used:

$$\text{CEC correction} = (7.71 - 0.02793 \times (\text{CEC} - 280)) / 7.71 \qquad (9.8)$$

Based on data of Blgg (nowadays Eurofins Agro in Wageningen, the Netherlands) for 2007-2008 (Arjan Reijneveld, Blgg personal communication) the average CEC per soil type has been estimated. These are 70 $mmol_c\ kg^{-1}$ for sand, 180 $mmol_c\ kg^{-1}$ for clay and loess and 300 $mmol_c\ kg^{-1}$ for peat and peat moss/cover-sand soils. Resulting correction factors for these soil types are 1.8, 1.4 and 0.9 respectively.

After correction for inorganic N fertilizer use and grazing system, emission factors based on TAN vary between 4.0 and 11.7 depending on soil type. Using the national soil use map of the Netherlands (LGN) it shows that 15% of the grassland is on peat, 47% on sand and 39% on clay and loess. Based on these areas and the CEC correction, a weighted emission factor in % of TAN is calculated (Bussink, 1996):

$$\text{EF } NH_3 \text{ grazing} = 4.0\%, \text{ with } Nration_{WUM} < 28 \text{ g N per kg DM}$$
$$\text{EF } NH_3 \text{ grazing} = 1.98 \times 10^{-5} * (Nration_{WUM})^{3.664}, \text{ with } Nration_{WUM} \geq 28 \text{ g N per kg DM} \qquad (9.9)$$

In which

EF NH_3 grazing : Emission factor (% of TAN) for grazing

$Nration_{WUM}$: Average N content of the ration during the grazing season according to the WUM (g N per kg dry matter).

High N rates in feed result in high N excretion and high TAN values, which lead to high NH_3 emission. In the Netherlands no measurement data are available for NH_3 emission from grazing by other grazing animal species (other cattle, horses, ponies and sheep). It is assumed that these will be equal to dairy cows. As a result, the formula for dairy cattle is also used for other grazing animals.

Uncertainty in emission factors for NH_3 from grazing

Uncertainties in TAN are estimated to be 10%.

Uncertainty in TAN excretion in nature areas is estimated to be 50%.

Uncertainty in grazing emission factor is 100%.

9.6.4 Uncertainty

Uncertainties are presented in Table 9.8. Implied emission factor uncertainties include uncertainties in N, TAN, manure excreted in nature areas and emission factor. Lower implied emission factor uncertainties indicate more underlying livestock categories.

***Table 9.8** Uncertainties of NH_3 emissions, activity data and implied emission factors from grazing*

NFR	Livestock category	U AD	U IEF	U emission
	Cattle for breeding			
	Young stock	1%	85%	85%
	Dairy cows	2%	110%	110%
	Cattle for fattening			
	Young stock	1%	90%	90%
	Suckling cows	2%	101%	101%
	Other grazing animals			
	Sheep (Ewes)	5%	101%	101%
	Horses and ponies (agriculture)	4%	88%	88%
	Mules and asses	5%	107%	107%
3Da3	Total			59%[1]

[1] Calculated using the Monte Carlo method

9.7 Source-specific aspects for NH_3 emission from remaining crop residues

9.7.1 Calculation method

For the calculation of the emission from crop residues the methodology and calculations of De Ruijter *et al.* (2013) are taken as the starting point:

$$NH_3 \text{ crop residues} = \sum \text{area grown} \times \text{N in above-ground residue} \times \text{EF } NH_3 \text{ crop residue} \times \text{contributing fraction} \times 17/14 \quad (9.10)$$

In which
NH_3 crop residues : NH_3 emission (kg NH_3/year) from crop residues
area grown : Area per crop cultivated in ha
N in above-ground residue: N contained within the crop residues per crop in kg N/ha
EF NH_3 crop residue : Emission factor for crop residues in % of the N content
contributing fraction : Fraction of the residues that contributes to NH_3 emission (i.e. is not being incorporated into the soil in the first days after harvest)
17/14 : Conversion factor from NH_3-N to NH_3

The percentage volatilization is based on N content of the residues and assumes full exposure of the crop residues to air, both in the amounts and over time (see section 9.7.3). As a result, only N in above-ground residues is taken into account. With the contributing residue fraction the part of the residues that are incorporated into the soils is being accounted for.

Crop residues also occur in the cutting, drying and collection of grass for the production of silage or hay and an average amount of 1,000 kg dry matter/ha/year is assumed (De Ruijter *et al.*, 2013). Pasture topping also generates crop residues but is not considered separately as it is accounted for in the emission factor for grazing (De Ruijter *et al.*, 2013). Emission is calculated using formula (9.10) using total area mown, and N content of fresh grass from the WUM.

9.7.2 Activity data

Areas of cultivated crops are derived from the Agricultural census. Data on grassland renovation were obtained from CBS and Wageningen Economic Research.

Uncertainty in activity data for crop residues
Uncertainty in area of cultivated crops is 5% per category and 2% on total crop area.

9.7.3 Emission factors

For the N contents of crop residues for grass, data of the WUM have been used. For other crops, data available from De Ruijter *et al.* (2013) was used for the N content of the crop residues. Uncertainty is estimated to be 25%. The uncertainty in fraction of crop residue that contributes to the emissions is estimated to be 15%.

To calculate the percentage of N that is emitted as NH_3 from crop residues, a regression model has been derived from literature describing the relationship between NH_3 emission and the N content of residues (De Ruijter and Huijsmans, 2012):

$$\text{EF } NH_3 \text{ crop residue} = 0.40 \times \text{N content} - 5.08 \quad (9.11)$$

In which
N content : N contained in above-ground crop residues (g/kg dry matter) per crop

Based on the regression equation, no emission occurs if the N content is below 12.7 g/kg. The model assumes complete exposure to air of all residues, for a prolonged period of time.

Uncertainty in emission factor for NH_3 from crop residues
Uncertainty in emission factor is estimated to be 80%.

9.7.4 Uncertainty

The uncertainty in crop residue is an aggregation of 54 different crops. Implied emission factor uncertainties include N content of the crop, the fraction remaining on the field and the emission factor.

Table 9.9 *Uncertainties in NH_3 emissions, activity data (AD) and implied emission factors (IEF) from crop residues*

NFR	Source category	U AD	U IEF	U emission
3Da4	Crop residues	2%	40%	40%

9.8 Source-specific aspects for NH_3 emission during crop cultivation

9.8.1 Calculation method

Emissions from standing crops in the Netherlands have been calculated using the DEPAC resistance model (Van Zanten *et al.*, 2010). In this the exchange of NH_3 between stomata of the plants, air layer directly above the crop and finally the atmosphere are modelled. Depending on ambient NH_3 concentration and type of crop, emission or deposition will take place. These were determined on an hourly basis and aggregated over the growing season.

For the Netherlands a total emission of 1.5 Gg NH_3-N was found using this method. This estimate has been adopted for the whole time series, instead of calculating the emissions for each year separately. Reason is the high associated uncertainty, estimated to be 300%, mainly originating from the stomatal compensation points needed for the calculation. It was deemed that using a calculation rule in which cultivated areas are taken into account, would represent a level of accuracy that cannot be attained at this point.

9.8.2 Activity data

For NH_3 emissions from standing crops, a fixed estimate is reported based on Van Zanten *et al.* (2010). Therefore no activity data is needed for the calculations.

9.8.3 Emission factors

For NH_3 emissions from standing crops, a fixed estimate is reported based on Van Zanten *et al.* (2010). Therefore no emission factors are needed for the calculations.

9.8.4 Uncertainty

Uncertainty in estimated NH_3 emission from standing crops is 300% (Van Zanten *et al.,* 2010).

10 NO_x emissions from crop production and agricultural soils (NFR category 3D)

10.1 Scope and definition

The NFR source category 3D Crop production and agricultural soils consists of:

- 3Da1 Inorganic N fertilizers (includes also urea application)
- 3Da2a Livestock manure applied to soils
- 3Da2b Sewage sludge applied to soils
- 3Da2c Other organic fertilizers applied to soils (including compost)
- 3Da3 Urine and dung deposited by grazing animals
- 3Da4 Crop residues applied to soils

No emissions of NO_x occur in the source categories 3Db Indirect emissions from managed soils, 3Dc Farm-level agricultural operations including storage, handling and transport of agricultural products, 3Dd Off-farm storage, handling and transport of bulk agricultural products, 3De Cultivated crops and 3Df Use of pesticides. Since field burning is prohibited by law in the Netherlands, also no emissions occur in category 3F Field burning of agricultural residues. Lastly it was chosen to report the emissions from the cultivation of organic soils under the category 3I Agriculture other.

Although emissions are reported as NO, nitrogen monoxide, by NEMA, it is referred to as NO_x in this report to prevent confusion with the notation key NO.

10.2 Source-specific aspects for NO_x emissions from inorganic N fertilizer application

10.2.1 Calculation method

Total NO_x emissions from inorganic N fertilizers are calculated as:

$$NO_x \text{ emission 3Da1} = \Sigma \text{ EF x supply source x } 30/14 \qquad (10.1)$$

NO_x emission 3Da1	: Nitrogen oxides emission (kg NO_x/year, expressed as nitrogen monoxide) for inorganic N fertilizers
supply source	: Amount of N (kg N/year) from inorganic N fertilizers
30/14	: Conversion factor from NO_x-N to NO_x, expressed as nitrogen monoxide

10.2.2 Activity data

The usage of the different types of inorganic N fertilizers is taken from the synthetic fertilizer statistics of Wageningen Economic Research. Uncertainty is estimated to be 25% for inorganic N fertilizer and 40% for rinsing liquid (section 9.2).

10.2.3 Emission factors

NO_x emissions from N input to the soil are calculated using the default EMEP emission factor of 0.012 kg NO_x-N/kg N input. EMEP gives an uncertainty of 160%.

10.2.4 Source-specific uncertainty

Uncertainty of inorganic N fertilizer including rinsing liquid gives an uncertainty in AD of 24%.

Table 10.1 *Uncertainties in NO_x emission, activity data and implied emission factor from inorganic N fertilizer*

NFR	Source category	U AD	U IEF	U emission
3Da1	Inorganic N fertilizer	24%	160%	166%

10.3 Source-specific aspects for NO_x emissions from animal manure applied to soils

10.3.1 Calculation method

Total NO_x emissions from animal manure applied to soils are calculated as:

$$NO_x \text{ emission 3Da2a} = \Sigma \text{ EF x supply source x } 30/14 \quad (10.2)$$

NO_x emission 3Da2a : Nitrogen oxides emission (kg NO_x/year, expressed as nitrogen monoxide) from animal manure applied to soils
supply source : Amount of N (kg N/year) from animal manure applied to soils
30/14 : Conversion factor from NO_x-N to NO_x, expressed as nitrogen monoxide

10.3.2 Activity data

The amount of N that is applied with manure to the soil is calculated from the urine N excretion and mineralization of organic N in animal houses and the gaseous N losses occurring in animal houses and manure storages. Based on CBS statistics, data from RVO and calculations of the manure market these amounts are corrected for manure processing, export of manure and import of manure. Calculated uncertainty is 4%. Calculation is described in section 9.3 including underlying uncertainties.

10.3.3 Emission factors

NO_x emissions from N input to the soil are calculated using the default EMEP emission factor of 0.012 kg NO_x-N/kg N input. EMEP gives an uncertainty of 160%.

10.3.4 Uncertainty

Table 10.2 presents the uncertainty in animal manure application, implied emission factor and resulting NO_x emission.

Table 10.2 *Uncertainties in NO_x emission, activity data (AD) and implied emission factor (IEF) from animal manure applied to soil*

NFR	Source category	U AD	U IEF	U emission
3Da2a	Animal manure applied to soils	4%	160%	160%

10.4 Source-specific aspects for NO_x emissions from sewage sludge applied to soils

10.4.1 Calculation method

Total NO_x emissions from sewage sludge applied to soils are calculated as:

$$NO_x \text{ emission 3Da2b} = \Sigma \text{ EF x supply source x } 30/14 \quad (10.3)$$

NO_x emission 3Da2b : Nitrogen oxides emission (kg NO_x/year, expressed as nitrogen monoxide) from sewage sludge applied to soils
supply source : Amount of N (kg N/year) from sewage sludge applied to soils
30/14 : Conversion factor from NO_x-N to NO_x, expressed as nitrogen monoxide

10.4.2 Activity data

The amount of sewage sludge applied to agricultural soils is calculated by CBS and published via Statline. Uncertainty is estimated to be 25% (expert judgement).

10.4.3 Emission factors

NO_x emissions from N input to the soil are calculated using the default EMEP emission factor of 0.012 kg NO_x-N/kg N input. EMEP gives an uncertainty of 160%.

10.4.4 Uncertainty

Table 10.3 presents the uncertainty in sewage sludge application, implied emission factor and resulting NO_x emission.

Table 10.3 *Uncertainties in NO_x emission, activity data and implied emission factor from sewage sludge*

NFR	Source category	U AD	U IEF	U emission
3Da2b	Sewage sludge applied to soils	25%	160%	167%

10.5 Source-specific aspects for NO_x emissions from other organic fertilizers applied to soils (including compost)

10.5.1 Calculation method

Total NO_x emissions from compost are calculated as:

$$NO_x \text{ emission 3Da2c} = \Sigma \text{ EF x supply source x } 30/14 \qquad (10.4)$$

NO_x emission 3Da2c : Nitrogen oxides emission (kg NO_x/year, expressed as nitrogen monoxide) from compost
supply source : Amount of N (kg N/year) in compost
30/14 : Conversion factor from NO_x-N to NO_x, expressed as nitrogen monoxide

10.5.2 Activity data

The amount of compost applied to agricultural soils is calculated by CBS and published via Statline. Uncertainty is estimated to be 25%.

10.5.3 Emission factors

NO_x emissions from N input to the soil are calculated using the default EMEP emission factor of 0.012 kg NO_x-N/kg N input. EMEP gives an uncertainty of 160%.

10.5.4 Uncertainty

Table 10.4 presents the uncertainty in compost use, implied emission factor and resulting NO_x emission.

Table 10.4 Uncertainties in NO_x emission, activity data and implied emission factor from compost

NFR	Source category	U AD	U IEF	U emission
3Da2c	Compost use	25%	160%	167%

10.6 Source-specific aspects for NO_x emissions from urine and dung deposited by grazing animals

10.6.1 Calculation method

Total NO_x emissions from urine and dung deposited by grazing animals are calculated as:

$$NO_x \text{ emission 3Da3} = \Sigma \, ([\text{ number of animals in livestock category (i) }] \times \text{N pasture}_i \times EF) \times 30/14 \quad (10.5)$$

NO_x emission 3Da3 : Nitrogen oxides emission (kg NO_x/year, expressed as nitrogen monoxide) from urine and dung deposited by grazing animals
N pasture$_i$: Amount of N per livestock category (kg N/head/year) in urine and dung deposited by grazing animals
30/14 : Conversion factor from NO_x-N to NO_x, expressed as nitrogen monoxide

10.6.2 Activity data

Part of the animal manure is produced on pasture land during grazing. The amount of nitrogen per animal is calculated by the WUM and is available from the CBS website, www.cbs.nl. Statistics concerning the livestock populations are also available on the CBS website. Uncertainty in amount of nitrogen deposited on pasture land is calculated to be 15%. The calculation is described in section 9.6.

10.6.3 Emission factors

NO_x emissions from N input to the soil are calculated using the default EMEP emission factor of 0.012 kg NO_x-N/kg N input. The EMEP default uncertainty of 160% is used.

10.6.4 Uncertainty

Table 10.5 presents the uncertainty in grazing, implied emission factor and resulting NO_x emission.

Table 10.5 *Uncertainties in NO_x emission, activity data (AD) and implied emission factor (IEF) from grazing animals*

NFR	Source category	U AD	U IEF	U emission
3Da3	Grazing	15%	160%	163%

10.7 Source-specfic aspects for NO_x emissions from remaining crop residues

10.7.1 Calculation method

Total NO_x emissions from crop residues applied to soils are calculated as:

$$NO_x \text{ emission 3Da4} = \Sigma \, EF \times \text{supply source} \times 30/14 \quad (10.6)$$

NO_x emission 3Da4 : Nitrogen oxides emission (kg NO_x/year, expressed as nitrogen monoxide) from crop residues applied to soils
supply source : Amount of N (kg N/year) from crop residues applied to soils
30/14 : Conversion factor from NO_x-N to NO_x, expressed as nitrogen monoxide

10.7.2 Activity data

Conform the IPCC calculation rules this includes all arable and outdoor horticultural crops (e.g. not from greenhouse farming). All crops that fall under both these two categories are included in the Agricultural census, available via www.cbs.nl, and are included in the calculations for NO_x emissions. In addition, a fixed country-specific value in kg N per hectare per crop type is used for the nitrogen content of the above-ground crop residues. Finally, the calculations take into account the fact that sometimes part of the above-ground crop residues are removed from the field and thus do not contribute to NO_x emissions. Country-specific values are used for these removals, as reported in Van der Hoek *et al.* (2007).

The areas used for these crops are taken from the annual Agricultural census. Uncertainty in area and nitrogen content is described in Chapter 9.

10.7.3 Emission factors

NO_x emissions from N input to the soil are calculated using the default EMEP emission factor of 0.012 kg NO_x-N/kg N input. EMEP gives a default uncertainty of 160%.

10.7.4 Uncertainty

Uncertainties in implied emission factor include N content of crop, amount of crop removed and emission factor.

***Table 10.6** Uncertainties in NO_x emission, activity data (AD) and implied emission factor (IEF) from crop residues*

NFR	Source category	U AD	U IEF	U total
3Da4	Crop residues$^{1)}$	2%		161%

$^{1)}$ Preliminary results, this is a new source and definitive uncertainty results are not available yet.

10.8 Source-specific aspects for NO_x emissions from agricultural use of organic soils

10.8.1 Calculation method

NO_x emissions are determined by multiplying the area of peat and other organic soils by specific Dutch mineralization and default EMEP emission factors. Total NO_x emissions from organic soils are calculated as:

$$NO_x \text{ emission 3I} = \Sigma \text{ EF x area}_{\text{soil type}} \text{ x mineralization x } 30/14 \qquad (10.7)$$

NO_x emission 3I : Nitrogen oxides emission (kg NO_x/year, expressed as nitrogen monoxide) for all defined supply sources (m)

$\text{area}_{\text{soil type}}$: Amount of N (kg N/year) for supply source (m)

30/14 : Conversion factor from NO_x-N to NO_x, expressed as nitrogen monoxide

10.8.2 Activity data

The extent of the areas cultivated is estimated from the land use maps of the Land Use, Land Use Change and Forestry (LULUCF) sector. Maps are available for the base year 1990, 2004, 2009 and 2013. Between these years interpolation takes place. An overview of the resulting areas can be found in annex 18 to Van Bruggen *et al.* (2015).

Uncertainty in activity data for cultivation of organic soils
Uncertainty in the area of histosols is estimated to be 20%.

Uncertainty in the area of other organic soils is estimated to be 35%. This area is a category between sand and peat and is harder to detect, so uncertainties are larger than the uncertainty in the area of histosols.

10.8.3 Emission factors

Average mineralization is 233.5 kg N per hectare peat soil and 204.5 kg N per hectare other organic soil (Kuikman *et al.*, 2005). Using default EMEP emission factor of 0.012 kg NO_x-N/kg N input.

Uncertainty in emission factors for NO_x from the cultivation of organic soils
Kuikman *et al.* (2005) gives an uncertainty of 25% for the mineralization.

EMEP gives a default uncertainty for the emission factor of 160%.

10.8.4 Uncertainty

Uncertainties in implied emission factor include mineralization and emission factor. The categories histosols and other organic soils are aggregated.

***Table 10.7** Uncertainties in NO_x emission, activity data (AD) and implied emission factor (IEF) from agricultural use of organic soils*

NFR	Source category	U AD	U IEF	U total
3I	Agricultural use of organic soils[1)]	18%	125%	127%

[1)] Preliminary results, this is a new source and definitive uncertainty results are not available yet.

11 N_2O emissions from crop production and agricultural soils (CRF sector 3D)

11.1 Scope and definition

This chapter describes the methodology and working processes for determining direct and indirect emissions of N_2O from the soil as a result of agricultural activities in the Netherlands. This concerns the CRF source categories 3Da Direct N_2O emissions from managed soils and 3Db Indirect N_2O emissions from managed soils, subdivided into:

- 3Da1 Inorganic N fertilizers
- 3Da2 Organic N fertilizers (with further subdivision into animal manure, sewage sludge and other organic fertilizers applied to soils)
- 3Da3 Urine and dung deposited by grazing animals
- 3Da4 Crop residues
- 3Da6 Cultivation of organic soils (i.e. histosols)
- 3Db1 Indirect N_2O emissions from atmospheric deposition
- 3Db2 Indirect N_2O emissions from nitrogen leaching and run-off

In source category 3Da5 Mineralization/immobilization associated with loss/gain of soil organic matter, only emissions from cropland remaining cropland have to be reported. According to the methodology used for the Land Use, Land Use Change and Forestry (LULUCF) sector in the Netherlands, no emissions occur in this case (Arets *et al.*, 2017). Also the Netherlands has not allocated emissions to source category 3Da7 Other.

Nitrous oxide is formed in the soil during the microbiological processes of nitrification and denitrification. Nitrification concerns the process whereby ammonia (NH_4^+) under aerobic (oxygen-rich) conditions is converted into nitrate by bacteria. In slurry oxygen is the limiting factor for nitrification. Nitrous oxide can be formed as a by-product, particularly when the nitrification process is delayed through lack of oxygen. No organic substances are required for nitrification. Denitrification is the microbiological transformation of NO_3^- under anaerobic (low-oxygen) conditions into the gaseous nitrogen compound N_2, with N_2O as a by-product. Organic substances are used as energy source. Organic soils have higher emissions of nitrous oxide than mineral soils.

The IPCC Guidelines (2006) give separate estimates of the direct and indirect emissions of nitrous oxide from the agricultural sector. *Direct* emissions occur in the agricultural system, primarily as a result of the application of inorganic N fertilizers and animal manure. *Indirect* emissions of nitrous oxide concern the formation of N_2O in soils and aquatic systems as a result of nitrogen losses from the soil to air and water. They are attributed to agriculture whether or not emission occurs on agricultural land or even within the country, as agricultural activities form the initial source.

11.2 Source-specific aspects for direct N_2O emissions from inorganic N fertilizer application

11.2.1 Calculation method

Direct N_2O emission from inorganic N fertilizers is calculated by multiplying the amount of nitrogen of inorganic N fertilizers by a country-specific emission factor.

$$N_2O \text{ emission inorganic N fertilizer} = \text{supply source} \times EF \times 44/28 \qquad (11.1)$$

In which
supply source : Application of N from inorganic N fertilizers (kg N)

EF : Emission factor for the application of N from inorganic N fertilizer in kg N_2O-N/kg N
44/28 : Conversion factor from N_2O-N to N_2O

These emissions are being reported under their respective CRF categories.

Comparison to IPCC methodology
The methodology described above conforms to the IPCC method, as described in the IPCC Guidelines (IPCC, 2006).

11.2.2 Activity data

Amount of nitrogen in inorganic N fertilizer applied to soil
Figures relating to the total gross amount of nitrogen in fertilizer are gathered annually by Wageningen Economic Research (see also http://www.wur.nl/nl/Expertises-Dienstverlening/Onderzoeksinstituten/Economic-Research.htm).

Uncertainty in activity data for inorganic N fertilizer application
The uncertainty on the inorganic N fertilizer excluding rinsing liquid is estimated to be 25% (see section NH_3 inorganic N fertilizer applied to soil). Uncertainty in rinsing liquid is estimated to be 40%.

11.2.3 Emission factors

An emission factor of 0.013 is used for inorganic N fertilizer application. This is the weighted mean of various inorganic N fertilizer and soil types (Velthof *et al.* (2010); Velthof and Mosquera (2011); Van Schijndel and Van der Sluis (2011), see Annex 10).

Uncertainty in emission factor for N_2O from inorganic N fertilizer application
Uncertainty is estimated to be 37%, see Annex 10.

11.2.4 Uncertainty

Uncertainties in inorganic fertilizer and rinsing liquid combined give an uncertainty of 24% in AD.

Table 11.1 *Uncertainty for N_2O emissions, activity data (AD) and implied emission factor (IEF) from application of inorganic N fertilizer*

IPCC	Source category	U AD	U IEF	U emission
3Da1	Inorganic N fertilizer	24%	37%	45%

11.3 Source-specfic aspects for direct N_2O emissions from animal manure applied to soils

11.3.1 Calculation method

Direct N_2O emission from application of N from animal manure is calculated by multiplying the amount of nitrogen application from animal manure by a country-specific emission factor.

$$N_2O \text{ emission direct} = \Sigma \text{ (supply source}_i \times EF_i \text{)} \times 44/28 \qquad (11.2)$$

In which
supply source$_i$: Application of N from animal manure per application technique(kg N)
EF_i : Emission factor for application of N from animal manure in kg N_2O-N/kg N in supply source per application technique
44/28 : Conversion factor from N_2O-N to N_2O

The use of animal manure is split into two types of manure application techniques, each has its own country-specific emission factor (see Annex 10 and Velthof and Mosquera, 2011).

These emissions are being reported under their respective CRF categories, with the sources animal manure, sewage sludge and compost reported together under 3Da2 Organic N fertilizers.

Comparison to IPCC methodology
The methodology described above conforms to the IPCC method, as described in the IPCC Guidelines (IPCC, 2006).

11.3.2 Activity data

Amount of nitrogen in animal manure applied to soil
The amount of nitrogen applied to soils is calculated using the N flow. N excretion calculation is described in Chapter 2. Emissions in animal houses and outside manure storages are calculated using the method described in Chapters 2 and 4. The amount of nitrogen in animal manure, after subtracting emissions from animal housing and outside storage plus the N in net exported manure (i.e. export - import) gives the amount of nitrogen applied to soils.

Uncertainty in activity data for manure application
The uncertainty is calculated via the N flow calculation, and the corresponding uncertainty is 3%.

11.3.3 Emission factors

An emission factor of 0.004 kg N_2O-N per kg net applied N is applied for surface spreading. This factor is 0.009 for low emission manure application. Both figures are weighted means for mineral and organic soils. The higher emission factor for low emission manure application methods is caused by the larger amount of N available for nitrification/denitrification using this method (Velthof *et al.* (2010); Velthof and Mosquera (2011); Van Schijndel and Van der Sluis (2011), see Annex 10). The amount of manure applied using surface spreading and the amount of manure applied using low emission techniques is taken from the Agricultural census.

Uncertainty in emission factors for N_2O from manure application
The uncertainty of the low emission application emission factor is 70% and the uncertainty of the emission factor for surface spreading is 81%. The calculation of these uncertainties is described in Annex 10.

Uncertainty is estimated to be 5% on the fraction of low emission techniques and 50% on the fraction of surface spreading (expert judgement).

11.3.4 Uncertainty

Table 11.2 presents the uncertainty in animal manure application, implied emission factor and resulting N_2O emission.

Table 11.2 *Uncertainty for N_2O emissions, activity data (AD) and implied emission factor (IEF) from animal manure application*

IPCC	Source category	U AD	Fraction technique	U EF	U IEF	U emission
	Animal manure low emission	4%	5%	70%		71%
	Animal manure surface spreading	4%	50%	81%		103%
3Da2a	Total	4%			66%	66%

11.4 Source-specific aspects for direct N_2O emissions from sewage sludge applied to soils

11.4.1 Calculation method

Direct nitrous oxide emission from sewage sludge is calculated by multiplying the amount of nitrogen from sewage sludge by a country-specific emission factor.

$$N_2O \text{ emission 3Da2b} = \text{supply source} \times EF \times 44/28 \qquad (11.3)$$

In which

supply source_m : Amount of N from sewage sludge in kg N

EF_m : Emission factor for sewage sludge in kg N_2O-N/kg N

44/28 : Conversion factor from N_2O-N to N_2O

These emissions are being reported under their respective CRF categories, with the sources animal manure, sewage sludge and compost reported together under 3Da2 Organic N fertilizers.

Comparison to IPCC methodology
The methodology described above conforms to the IPCC method, as described in the IPCC Guidelines (IPCC, 2006).

11.4.2 Activity data

The amount of sewage sludge applied to agricultural soils is calculated by CBS and published via Statline.

Uncertainty in activity data for sewage sludge application
Uncertainty is estimated to be 25%.

11.4.3 Emission factors

For sewage sludge the emission factors and uncertainties of manure application are used. These are 0.004 kg N_2O-N per kg N for surface application and 0.009 kg N_2O-N for low-ammonia emission application.

Uncertainty in emission factors for N_2O from sewage sludge application
The uncertainty is estimated to be 100%. This is higher than the uncertainty for the same emission factors for manure application because the measurements are from use of animal manure.

11.4.4 Uncertainty

Table 11.3 presents the uncertainty in sewage sludge application, implied emission factor and resulting N_2O emission.

Table 11.3 *Uncertainty for N_2O emissions, activity data (AD) and implied emission factor (IEF) from sewage sludge application*

IPCC	Source category	U AD	U IEF	U emission
3Da2b	Sewage sludge application	25%	100%	106%

11.5 Source-specific aspects for direct N_2O emissions from other organic fertilizers applied to soils (including compost)

11.5.1 Calculation method

N_2O oxide emission from compost is calculated by multiplying the amount of nitrogen from compost by a country-specific emission factor.

$$N_2O \text{ emission 3Da2c} = \text{supply source} \times EF \times 44/28 \quad (11.4)$$

In which
supply source : Amount of N from compost in kg N
EF : Emission factor for compost in kg N_2O-N/kg N
44/28 : Conversion factor from N_2O-N to N_2O

These emissions are being reported under their respective CRF categories, with the sources animal manure, sewage sludge and compost reported together under 3Da2 Organic N fertilizers.

Comparison to IPCC methodology
The methodology described above conforms to the IPCC method, as described in the IPCC Guidelines (IPCC, 2006).

11.5.2 Activity data

The amounts of organic waste and green refuse compost applied to agricultural soils or used outside agriculture, is calculated by CBS and published via Statline.

Uncertainty in activity data for compost use
Uncertainty is estimated to be 25%.

11.5.3 Emission factors

All compost is assumed to be surface applied, and has an emission factor of 0.004 kg N_2O-N per kg N applied (section 11.3).

Uncertainty in emission factors for N_2O from compost use
Uncertainty is 100%. This is higher than the uncertainty calculated for the emission factor in section 11.3 because this emission factor is measured for animal manure and assumed to be the same for compost.

11.5.4 Uncertainty

Table 11.4 presents the uncertainty in compost use, implied emission factor and resulting N_2O emission.

Table 11.4 *Uncertainty for N_2O emissions, activity data (AD) and implied emission factor (IEF) from compost application*

IPCC	Source category	U activity	U IEF	U total
3Da2c	Compost use	25%	100%	106%

11.6 Source-specific aspects for direct N_2O emissions from urine and dung deposited by grazing animals

11.6.1 Calculation method

N_2O emissions from urine and dung deposited by grazing animals are calculated by multiplying the amount of nitrogen by a country-specific emission factor.

$$N_2O \text{ emission 3Da3} = \text{supply source} \times EF \times 44/28 \qquad (11.5)$$

In which

supply source	: Amount of N for urine and dung deposited by grazing animals in kg N
EF	: Emission factor for urine and dung deposited by grazing animals in kg N_2O-N/kg N
44/28	: Conversion factor from N_2O-N to N_2O

These emissions are being reported under their respective CRF categories.

Comparison to IPCC methodology
The methodology described above conforms to the IPCC method, as described in the IPCC Guidelines (IPCC, 2006).

11.6.2 Activity data

Part of the animal manure is produced on pasture land. The amount of nitrogen per animal is calculated by the WUM and is available from www.cbs.nl. Statistics concerning the livestock populations are also available on the CBS website.

Uncertainty in activity data for grazing
Uncertainty in nitrogen excretion is described in section 2.4.

11.6.3 Emission factors

For grazing, an emission factor of 0.033 kg N_2O-N per kg net produced N is used. This is a weighted mean over soil types (Annex 10).

Uncertainty in emission factors for N_2O from grazing
The uncertainty is 64%. The uncertainty is calculated using uncertainties for the emission factors per soil type and the uncertainties of manure distribution over these soil types (Annex 10).

11.6.4 Uncertainty

Table 11.5 presents the uncertainty in grazing, implied emission factor and resulting N_2O emission.

Table 11.5 *Uncertainty for N_2O emissions, activity data (AD) and implied emission factor (IEF) from urine and dung deposited by grazing animals*

IPCC	Source category	U AD	U IEF	U emission
3Da3	Urine and dung deposited by grazing animals	15%	64%	67%

11.7 Source-specific aspects for direct N_2O emissions from remaining crop residues

11.7.1 Calculation method

Direct N_2O emissions from remaining crop residues are calculated by multiplying the amount of nitrogen from remaining crop residues by a country-specific emission factor.

$$N_2O \text{ emission 3Da4} = \text{supply source} \times EF \times 44/28 \quad (11.6)$$

In which

supply source	: Amount of N from remaining crop residues in kg N
EF	: Emission factor for remaining crop residues in kg N_2O-N/kg N
44/28	: Conversion factor from N_2O-N to N_2O

These emissions are being reported under their respective CRF categories.

Comparison to IPCC methodology
The methodology described above conforms to the IPCC method, as described in the IPCC Guidelines (IPCC, 2006).

11.7.2 Activity data

Amount of nitrogen in crop residues
Conform the IPCC calculation rules this includes all arable and outdoor horticultural crops (e.g. not from greenhouse farming). All crops that are part of these two categories are included in the Agricultural census, available via www.cbs.nl, and are included in the calculations for nitrous oxide emissions. In addition, a fixed country-specific value in kg N per hectare per crop type is used for the nitrogen content of the above- and below ground crop residues. Finally, the calculations take account of the fact that sometimes part of the above-ground crop residues are removed from the field and thus do not contribute to nitrous oxide emissions. Country-specific values are used for these removals, as reported in Van der Hoek *et al.* (2007).

The areas used for these crops are taken from the annual Agricultural census, which includes all agricultural companies with their headquarters in the Netherlands and which are larger than, or equal to, three Netherlands size units (nge, until 2009) or 3,000 Standard Output (SO, from 2010).

Uncertainty in activity data for crop residues
Uncertainties in areas of crops are described in Chapter 9.

Uncertainty in activity data for pasture renewal is estimated to be 25%.

11.7.3 Emission factors

For crop residues an emission factor of 0.01 kg N_2O-N per kg N is used for the crop residues remaining on mineral soils. This value is estimated from Dutch research studies carried out in the first half of the 1990s (Kroeze, 1994). Arable farming and outdoor horticulture hardly ever occur in organic soils.

Uncertainty in emission factors for N_2O from crop residues
Uncertainty in emission factor is estimated to be 80% based on Kroeze (1994). It depends on the age of the grass and the management.

11.7.4 Uncertainty

Table 11.6 presents the uncertainty in remaining crop residues, implied emission factor and resulting N_2O emission.

***Table 11.6** Uncertainty for N_2O emissions, activity data (AD) and implied emission factor (IEF) from remaining crop residues*

IPCC	Source category	U AD	U IEF	U emission
3Da4	Remaining crop residues	2%	44%	44%

11.8 Source-specific aspects for direct N_2O emissions from agricultural use of organic soils

11.8.1 Calculation method

Direct nitrous oxide emissions from agricultural use of organic soils are calculated by multiplying the amount of mineralized nitrogen in organic soils, peat soils and other organic soils, by a country-specific emission factor.

$$N_2O \text{ emission 3Da6} = \Sigma \text{ (supply source}_m \text{ x EF}_m\text{) x 44/28} \tag{11.7}$$

In which

supply source$_m$	: Amount of N mineralized in organic soils (peat soils and other organic soils) in kg N
EF$_m$	: Emission factor for mineralized nitrogen in organic soils in kg N_2O-N/kg N in supply source
44/28	: Conversion factor from N_2O-N to N_2O

These emissions are being reported under their respective CRF categories.

Comparison to IPCC methodology
The methodology described above conforms to the IPCC method, as described in the IPCC Guidelines (IPCC, 2006).

11.8.2 Activity data

Nitrous oxide emissions are determined by multiplying the area of peat and other organic soils by specific Dutch emission factors. The extent of the areas cultivated is estimated from the land use maps of the Land Use, Land Use Change and Forestry (LULUCF) sector. Maps are available for the base year 1990, 2004, 2009 and 2013. Between these years interpolation takes place. An overview of the resulting areas can be found in Annex 18 to Van Bruggen *et al.* (2015).

Uncertainty in activity data for cultivation of organic soils
Uncertainty in the area of histosols is estimated to be 20%. Uncertainty in the area of other organic soils is estimated to be 35%. This area is a category between sand and peat and is harder to detect, so uncertainties are larger than the uncertainty in the area of histosols.

11.8.3 Emission factors

Average mineralization is 233.5 kg N per hectare peat soil and 204.5 kg N per hectare other organic soil (Kuikman *et al.*, 2005). Using an emission factor of 0.02 (largely taken from Dutch research projects conducted in the first half of the 1990s and reported in Kroeze, 1994), the nitrous oxide emission of histosols amounts to 4.67 kg N_2O–N per hectare peat soil and 4.09 kg N_2O-N per hectare other organic soils.

Uncertainty in emission factors for N_2O from the cultivation of organic soils
Uncertainty in mineralization is 25% (expert judgement based on Kuikman *et al.*, 2005). Kroeze (1994) gives a range in emission factor between 1.25% and 2.5%. The largest of these two gives an uncertainty of 37.5%. The same emission factor as the histosols is used for other organic soils. Because measurements are only done for histosols uncertainty is larger: 50%.

11.8.4 Uncertainty

The implied emission factor includes mineralization and the emission factor. The categories histosols and other organic soils are aggregated.

Table 11.7 *Uncertainty for N_2O emissions, activity data (AD) and implied emission factor (IEF) from agricultural use of organic soils*

IPCC	Source category	U AD	U IEF	U emission
3Da6	Agricultural use of organic soils	18%	37%	41%

11.9 Source-specific aspects for indirect N_2O emissions after depositions of NH_3 and NO_x on the soil

11.9.1 Calculation method

Indirect N_2O emissions occur after atmospheric depositions of nitrogen compounds that have evaporated in the form of NH_3 and NO_x from animal houses and manure storage (attributed to manure management, see Chapter 5 and 6); from inorganic N fertilizer, animal manure application, grazing, sewage sludge and compost (attributed to agricultural soils, this chapter).

Indirect N_2O emissions after atmospheric depositions of nitrogen compounds are calculated by multiplying the amount of nitrogen by the default 2006 IPCC emission factors.

$$N_2O \text{ emission 3Db1} = \sum \text{supply source}_m \times EF \times 44/28 \qquad (11.8)$$

In which

supply source$_m$	: Amount of N from atmospheric deposition
EF	: Default IPCC emission factor (kg N_2O-N/kg N supply) for atmospheric deposition
44/28	: Conversion factor from N_2O-N to N_2O

Comparison to IPCC methodology
The aforementioned method is similar to the IPCC method as described in the IPCC Guidelines (IPCC, 2006).

The IPCC also differentiates between one other supply sources. N_2O formation in the atmosphere from NH_3 emissions. The IPCC gives no calculation method for this source, therefore the nitrous oxide emissions created by NH_3 in the atmosphere are not included here.

Determining the extent of the various supply sources is carried out using country-specific data at Tier 2 or 3 level. The N_2O emissions are determined via a Tier 1 analysis. Default IPCC emission factors are used.

11.9.2 Activity data

Although the term ‘deposition’ is used here, it follows from the IPCC Guidelines that this refers not to real NH_3 and NO_x depositions, but to the total NH_3 and NO_x emissions by the agricultural sector in the Netherlands. This primarily concerns the total depositions of all NH_3 and NO_x emitted by the Netherlands’ agricultural sector, whatever the geographical location of these depositions (thus also outside the country’s borders).

The extent of the NH_3 emissions from inorganic N fertilizer and animal manure application and during grazing, are calculated within the National Emission Model for Agriculture (NEMA) using country-specific emission factors, described in Chapters 5 and 9. For NO_x emissions EMEP default emission factors for the application of inorganic N fertilizer, application of animal manure and grazing are applied, described in Chapters 6 and 10.

Uncertainty in activity data for indirect emissions following atmospheric deposition
Uncertainty for total N emissions is 25%.

11.9.3 Emission factors

The lack of measurement data in the Netherlands means that IPCC default emission factors of 0.01 kg N_2O–N per kg N supply were chosen when calculating the indirect emissions of nitrous oxide (Denier van der Gon *et al.*, 2004; Van der Hoek *et al.,* 2007). IPCC gives an uncertainty of 400%.

11.9.4 Uncertainty

Table 11.8 presents the uncertainty in NH_3 and NO_x emissions from agricultural soils, implied emission factor and resulting N_2O emission.

Table 11.8 *Uncertainty for N_2O emissions, activity data (AD) and implied emission factor (IEF) from indirect N_2O from atmospheric deposition*

IPCC	Source category	U AD	U IEF	U emission
3Db1	Indirect N_2O from atmospheric deposition	25%	400%	413%

11.10 Source-specific aspects for indirect N_2O emissions from leaching and runoff of nitrogen added to the soil

11.10.1 Calculation method

Indirect nitrous oxide emissions from aquatic systems occur through nitrogen (especially nitrate) leaching and runoff from agricultural soils. Nitrate undergoes denitrification in groundwater or surface water, which creates nitrous oxide.

The following calculation rule is used to calculate the nitrous oxide emissions for this supply source.

$$N_2O \text{ emission 3Db2} = \sum (NH_3\text{-N emissions} + NO_x\text{-N emissions}) \times FRAC_{leach} \times EF \times 44/28 \quad (11.9)$$

In which
$FRAC_{leach}$: Fraction of the nitrogen that is leaching and running off
EF : Emission factor in kg N_2O-N/kg N supply
44/28 : Conversion factor from N_2O-N to N_2O

The amount of nitrogen refers to the total amount of inorganic N fertilizer and the amount of animal manure applied to soils. The emission factor used is the IPCC default and the $FRAC_{leach}$ is country-specific. Further background information on the $FRAC_{leach}$ values can be found in Velthof and Mosquera (2011). Further information concerning the nitrous oxide emission factor of 0.0075 can be found in the 2006 IPCC Guidelines (footnote on p. 11.24).

Comparison to IPCC methodology
The aforementioned method is similar to the IPCC method as described in the IPCC Guidelines (IPCC, 2006).

The IPCC also differentiates between one other supply sources. Discharging effluent from sewage treatment plants into surface water. The nitrous oxide emissions created from discharging effluent into surface water are not included in the agricultural sector, but in the CRF (Common Reporting Format) Category 5B.

Determining the extent of the various supply sources is carried out using country-specific data at Tier 2 or 3 level. The N_2O emissions are determined via a Tier 1 analysis. Default IPCC emission factors are used.

11.10.2 Activity data

Activity data includes all nitrogen applied to soils directly, inorganic fertilizer described in section 11.2, animal manure described in section 11.3, sewage sludge described in section 11.4, compost described in section 11.5, urine and dung deposited by grazing animals described in section 11.6, crop residues described in section 11.7 and mineralization of organic soils described in section 11.8.

Uncertainty in activity data for leaching and run-off
Uncertainty is also calculated and is 9%.

11.10.3 Emission factors

With respect to *leaching and runoff* of the nitrogen added to soil, the emission factor concerns that part of the nitrogen that is leached and runoff, the so-called $FRAC_{leach}$. A country-specific value of 15 to 13% is applied because of the relatively high groundwater tables in the Netherlands (Velthof and Mosquera, 2011). The default emission factor of 0.0075 is used.

Table 11.9 *$FRAC_{leach}$ and nitrous oxide emission factors for indirect nitrous oxide emissions from leaching and runoff.*

Supply source	Factor
- $FRAC_{leach}$	0.15 kg N per kg N to soil (1990-1991)
	0.14 kg N per kg N to soil (1992-1997)
	0.13 kg N per kg N to soil (1998-present)
- nitrous oxide emission factor	0.0075 kg N_2O–N per kg N leached/runoff

Source: Velthof and Mosquera, 2011.

Uncertainties in indirect N_2O emissions are described in Table 11.10.

Uncertainty in emission factors for indirect N_2O emission from leaching and run-off
Uncertainty in $FRAC_{leach}$ is estimated to be 50%.

The uncertainty in the emission factor is 233% (largest range in the Guidelines: highest value 0.025).

11.10.4 Uncertainty

Multiplying uncertainty in N supply and leaching fraction gives an uncertainty in activity data of 51%.

Table 11.10 *Uncertainties of indirect N_2O emissions, activity data and implied emission factor from leaching and runoff*

IPCC	Source category	U AD	U IEF	U emission
3Db2	Indirect leaching and runoff	51%	233%	267%

12 $PM_{10/2.5}$ emissions from crop production and agricultural soils (NFR category 3D)

12.1 Scope and definition

The NFR source category 3D Crop production and agricultural soils consists of:
- 3Dc Farm-level agricultural operations including storage, handling and transport of agricultural products
- 3De Cultivated crops
- 3Df Use of pesticides

PM emissions occurring during the use of inorganic N fertilizers, take place during the loading of the applicator. Therefore these are not reported under category 3Da1 Inorganic N fertilizers (includes also urea application) but 3Dc Farm-level agricultural operations including storage, handling and transport of agricultural products. No emissions of PM occur in the source categories 3Da2a Livestock manure applied to soils, 3Da2a Sewage sludge applied to soils, 3Da2c Other organic fertilizers applied to soils (including compost), 3Da3 Urine and dung deposited by grazing animals, 3Da4 Crop residues applied to soils and 3Db Indirect emissions from managed soils. Activities under 3Dd Off-farm storage, handling and transport of bulk agricultural products are covered by other sectors. Since field burning is prohibited by law (article 10.2 of the Environmental Management Act, or 'Wet Milieubeheer' in Dutch) no emissions take place in category 3F Field burning of agricultural residues. Lastly the Netherlands chose not to report PM emissions under category 3I Agriculture other.

Particulate matter emissions from crop production occur during soil cultivation or crop harvesting, and depend on crop sort, soil type, methods used and the weather. Also during other agricultural activities particulate matter is being emitted (e.g. during haymaking and in the use of concentrates, inorganic N fertilizers and pesticides). These emissions are allocated towards categories 3De and 3Dc, respectively.

12.2 Source specific aspects for PM emissions from farm level operations

12.2.1 Calculation method

PM emissions from farm level operations consist of PM_{10} and $PM_{2.5}$ for the use of concentrates, fertilizer and pesticides. PM emissions during transport and handling of concentrates, fertilizer and pesticide have been calculated once using a country-specific method (Chardon and Van der Hoek, 2002) and kept constant for the whole time series.

12.2.2 Activity data

Activity data for inorganic fertilizer use are described in section 9.2.2.

Uncertainty in activity data for PM from farm level operations
Uncertainties in fertilizer, pesticide and concentrate use are estimated to be 25% (expert judgement). Use of rinsing liquid has no PM emissions because it is a liquid.

12.2.3 Emission factor

Table 12.1 presents the emission estimates for farm level operations.

Table 12.1 Emission factors for particulate matter from other sources

Source category	PM_{10}	$PM_{2.5}$
	Emission (ton/year)	
Synthetic fertilizers	105.0	21.0
Concentrates	90.0	18.0
Pesticides	125.0	25.0

Source: Chardon and Van der Hoek (2002).

Uncertainties are estimated to be 100% (expert judgement).

12.2.4 Uncertainty

Table 12.2 presents the uncertainty in farm level operations, implied emission factor and resulting PM emission.

***Table 12.2** Uncertainty for PM emissions, activity data and implied emission factors from farm level operations*

NFR	Source category	U AD	U IEF	U emission
3Dc	Inorganic fertilizer	25%	100%	106%
3Dc	Concentrates	25%	100%	106%
3Df	Pesticides	25%	100%	106%

12.3 Source-specific aspects for PM emissions from crop cultivation

12.3.1 Calculation method

PM emissions from crop cultivation are calculated using a Tier 2 method. The area of each crop is multiplied by emission factors for soil cultivation, harvesting, cleaning and drying in wet climate conditions. The total PM emissions from all supply sources are then calculated by adding up the PM emissions per supply source.

Crop cultivation is calculated using formula 12.1:

$$\text{PM emission (kg PM)} = \sum \text{area}_q \times \text{EF}_q \times n \qquad (12.1)$$

In which

area_q	: Cropped area for the defined crop (q) (ha)
EF_q	: Emission factor for the defined crop (q) in kg per ha
n	: Number of times the operation is performed on the crop

The emission factor in aforementioned formula takes into account the following operations:
1. Soil cultivation;
2. Harvesting;
3. Cleaning;
4. Drying.

The emission of haymaking has been calculated by multiplying the production by an emission factor. But due to uncertainties the emission is kept constant during the time series.

These emissions are being reported under NFR category 3Dc Farm-level agricultural operations including storage, handling and transport of agricultural products.

Comparison to EMEP methodology
The methodology described above conforms to the EMEP method.

12.3.2 Activity data

Information on the areas used for crop production are taken from the Agricultural census. The production of hay making comes from Chardon and Van der Hoek. Uncertainty in crop area is 5%. Uncertainty in haymaking is 25% (expert judgement).

12.3.3 Emission factors

For emissions that arise during the tillage of crops, EMEP default emission factors are used (EEA, 2016). Uncertainties in emission factors are 400%. Haymaking has an additional estimate, as derived by Chardon and Van der Hoek (2002). Table 12.3 presents an overview.

Table 12.3 *Emission factors for particulate matter from crops*

Crop	PM_{10}	$PM_{2.5}$
	Emission factor (kg/ha)	
Wheat	1.49	0.212
Barley	1.25	0.168
Rye	1.15	0.149
Oats	1.78	0.251
Other crops	0.25	0.015
	Added estimate (ton/year)	
Haymaking	6.0	1.2

Source: EEA (2016), Chardon and Van der Hoek (2002).

Uncertainty is estimated to be 100% for haymaking (expert judgement).

12.3.4 Source-specific uncertainty

Table 12.4 presents the uncertainty in crop cultivation, implied emission factor and resulting PM emission.

Table 12.4 *Uncertainty for PM emissions, activity data and implied emission factors from harvesting*

NFR	Source category	U AD	U IEF	U emission
3Dc	Harvesting	2%	28%	28%

13 CO_2 emissions from liming (CRF category 3G)

13.1 Scope and definition

Calcareous fertilizers (calcic limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$)) are used to reduce soil acidity. CO_2 emissions occur as the carbonate lime dissolves and releases bicarbonate. Bicarbonate ($2HCO_3^-$) evolves into H_2O and CO_2.

13.2 Source-specific aspects

13.2.1 Calculation method

CO_2 emissions as a result of using lime on agricultural soils are determined for reporting in Table 3G of the CRF. The amounts used are reported in the Agricultural Statistics for the total of lime fertilizer products (Wageningen Economic Research/Statistics Netherlands, for various years). The available figures are totals and do not specify the application on grassland and cropland separately. Since these figures are reported in CO_2-eq there is no need to correct for inaccuracy and the CO_2 emissions can be calculated with a Tier 1 method as follows:

$$CO_2 \text{ emissions 3G} = (\text{limestone use} \times EF_{limestone} + \text{dolomite use} \times EF_{dolomite}) \times 44/12 \qquad (13.1)$$

In which

CO_2 emissions 3G	: Carbon dioxide emissions (kg CO_2/year) from CRF source category 3G Liming
$EF_{limestone}$	: Emission factor (kg CO_2-C/kg applied) for limestone
$EF_{dolomite}$	: Emission factor (kg CO_2-C/kg applied) for dolomite
44/12	: Conversion factor from CO_2-C to CO_2

13.2.2 Activity data

Information on the amount of carbonate applied to soil originates from Wageningen Economic Research. Input on carbonate use comes from industrial processing records and import/export data from retailers of lime fertilizers.

Uncertainty in activity data for liming
Uncertainty in the use of limestone is 18% as is the uncertainty in dolomite use (25% in total use; expert judgement).

13.2.3 Emission factors

IPCC 2006 Tier 1 default values are used for lime use on agricultural soils, i.e. 0.12 kg CO_2-C/kg limestone and 0.13 kg CO_2-C/kg dolomite. These translate to 440 kg CO_2/ton pure limestone and 477 kg CO_2/ton pure dolomite.

Uncertainty in emission factors for CO_2 from liming
Uncertainty in both emission factors is 1% (expert judgement) This uncertainty is very low, because in the end all C will emit as CO_2.

13.2.4 Uncertainty

Table 13.1 presents the uncertainty in liming, implied emission factors and resulting CO_2 emission.

Table 13.1 *Uncertainty for CO_2 emissions, activity data and implied emission factors from liming*

IPCC	Source category	U AD	U IEF	U emission
	Limestone	37%	1%	37%
	Dolomite	34%	1%	34%
3G	Liming			25%

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Justification

This report is an account of the methods used for the calculation of emissions to air from agriculture in the Netherlands over the 1990-2016 period, as reported in the National Inventory Report 2018 (NIR; for greenhouse gases) and Informative Inventory Report 2018 (IIR; for air pollutants). With these annual reports, the Netherlands fulfills the reporting requirements of the Kyoto and Gothenburg protocols. Results were also published in the Dutch language (see Van Bruggen *et al.*, in press).

Emissions are assessed with the National Emission Model for Agriculture (NEMA) which is approved by the independent Dutch Scientific Committee of the Manure Act (CDM). Statistics Netherlands (CBS) is the administrator of the NEMA model. The work is guided by the task force Agriculture and Land Use (TgL) of the Pollutant Release and Transfer Register (PRTR, or “Emissieregistratie” (ER) in Dutch). For greenhouse gas reporting, the Netherlands Enterprise Agency (RVO.nl) reviews proceedings acting as the National Inventory Entity (NIE).

The methodologies used follow or comply with the 2006 IPCC Guidelines (greenhouse gases) and the 2016 EMEP Guidebook (air pollutants). The draft report was reviewed and approved by Peter Zijlema and Harry Vreuls (RVO.nl).

Annex 1 Calculation of TAN excretion for dairy cattle and young stock

Translation with adaptation of the annex from L. Šebek & A. Bannink (Division Animal Husbandry, Animal Sciences Group (ASG), WUR) in Velthof *et al.*, 2009.

Introduction
Until 2009, the NH_3 emission is estimated by means of an emission percentage applied on total N excretion. It is however mainly the excretion of urine N that is responsible for the NH_3 emission. Therefore, the current aim is to estimate NH_3 emission based on excreted urine N. Excretion of urine N is comparable to that of total ammoniacal N (TAN). A description of the calculation method of TAN is given here.

Calculation method
The total N excretion is calculated in accordance with the method used by the WUM, also used by Tamminga *et al.* (2000, 2004) to derive the fixed excretion figures for various livestock categories. In this method the uptake of N with the separate ration components is calculated, and total N excretion as the difference between N uptake and N retained in animal products (milk, growth, offspring).

For the results reported in the present document, the same method was used but it was extended with an estimation of the digestion coefficient (DC) for crude protein (CP). Introduction of DC-CP is required to be able to calculate TAN. The calculation is performed for each feedstuff in the ration separately. With the DC-CP per feedstuff the percentage of crude protein uptake can be calculated that is absorbed by the intestine (= digested). The remainder (100% - DC-CP) of crude protein uptake leaves the body with the faeces. Protein absorbed by the intestine is either used for production (milk, growth, offspring) or excreted as urine N by the kidneys. By setting the TAN equal to the excretion of urine N, TAN is calculated by the following steps:

- summation of the amount crude protein uptake that is absorbed in the intestine for all feedstuffs in the ration,
- conversion of absorbed protein to absorbed N,
- calculation of N retained with animal production,
- calculation of excreted urine N as the difference between absorbed N and N retained with animal production.

Calculation of the DC-CP
The CVB animal feed table (CVB, 2005a) lists DC-CP values (as a % of crude protein content) for all common products. For roughages this is dependent on the quality of the roughage. Regression equations have been published to calculate the DC-CP based on chemical composition (crude protein content, crude ash content and crude crude fibre content; CVB, 2005b). In Table A1.1 the DC-CP is given for the various ration components fed to young stock.

Fecal N digestibility of dairy is now calculated using the Tier 3 method because above method gives an overestimation. For young cattle above method is corrected using the difference calculated for dairy cattle.

Used data
The amounts of feed that has been provided yearly to the different livestock categories are according to the report of the Working group on Uniformity of Manure and mineral data (WUM). Also data are available for milk production, and the composition of roughages (based on yearly statistics on analyses of silages by the laboratory Eurofins Agro (formerly Blgg and AgroXpertus), concentrates (based on reports of feed manufacturers) and by-products (based on amounts of products marketed). These figures are recently used and described by Smink *et al.* (2005) for the calculation of the methane emission of dairy cattle and the same data are used in the present study. For moisture-rich by-products it is assumed that these consisted of 25, 40 and 35% of brewers' grains, potato products and sugar beet pulp. This division compares well to the WUM report of the availability by-products for cattle (respectively 26, 35 and 26%; 30:40:30 ratio).

For young stock the WUM rations of 1990 have been used in accordance with the starting points in the available WUM-Rav excretion data. The composition of roughages and concentrates was assumed equal to that of dairy cattle in the year 2001.

Table A1.1 The CP content, the ammonia content and the faecal CP digestibility for the various ration components in the ration of young stock

	CP content[1)]	Ammonia content	DC-CP[2)]
	g CP/kg DM	% CP	%
Fresh grass / grass herbage	229	0	85
Grass silage (+ hay)	191	10	77
Maize silage	81	10	50
Standard concentrate	180	0	70
Protein-rich concentrate	330	0	82
By-products[3)]			
Brewers' grains	250	0	80
Potato pulp	85	0	36
Pressed sugar beet pulp	115	0	65
Whole milk	35	0	86

[1)] Including ammonia N.

[2)] Concerns an estimation of the real instead of apparent digestibility of crude protein.

[3)] Only most abundant product in the category mentioned here (brewers' grains for category protein-rich by-products, potato pulp for category of rest material potato processing industry, pressed sugar beet pulp for category of pulps and vegetables).

Other starting points/assumptions

Correction CP content for ammonia fraction. It was assumed that ammonia N (expressed as CP) accounted for 10% of the total CP content in both grass silage and maize silage.

Correction feed uptake for so-called "feed losses". For the time being no corrections have been made for feed losses because these also seem not to have been made in the calculation of the N excretions in WUM-Rav. If the corrections in the feeding of dairy cattle according to the current WUM methodology (0, 5, 3 and 2% feed losses for respectively fresh grass, grass silage, maize silage, moist by-products and concentrates) were to be made this would lead to much lower N excretions than the reported 131.0 kg N/dairy cow/year according to WUM-Rav.

Composition urine N. For the time being 100% of the urine N is considered as TAN and no differentiation is made between N holding components that do not (quickly) lead to ammonia formation (Reijs, 2007).

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Annex 2 Calculation of TAN excretion for pigs

Translation with adaptation of the annex from Age Jongbloed (Animal Sciences Group (ASG), Wageningen UR, Lelystad) in Velthof *et al.*, 2009.

A2.1 The excretion of nitrogen in pig farming

A2.1.1 Nitrogen content in pigs

In Table A2.1 is indicated what the N contents (g per kg live weight) are in the livestock categories distinguished. Also the sources are indicated.

Table A2.1 N contents in livestock categories distinguished (Ref. = reference year)

Livestock category	Physiological status	Ref.	Weight Ref. (kg)	N content Ref.	Weight 2005 (kg)	N content 2005 (g/kg)	Source contents Ref.
Stillborn piglet	0 days	1994	1.3	19.2	1.3	18.73	1
Lost piglet	1-28 days	1994	2.8	19.2	2.8	23.1	1
Lost piglet	29-42 days	1994	9.0	24.0	9.0	24.3	1
Weaned piglet	6 weeks	1994	11.0	24.0	11.0	24.4	1
Lost piglet	7 weeks	1994	12.0	24.0	12.0	24.5	1
Starter piglet	Ca. 10 weeks	1991	25.7	24.0	25.6	24.8	1
Fattening pig	Ca. 26 weeks	1991	109	23.0	115.7	25.0	1
Gilts	7 months	2001	125	24.9	125	24.9	2
Gilts	First mating	2001	140	24.9	140	24.9	2
Young boar	7 months	2001	135	24.9	135	24.9	2
Boar	7 months	1991	130	23.3	-	-	1
Boar	2 years	1991	300	24.6	325	25.0	1
Sow	At weaning	1994	205	24.9	220	25.0	1
Slaughter sow	1 week after weaning piglets	1994	205	24.9	220	25.0	1

1 = WUM, 1994; 2 = Jongbloed and Kemme, 2002.

A2.1.2 The N content and the N digestibility of pig feeds

In Table A2.2 an overview is given of the N contents in the various pig feeds with which calculations have been made.

The N content in the various feeds in the reference year is for an important part derived from WUM (1994) for the year concerned and for the reference year 2001 from Jongbloed and Kemme (2005). The N content in the feeds for 2005 is for most feeds derived from Jongbloed and Van Bruggen (2008).

Table A2.2 Overview of the N contents and the N digestibility (DC-N) in the various pig feeds for the reference year and 2005

	Reference year			2005	
	Year	N (g/kg)	DC-N (%)	N (g/kg)	DC-N (%)
Piglet rearing feed/weaning feed	1994	29.0	83.0	28.8	83.0
Baby piglet feed (12-26 kg)	1994	29.0	83.0	28.8	83.0
Starting feed (26-40 kg)	1991	28.2	81.9	25.2	81.0
Starting feed gilts/young boars (26-40 kg)	2001	27.1	81.0	27.1	81.0
Fattening pig feed (40-110 kg)	1991	26.0	80.1	25.2	78.6
Gilts/young boars feed (40-125 kg)	2001	24.5	80.5	25.2	78.0
Standard sow feed	1991	25.7	79.0	-	-

	Reference year			2005	
Standard sow feed	1994	25.4	79.0	-	-
Lactating sow feed	1991	24.6	80.0	25.2	78.0
Lactating sow feed	1994	-	-	25.2	78.0
Lactating sow feed	2001	24.5	80.0	25.2	78.0
Sow in pig feed	1994	-	-	21.9	66.2

A2.1.3 Estimation of the N digestibility in the feeds

The digestibility of N in the feeds is for the reference year based on some publications in which the resource composition of feeds was given. On enquiry with several composite feed companies no information on this was available as it is stored for only five or six years. The digestibility of N is estimated based on the given digestibilities for those according to the Animal feed table (CVB, 2007). Unfortunately only sporadic information was available of the resource composition of the feeds that were produced in 2005. In the same way as above the N digestibility was estimated. There where data were missing based on consultation with some specialists within and outside ASG a best possible estimation of the N digestibility was made.

A2.2 Breeding sows with piglets up to ca. 6 weeks of age (category 400)

A2.2.1 Starting points

The start weight of the sows for 1994 and for 2005 is set to 140 kg and the end weight is for 1994 and 2005 set to 205 respectively 220 kg. Based on Agrovision (1994, 2005) for 1994 calculations can be made with a farm litter index of 2.25 and for 2005 of 2.31.

The replacement of sows amounted 47% in 1994 and in 2005 this was 45% (Agrovision, 1994; 2005). According to Agrovision (1994) a breeding sow of which the piglets are weaned at 4 weeks, takes up 1,079 kg of feed per year in 1994; in 2005 that is 1,145 kg, of which circa 65% as sow in pig feed and 35% as lactating sow feed.

The number of live born piglets per litter is according to Agrovision (1994) on average 10.9 and in 2005 the number of live born piglets per litter is 12.0. The number stillborn piglets per litter was in 1994 and 2005 0.7 respectively 1.0 (Agrovision, 1994; 2005).

The weight of piglets on 42 days is 11.0 kg in 1994 and 10.8 kg in 2005. The feed uptake of piglets up to day 42 after birth is set to 4.5 kg in 1994 (Backus *et al.*, 1997) and 4.48 kg in 2005. This amount is in vast majority weaning feed.

The N content of the weaning feed in 1994 was 29.0 g/kg and in 2005 28.8 g/kg. The N digestibility in the weaning pellet is derived from the feed composition according to Kloosterman and Huiskes (1992) and was 83.3%; for 2005 83.0% is taken. The sow feed in 1994 contained 25.4 g N/kg (WUM, 1994), while in 2005 the sow in pig feed and lactating sow feed contained 21.9 respectively 25.2 g N/kg (Jongbloed and Van Bruggen, 2008). The N digestibility of the sow feed in 1994 is estimated based on the feed composition according to Everts *et al.* (1991) and was 79.0%. The N digestibility of the sow in pig feed is derived from the feed composition of a composite feed manufacturer during the first half of 2006 and was 66.2%. According to another composite feed manufacturer in 2005 the N digestibility of lactating sow feed was 78.0%.

A2.2.2 Results breeding sows with piglets up to ca. 6 weeks of age

In Table A2.3 is based on above mentioned starting points for breeding sows with piglets up to ca. 6 weeks of age an overview given of the N housekeeping if a sow place would be occupied the whole year (no days lost).

Table A2.3 N housekeeping (kg) by breeding sows with piglets up to ca. 6 weeks of age on yearly basis (category 400)

Category 400	1994			2005		
	g N/kg	DC-N	N uptake (kg)	g N/kg	DC-N	N uptake (kg)
Weaning feed	29.0	83.3	2.71	28.8	83.0	3.15
Sow in pig feed	25.4	78.9	17.81	21.9	66.2	16.15
Lactating sow feed	25.4	78.9	9.59	25.2	78.0	10.27
Total uptake			30.12			29.57
Fixation			7.13			7.71
Excretion			22.98			21.86
In faeces			6.2			8.3
In urine			16.8			13.6
In urine (%)			72.9			62.2

Table A2.3 shows that the N excretion per sow per year compared to 1994, in 2005 has decreased by over 1.0 kg and that there has been a large shift towards much more N in the faeces and much less in the urine. The percentage of the N excretion in the urine decreased from 72.9 to 62.2. This shift is mostly due to the introduction of a sow in pig feed that has to contain much raw fibre in the framework of the Pig decree (1994).

A2.3 Breeding sows with piglets up to ca. 25 kg (category 401)

A2.3.1 Starting points

For data of the breeding sows is referred to the previous section (the description for category 400). The weight of piglets by the start of fattening is according to Agrovision (1994; 2005) 25.7 kg in 1994 and 25.6 kg in 2005. The age at the start of fattening is on average 80 days. The amount of weaning feed taken up per piglet is 4.5 kg. Based on a feed conversion of 1.65 a piglet takes up 30.0 kg of feed before start of fattening in 1994 and in 2005 feed conversion is 1.59 so that per piglet 28.7 kg of feed is taken up (Agrovision, 1994; 2004).

The N contents of the baby piglet feed in 1994 and 2005 were 29.0 respectively 28.8 g/kg. The N digestibility of the baby piglet feed in 1994 is derived from the feed compositions according to Kloosterman and Huiskes (1992) and was 83.3%; for 2005 83.0% is taken.

A2.3.2 Results breeding sows with piglets up to ca. 25 kg

In Table A2.4 is based on abovementioned assumptions for breeding sows with piglets up to ca. 25 kg an overview given of the N housekeeping if a sow place would be occupied the whole year (no days lost).

Table A2.4 N uptake and N excretion (kg) by breeding sows with piglets up to ca. 25 kg on yearly basis (category 401)

Category 401	1994			2005		
	g N/kg	DC-N	N uptake (kg)	g N/kg	DC-N	N uptake (kg)
Weaning feed	29.0	83.3	2.71	28.8	83.0	3.16
Baby piglet feed	29.0	83.3	15.38	28.8	83.0	16.71
Sow in pig feed	25.4	78.9	17.81	21.9	66.2	16.15
Lactating sow feed	25.4	78.9	9.59	25.2	78.0	10.27
Total uptake			45.49			46.30
Retention			14.11			16.53
Excretion			31.38			29.77
In faeces			8.8			11.1
In urine			22.6			18.7
In urine (%)			71.9			62.7

A2.3.3 Discussion breeding sows

Table A2.3 shows that the N excretion per sow per year compared to 1994, decreased with over 1.5 kg in 2005 and that there has been a large shift towards much more N in the faeces and much less in the urine. The percentage of the N excretion in the urine has declined from 71.9 to 62.7. This shift is mainly due to the introduction of a sow in pig feed that has to contain much raw fibre in the framework of the Pig decree (1994).

It has been examined what the effect is on the excretion in faeces and urine if the N digestibility is 1% unit higher or lower. Table A2.5 gives the results of this.

Table A2.5 N uptake and N excretion (kg) by breeding sows with piglets up to ca. 25 kg on yearly basis (category 401) with a higher or lower N digestibility

Category 401	1994			2005		
	DC-N 1 unit lower	DC-N starting point	DC-N 1 unit higher	DC-N 1 unit lower	DC-N starting point	DC-N 1 unit higher
Total uptake	45.49	49.49	45.49	46.30	46.30	46.30
Excretion	31.38	31.38	31.38	29.77	29.77	29.77
In faeces	9.26	8.80	8.35	11.56	11.10	10.63
In urine	22.12	22.58	23.03	18.21	18.67	19.14
In urine (%)	70.5	71.9	73.4	61.2	62.7	64.3

From Table A2.5 follows that as a result of a difference in N digestibility of 2% units a shift of on average 3.0% units will occur.

A2.4 Gilts not yet in pig of ca. 25 kg to ca. 7 months (category 402)

A2.4.1 Starting points

The start and end weight of the gilts not yet in pig for both 2002 is set to 26 respectively 125 kg. This end weight is derived from Jongbloed and Kemme (2005). The average length of the period is calculated to be 133 days, such that the average growth is 744 g/day. In 2002 the ratio between the starting feed and rearing feed for gilts not yet in pig is set to 15:85 (Jongbloed and Kemme, 2005). The total amount of feed during the lay on period for this category of gilts not yet in pig is 287 kg for 2002. For 2005 the same starting points as for 2002 are taken. The N contents of the starting feed and rearing feed in 2002 were 27.1 respectively 24.5 g/kg. For 2005 these contents are 27.1 respectively 25.2 g/kg. The N digestibility of the starting feed is set to 81.0 and of the rearing feed to 78.0 which is equal to the N digestibility of the lactating sow feed.

A2.4.2 Results gilts not yet in pig of 25 kg to ca. 7 months

In Table A2.6 is based on abovementioned starting points for gilts not yet in pig to ca. 7 months an overview given of the N housekeeping if a pig place would be occupied the whole year (no lost days).

Table A2.6 N uptake and excretion (kg) by gilts not yet in pig of 25 kg to ca. 7 months on yearly basis (category 402)

Category 402	2001			2005		
	g N/kg	DC-N	N uptake (kg)	g N/kg	DC-N	N uptake (kg)
Starting feed	27.1	81.0	4.27	27.1	81.0	4.27
Lactating sow feed	24.5	80.0	15.44	25.2	78.0	15.88
Total uptake			19.71			20.15
Retention			6.77			6.77
Excretion			12.93			13.38
In faeces			3.9			4.3
In urine			9.0			9.1
In urine (%)			69.9			67.8

Table A2.6 shows that the N excretion per gilt not yet in pig compared to 2001 decreased somewhat in 2005 and that there has been a shift to more N in the faeces. The percentage of the N excretion in the urine has decreased from 69.9 to 67.8.

A2.5 Gilts not yet in pig of ca. 7 months to first mating (category 403)

A2.5.1 Starting points

The start and end weight of these gilts not yet in pig for both 2002 and 2006 is set to 125 respectively 140 kg (Topigs, 2004). According to this reference it follows that the age at first insemination on average is 243 days, thus the average length of the period can be set to 30 days in 2001 and 2005. The average growth is 500 g/day.

The total amount of the lactating sow feed during the lay on period for this category gilts not yet in pig, is calculated to 72 kg for 2001 and 2005.

The N contents of the lactating sow feed in 2001 and 2005 are 24.5 respectively 25.2 g/kg. The N digestibility of the lactating sow feed is 80.0 respectively 78.0%.

A2.5.2 Results gilts not yet in pig of ca. 7 months to first mating

In Table A2.7 is based on abovementioned starting points for this category gilts not yet in pig an overview given of the N excretion if a pig place would be occupied for the whole year (no loss of days).

Table A2.7 N uptake and excretion (kg) by gilts not yet in pig of ca. 7 months to first mating on yearly basis (category 403)

Category 403	2001			2005		
	g N/kg	DC-N	N uptake (kg)	g N/kg	DC-N	N uptake (kg)
Lactating sow feed	24.5	80.0	21.46	25.2	78.0	22.08
Fixation			4.54			4.54
Excretion			16.92			17.53
In faeces			4.3			4.9
In urine			12.6			12.7
In urine (%)			74.6			72.3

Table A2.7 shows that the N excretion per gilt not yet in pig compared to 2001 increased somewhat in 2005 and that there has been a shift to more N in the faeces. The percentage of the N excretion in the urine decreased from 74.6 to 72.3%.

A2.6 Gilts not yet in pig of ca. 25 kg to first mating (category 404)

A2.6.1 Starting points

The begin and end weight of the gilts not yet in pig for both 2001 and 2005 is set to 26 respectively 140 kg (for more details see the description for categories 402 and 403). The average length of the period is calculated to 163 days, so that the average growth is 699 g/day. In 2002 the ratio between the starting feed, rearing feed and lactating sow feed for gilts not yet in pig during the lay on period is set to 16:64:20, and for 2006 to 4:76:20 (Jongbloed and Kemme, 2005). The total amount of feed during the lay on period for this category gilts not yet in pig for 2001 and 2005 is 359 kg. For 2005 further the same starting points as for 2001 are taken.

The N contents of the starting feed, gilts not yet in pig feed and lactating sow feed in 2001 were 27.1, 24.5 respectively 24.5 g/kg. For 2005 the contents in these feeds are 27.1, 25.2 respectively 25.2 g/kg. The N digestibility of the feeds in 2001 is set to 81.0, 80.5 respectively 80.0%, while those for 2005 were 81.0%, 79.0% respectively 79.0%.

A2.6.2 Results gilts not yet in pig of 25 kg to first mating

In Table A2.8 is based on abovementioned starting points for gilts not yet in pig an overview given of the N housekeeping if a pig place were to be occupied the whole year (no loss of days).

Table A2.8 N uptake and excretion (kg) by gilts not yet in pig of 25 kg to first mating on yearly basis (category 404)

Category 404	2001			2005		
	g N/kg	DC-N	N uptake (kg)	g N/kg	DC-N	N uptake (kg)
Starting feed	27.1	81.0	3.49	27.1	81.0	3.49
Gilts not yet in pig feed	24.5	80.5	12.61	25.2	78.0	15.40
Lactating sow feed	24.5	80.0	3.94	25.2	78.0	1.62
Total uptake			20.03			20.50
Fixation			6.36			6.36
Excretion			13.67			14.14
In faeces			3.9			4.4
In urine			9.8			9.7
In urine (%)			71.4			68.8

Table A2.8 shows that the N excretion per gilt not yet in pig per year compared to 2001 increased somewhat in 2005 and that a shift occurred to more N in the faeces. The percentage of the N excretion in the urine has decreased from 71.4 to 68.8%.

A2.7 Young boars of ca. 25 kg to ca. 7 months (category 405)

A2.7.1 Starting points

The start and end weight of the young boars for both 2001 as 2005 is set to 26 respectively 135 kg. The average length of the period is 133 days in 2001 and 2005, so that the average growth per animal per day is 820 grams. In 2001 and 2005 the feed conversion of this category pigs is 2.66. In 2001 and also 2005 during the lay on period a ratio between starting feed, growth feed and finishing feed of 15:20:65 is taken (Jongbloed and Kemme, 2005). This ratio is applied on the total amount of feed (290 kg).

The N contents of the starting feed, growth feed and finishing feed in 2001 were 27.1, 24.5 respectively 25.7 g/kg. These contents in 2005 were 27.1, 25.2 respectively 25.2 g/kg.

The N digestibility of the feeds was in 2001 81.0%, 80.5% respectively 80.5% and in 2005 81.0%, 78.0% respectively 81.0%.

A2.7.2 Results young boars

In Table A2.9 is based on abovementioned starting points for young boars an overview given of the N housekeeping if a pig place were to be occupied the whole year (no loss of days).

Table A2.9 N uptake and excretion (kg) by young boars to ca. 7 months on yearly basis (category 405)

Category 405	1991			2005		
	g N/kg	DC-N	N uptake (kg)	g N/kg	DC-N	N uptake (kg)
Starting feed	27.1	81.0	3.24	27.1	81.0	3.24
Lactating sow feed	24.5	80.5	16.57	25.2	78.0	17.05
Total uptake			19.81			20.28
Fixation			7.46			7.45
Excretion			12.35			12.83
In faeces			3.8			4.4
In urine			8.5			8.5
In urine (%)			68.9			66.0

Table A2.9 shows that the N excretion per young boar per year compared to 2001 increased somewhat in 2005 and that a shift occurred toward more N in the faeces. The percentage of the N excretion in the urine decreased from 68.9 to 66.0%.

A2.8 Breeding boars of ca. 7 months and older (category 406)

A2.8.1 Starting points

The start and end weight of the breeding boars for 1991 is set to 130 kg respectively 300 kg, for 2005 these weights are 135 kg respectively 325 kg. The average length of the period that these breeding boars are present is 548 days (WUM, 1994) which is also taken for 2005. The average feed uptake in 1991 is set to 2.9 kg/day (WUM, 1994) and in 2005 3.0 kg/day (Jongbloed and Kemme, 2005).

The N content of the feed that is given to breeding boars (sow feed) was in 1991 25.7 g/kg and in 2005 the lactating sow feed contained 25.2 g/kg. The N digestibility in the sow feed was in 1991 and 2005 78.9% respectively 78.0%.

A2.8.2 Results breeding boars older than 7 months

In Table A2.10 is based on abovementioned assumptions for breeding boars an overview given of the N housekeeping if a pig place would be occupied the whole year (no loss of days).

Table A2.10 N uptake and excretion (kg) by breeding boars of 7 months and older on yearly basis (category 406)

Category 406	1991			2005		
	g N/kg	DC-N	N uptake (kg)	g N/kg	DC-N	N uptake (kg)
Lactating sow feed	25.7	78.9	27.20	25.2	78.0	27.59
Fixation			2.90			3.18
Excretion			24.30			24.42
In faeces			5.7			6.1
In urine			18.6			18.3
In urine (%)			76.4			75.1

Table A2.10 shows that the N excretion per breeding boar compared to 1991 remained almost the same in 2005 and that a shift has occurred towards more N in the faeces. The percentage of the N excretion in the urine has decreased from 76.4 to 75.1%.

A2.9 Piglets of ca. 6 weeks to ca. 25 kg (category 407)

A2.9.1 Starting points

The start and end weight of the piglets for 1994 was 11.0 respectively 25.7 kg. For 2005 the weights are set to 10.8 respectively 25.6 kg. The average length of the period is 33 respectively 38 days. The average growth is for 1994 and 2005 445 respectively 389 g per animal per day. The feed conversion of this category piglets in 1994 was 1.74 and is 1.72 in 2005. The N content of the baby piglet feed is 1994 was 29.0 and in 2005 this content was 28.8 g/kg. The N digestibility of the baby piglet feed is in 1994 and 2005 83.0%.

A2.9.2 Results piglets of 6 weeks to 25 kg

In Table A2.11 is based on abovementioned assumptions for piglets of 6 weeks to ca. 25 kg an overview given of the N housekeeping as a pig place would be occupied the whole year (no loss of days).

Table A2.11 N uptake and excretion (kg) by piglets of 6 weeks to ca. 25 kg on yearly basis (category 407)

Category 407	1994			2005		
	g N/kg	DC-N	N uptake (kg)	g N/kg	DC-N	N uptake (kg)
Uptake piglet feed	29.0	83.0	8.18	28.8	83.0	7.04
Fixation			3.92			3.56
Excretion			4.26			3.48
In faeces			1.4			1.2
In urine			2.9			2.3
In urine (%)			67.3			65.6

Table A2.11 shows that the N excretion per weaned piglet of 6 weeks to ca. 25 kg per year compared to 1994 decreased considerably in 2005 and that considerably less N is excreted through the urine. The percentage of the N excretion in the urine decreased from 67.3 to 65.6%.

A2.10 Sows for slaughter (category 410)

A2.10.1 Starting points

The start and end weight of the sows for slaughter in 1994 is 205 kg and for 2005 220 kg. The average length of the period kept is 7 days. It is assumed that in both years per day 3 kg lactating sow feed is taken up.

The N content of the sow feed in 1994 was 24.5 g/kg and of the lactating sow feed in 2005 25.2 g/kg. The N digestibility of these feeds was 78.9 respectively 78.0%.

A2.10.2 Results sows for slaughter

In Table A2.12 is based on abovementioned assumptions for sows for slaughter an overview given of the N housekeeping if a pig place would be occupied the whole year (no loss of days).

Table A2.12 N uptake and excretion (kg) by sows for slaughter of 220 kg on yearly basis (category 410)

Category 410	1994			2005		
	g N/kg	DC-N	N uptake (kg)	g N/kg	DC-N	N uptake (kg)
Uptake sow feed	24.5	78.9	26.83	25.2	78.0	27.59
Fixation			0.0			0.0
Excretion			26.83			27.59
In faeces			5.7			6.1
In urine			21.2			21.5
In urine (%)			78.9			78.0

Table A2.12 shows that the N excretion per sow for slaughter per year compared to 1994 remained almost equal in 2005 and that the percentage of the N excretion in the urine decreased somewhat from 78.9 to 78.0%.

A2.11 Fattening pigs of ca. 25 to ca. 110 kg (category 411)

A2.11.1 Starting points

The start and end weight of the pigs in 1991 is set to 25 respectively 109 kg (WUM, 1994). In 2005 these weights are 25.6 respectively 115.7 kg (Agrovision, 2005). The average growth per animal per day was 712 g in 1991 (WUM, 1994) and in 2005 that was 773 g (Agrovision, 2005). The length of the growth period was therefore 118 respectively 117 days. The feed conversion of the fattening pigs was 2.87 in 1991 and in 2005 that was 2.67. In 1991 during the first part of the lay on period an average amount of 44 kg starting feed and 197 kg fattening pig feed was given (WUM, 1994). In 2005 45 kg starting feed per pig was taken up, 70 kg growth feed and 126 kg finishing feed (Agrovision, 2005). The N content of the starting feed and fattening pig feed in 1991 was 28.2 respectively 26.0 g/kg. For 2005 these contents in the feeds are on average 25.2 g/kg (Jongbloed and Van Bruggen, 2008). The N digestibility of the starting feed in 1991 is estimated based on the raw material composition according to Van der Peet-Schwering (1990) and Kloosterman and Huiskes (1992) and was on average 81.9%. The N digestibility of the fattening pig feed in 1991 is estimated based on the raw material composition according to Van der Peet-Schwering (1990), Kloosterman and Huiskes (1992) and Wahle and Huiskes (1992) and was on average 80.1%.

The N digestibility of the starting feed in 2005 is estimated based on the starting point that as result of the addition of amino acids and somewhat different raw materials, so that it is ca. 1% unit lower than in 1991 and thus 81.0% is assumed. The N digestibility of the fattening pig feed in 2005 is estimated based on the raw material composition of a composite feed manufacturer in the first half year of 2006, and was on average 78.6% of the feeds with an energy value of 1.05 and 1.10.

A2.11.2 Results fattening pigs

In Table A2.13 is based on abovementioned starting points for fattening pigs an overview given of the N housekeeping if a pig place would be occupied during the whole year (no lost days).

Table A2.13 N uptake and excretion (kg) by fattening pigs of ca. 25 to 114 kg on yearly basis (category 411)

Category 411	1991			2005		
	g N/kg	DC-N	N uptake (kg)	g N/kg	DC-N	N uptake (kg)
Starting feed	28.2	81.9	3.83	25.2	81.0	3.55
Fattening pig feed	26.0	80.1	15.83	25.2	78.6	15.43
Total uptake			19.66			18.98
Fixation			5.97			7.07
Excretion			13.70			11.91
In faeces			3.8			4.0
In urine			9.8			7.9
In urine (%)			71.9			66.6

A2.11.3 Discussion fattening pigs

Table A2.13 shows that the N excretion per fattening pig per year compared to 1991 decreased considerably in 2005. As result of the higher N retention the percentage of the N excretion in the urine decreased considerably from 71.9 to 66.6%.

For fattening pigs is examined what the effect is on the excretion in faeces and urine if the digestibility of N in the feeds for fattening pigs is 1% unit lower or higher than in the starting situation (Table A2.14).

Table A2.14 N uptake and excretion (kg) by fattening pigs of ca. 25 to 114 kg on yearly basis (category 411) at a higher or lower N digestibility

Category 411	1991			2005		
	DC-N 1 unit lower	DC-N starting point	DC-N 1 unit higher	DC-N 1 unit lower	DC-N starting point	DC-N 1 unit higher
Total uptake	19.66	19.66	19.66	18.98	18.98	18.98
Excretion	13.70	13.70	13.70	11.91	11.91	11.91
In faeces	4.04	3.84	3.65	4.17	3.98	3.79
In urine	9.65	9.85	10.05	7.75	7.94	8.13
In urine (%)	70.5	71.9	73.4	65.0	66.6	68.2

From Table A2.14 it can be seen that in the dependability of the digestibility of N with a deviation of 2% units, no large shifts occur in the division of N over faeces and urine; this is a difference of 2.9% units in 1991 and 3.2% units in 2005.

A2.12 General discussion

An important attention point is a good insight in the N contents of the various feeds. Also because the use of a whole range of feeds for various categories pigs it is sometimes difficult to know how long those feeds are given. However by means of data from Levies Office (Bureau Heffingen) that insight can be obtained for some important feeds but are lacking for small livestock categories. This needs to receive more attention.

Another point is the N digestibility. Also because of a storage period of five to six years, data on this are lacking in the compound feed industry particularly for the reference years (1991 to 2002). The N digestibility also is not of interest in the formation of the feeds: for protein this is based on ileal or faecal digestible amino acids. Also for the year 2005 it was not possible to gain a reliable insight in the N digestibility. Besides there is such a large array of feeds that it is difficult to classify these correctly. It is hard for the compound feed industry to calculate these data, and possibly competition is a reason not to make these available after all. Ways should be found to obtain more reliable data on the N digestibility in the feeds.

A2.13 Summary pigs

In Table A2.15 a summary is given of the excretion of N and % TAN by various categories of pigs in the reference year and in 2005 in g/year.

Table A2.15 Overview of the excretion of N and % TAN by the various categories of pigs in the reference year and 2005 (kg/year)

Category	Number	Ref. year	N in ref. year	% TAN in ref. year	N in 2005	% TAN in 2005
Breeding sows with piglets up to 6 weeks of age	400	1994	23.0	72.9	21.9	62.2
Breeding sows with piglets to ca. 25 kg	401	1994	31.4	71.9	29.8	62.7
Gilts not yet in pig of ca. 25 kg to ca. 7 months	402	2001	12.9	69.9	13.4	67.8
Gilts not yet in pig of ca. 7 months to first mating	403	2001	16.9	74.6	17.5	72.3
Gilts not yet in pig of ca. 25 kg to ca. 7 months	404	2001	13.7	71.4	14.1	68.8
Young boars of ca. 25 kg to ca. 7 months	405	1991	12.4	68.9	12.8	66.0
Breeding boars of ca. 7 months and older	406	1991	24.3	76.4	24.4	75.1
Piglets of ca. 6 weeks to ca. 25 kg	407	1991	4.3	67.3	3.5	65.6
Sows for slaughter	410	1994	27.8	78.9	27.6	78.0
Fattening pigs	411	1991	13.7	71.9	11.9	66.6

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Annex 3 Calculation of TAN excretion for poultry

Translation with adaptation of the annex from Age Jongbloed (Animal Sciences Group (ASG), WUR, Lelystad) in Velthof *et al.*, 2009.

A3.1 The excretion of nitrogen in the poultry sector

A3.1.1 Calculation methodology

For the approach followed reference can be made to section A2.1.2 and A2.1.3 (see Annex 2).

A3.1.2 Contents of nitrogen in chickens and chicken eggs

In Table A3.1 is indicated what are the N contents (g per kg live weight or per kg produce) for the livestock categories distinguished. Also the references are indicated. The start weight of day-old chickens for respectively the meat sector and the laying sector is set to 42 and 36 g in these calculations.

Table A3.1 Weights and contents of N in various categories of chickens (Ref. = reference year)

Livestock category	Physiological status	Ref.	Weight Ref. (g)	N content Ref. (g/kg)	Weight (g) 2005	N content 2005 (g/kg)	Literature contents
Egg meat sector	-	1993	62	19.2	62	19.3	1
Day-old chicken meat	1 day		42	30.4	42	30.4	3
Broiler	Delivery	2002	2,100	27.8	2,200	27.8	2
Broiler mother parent	19 weeks	2000	2,000	33.4	2,000	33.4	1
Broiler father parent	19 weeks	2000	2,750	34.5	2,750	34.5	1
Broiler mother parent	19 weeks and older	1996	3,600	28.4	3,900	28.4	1
Broiler father parent	19 weeks and older	1996	4,800	35.4	5,000	35.4	1
Egg laying sector	-	1993	62.4	19.2	62.5	18.5	2
Day-old chicken laying	1 day	1993	36	30.4	35	30.4	3
Laying hens battery light	17 weeks old	1991	1,215	28.0	1,285	28.0	2
Laying hens battery heavy	17 weeks old	1991	1,420	28.0	1,520	28.0	2

Livestock category	Physiological status	Ref.	Weight Ref. (g)	N content Ref. (g/kg)	Weight (g) 2005	N content 2005 (g/kg)	Literature contents
Laying hens other heavy	17 weeks old		1,520	28.0	1,520	28.0	2
Laying hens battery light	18 weeks and older	1993	1,750	28.0	1,600	28.0	2
Laying hens battery heavy	18 weeks and older	1993	2,050	28.0	1,800	28.0	2
Laying hens other heavy	18 weeks and older	1998	1,900	28.0	1,800	28.0	2

1 = Versteegh and Jongbloed, 2000; 2 = Jongbloed and Kemme, 2002; 3 = LNV, 2004.

A3.1.3 The N content and N digestibility in chicken feeds

In Table A3.2 an overview is given of the N contents and the digestibility of N in the various chicken feeds with which calculations are made in this study. In the corresponding sections the basis for the N contents and the N digestibility in the feeds is described further.

Table A3.2 Overview of the N contents and the N digestibility (DC-N) in the various chicken feeds for the reference year and in 2005

	Reference year			2005	
Feed type	Year	g N/kg	DC-N (%)	g N/kg	DC-N (%)
Laying hens feed 1	1993	29.1	83.1	24.9	84.5
Laying hens feed 2	1993	29.1	82.8	24.9	84.5
Laying hens feed 3	1993	29.1	82.2	24.9	84.0
Rearing feed start laying varieties	1991	31.3	80.7	27.0	79.1
Laying hens feed 1	1998	26.4	83.1	24.9	84.5
Laying hens feed 2	1998	26.4	82.8	24.9	84.5
Laying hens feed 3	1998	26.4	82.2	24.9	84.0
Rearing feed start laying varieties	1998	28.6	79.1	27.0	79.1
Rearing feed 1 (laying varieties)	1991	31.3	80.7	26.1	80.7
Rearing feed 2 (laying varieties)	1991	31.3	79.1	26.1	79.1
Rearing feed start meat varieties	-	-	-	31.0	84.2
Rearing feed 1 (meat varieties)	2000	28.6	80.8	28.4	80.8
Rearing feed 2 (meat varieties)	2000	28.6	80.8	25.2	80.8
Start feed (broiler parents)	1996	31.0	80.8	25.2	80.8
Breeding brood feed 1 (broiler parents)	1996	27.8	83.2	24.3	83.2
Breeding brood feed 2 (broiler parents)	1996	27.8	82.3	24.2	82.3
Broiler feed 1	2002	34.6	85.1	36.0	85.4
Broiler feed 2	2002	32.0	84.3	34.1	83.9
Broiler feed 3	2002	30.9	84.3	33.1	83.4

A3.2 Rearing hens and roosters of laying varieties younger than ca. 18 weeks in battery housing (category 300A)

A3.2.1 Starting points

The start weight of the rearing laying hens for both 1993 and 2005 is set to 35 g (Reuvekamp, 2004). The end weight of this category in 1993 is for middle heavy and white laying hens 1,420 respectively 1,215 g (KWIN-V, 1991). For 2005 these weights are 1,520 respectively 1,285 g. The length of the rearing period is 122.5 respectively 119 days (KWIN-V, 1991; 2005). The division over middle heavy and white laying hens in battery housing was in 1991 56:44 (WUM, 1994) and for 2005 50:50 is taken (Cijferinfo Pluimveesector 99/11; PVE, 1999). Per rearing period is for 1991 the feed uptake per delivered hen respectively 5.6 and 5.0 kg (KWIN-V, 1991) resulting in 5.5 and 4.9 kg feed per hen present for middle heavy and white laying hens (on average 5.2 kg) and a feed conversion of 4.04. The ratio between uptake of rearing feed 1 and 2 is in 1991 20:80. For 2005 the feed uptake per rearing period per delivered hen for middle heavy and white laying hens 5.6 respectively 5.2 kg (per hen present 5.4 respectively 5.2 kg), resulting in an average feed uptake of 5.3 kg per hen present and a feed conversion of 3.87. The ratio between uptake of start feed, rearing feed 1 and 2 in 2005 is 5.6:25.9:68.5 (KWIN-V, 2005).

The loss of animals amounts for 1991 to 4.5% for both middle heavy and white laying hens and for 2005 that is 3.0 respectively 5.0%. This percentage is only used for conversion of delivered hen to average present hen. In 1991 the rearing feeds contained on average 31.3 g N/kg, while these feeds in 2005 contained on average 26.1 g N/kg. The digestibility of the rearing feeds in 1991 is derived from the feed compositions of Van Niekerk and Reuvekamp (1994; 1995a and 1995b). For rearing feed 1 there were three observations just like as for rearing feed 2. For the start feed the digestibility of the rearing feed 1 is taken. Because of the lack of data about composition and N digestibility of rearing feeds in 2005 the same N digestibilities as for 1991 are taken.

A3.2.2 Results rearing hens and roosters of laying varieties younger than ca. 18 weeks in battery housing

In Table A3.3a is based on abovementioned starting points an overview given of the N uptake and excretion for rearing hens and roosters of laying varieties younger than ca. 18 weeks housed in batteries. Also in Table A3.3b and A3.3c the results are presented if 100% rearing hens respectively middle heavy (brown) rearing hens are kept. The calculated excretion is expressed per animal year (1 animal present the whole year).

Table A3.3a N housekeeping (g) by rearing hens and roosters (ca. 50% white) of laying varieties younger than ca. 18 weeks in battery housing in kg N per animal year (category 300A)

Category 300A	1991			2005		
	g N/kg	DC-N (%)	N uptake (g)	g N/kg	DC-N (%)	N uptake (g)
Start feed	-	-	-	26.1	80.7	24
Rearing feed 1	31.3	80.7	96	26.1	80.7	110
Rearing feed 2	31.3	79.1	405	26.1	79.1	290
Total uptake			501			424
Fixation			112			117
Excretion			389			307
In faeces			103			86
In urine			286			220
In urine (%)			73.5			71.8

Table A3.3b N housekeeping (g) by rearing hens and roosters (100% white) of laying varieties younger than ca. 18 weeks in battery housing in kg N per animal year (category 300A)

Category 300A	1991			2005		
	g N/kg	DC-N (%)	N uptake (g)	g N/kg	DC-N (%)	N uptake (g)
Start feed	-	-	-	26.1	80.7	23
Rearing feed 1	31.3	80.7	96	26.1	80.7	105
Rearing feed 2	31.3	79.1	360	26.1	79.1	281
Total uptake			456			410
Fixation			99			107
Excretion			357			303
In faeces			94			84
In urine			263			219
In urine (%)			73.7			72.4

Results in the Tables A3.3a, A3.3b and A3.3c show that the N excretion in 2005 is much lower than in 1991, mainly because of the lower N content of the feeds. Since the N retention hardly differs between both years there is a much lower N excretion in the urine. The proportion of the percentage N in urine : N in faeces is on average 1.7% unit lower in 2005 compared to 1991.

Table A3.3c N housekeeping (g) by rearing hens and roosters (100% brown) of laying varieties younger than ca. 18 weeks in battery housing in kg N per animal year (category 300A)

Category 300A	1991			2005		
	g N/kg	DC-N (%)	N uptake (g)	g N/kg	DC-N (%)	N uptake (g)
Start feed	-	-	-	26.1	80.7	24
Rearing feed 1	31.3	80.7	109	26.1	80.7	117
Rearing feed 2	31.3	79.1	402	26.1	79.1	308
Total uptake			510			450
Fixation			116			127
Excretion			394			322
In faeces			105			92
In urine			290			231
In urine (%)			73.4			71.6

A3.3 Rearing hens and roosters of laying varieties younger than ca. 18 weeks in housing other than battery (category 300B)

In section A3.2 some general remarks are made which are also valid for this section. Also it needs to be mentioned that to make an estimation of the technical results in this housing systems research data of free range housing is used.

A3.3.1 Starting points

In the alternative housing (free range) almost completely middle heavy hens are used (Cijferinfo Pluimveesector 99/11; PVE, 1999). Also the data from research concerns these hens. As a result it is chosen to take only middle heavy hens for this category, both for 2002 and 2006.

The start weight of the rearing hens for both 2000 and 2005 is set to 35 g (Reuvekamp, 2004). The end weight of this category is for both 2000 and 2005 1,520 g (Managementgids Isabrown, 2004; Vermeij, 2005; Hendrix-Poultry, 2005). The length of the rearing period is 119 days (KWIN-V, 2000; 2005). Per rearing period for 2000 the feed uptake per delivered hen is 5.9 kg (per middle heavy hen present 5.8 kg) (KWIN-V, 2000). This results in a feed conversion of 4.20. The ratio between uptake of rearing feed 1 and 2 is 20:80. For 2005 the feed conversion per rearing period per animal present for middle heavy laying hens is 6.0 kg and the feed conversion is 3.96. The ratio between uptake of start feed, rearing feed 1 and 2 in 2005 is 5:26:69. The loss of animals for 2000 is 4.0% and for 2005 also 4.0%. The percentage animals lost is only used for the conversion of delivered hen to average present hen.

In 2000 the rearing feeds contain on average 28.6 g N/kg, while these feeds in 2005 contain on average 26.1 g N/kg. The digestibility of the rearing feeds in 2000 is derived from the feed compositions of Van Niekerk and Reuvekamp (1994; 1995a and 1995b). For rearing feed 1 there were three observations and for rearing feed 2 the same. For the start feed the digestibility of rearing feed 1 is taken. Because the lack of data on rearing feeds in 2005 the same digestibilities as in 2000 are used.

A3.3.2 Results rearing hens and roosters of laying varieties younger than ca. 18 weeks in housing other than battery

In Table A3.4 is based on abovementioned starting points an overview given of the N uptake and excretion for rearing hens and roosters of laying varieties younger than ca. 18 weeks in non-battery housing systems. The calculated excretion is expressed per animal year (1 animal that is present the whole year). With this the figure differs from usual parameters within the sector.

Table A3.4 N housekeeping (g) by rearing hens and roosters (100% brown) of laying varieties younger than ca. 18 weeks in non-battery housing in kg N per animal year (category 300B)

Category 300B	2000			2005		
	g N/kg	DC-N (%)	N uptake (g)	g N/kg	DC-N (%)	N uptake (g)
Start feed	-	-	-	26.1	80.7	24
Rearing feed 1	28.6	80.7	99	26.1	80.7	121
Rearing feed 2	28.6	79.1	408	26.1	79.1	326
Total uptake			507			471
Fixation			119			128
Excretion			388			343
In faeces			104			96
In urine			284			247
In urine (%)			73.1			72.0

Results in Table A3.4 show that the N excretion in 2005 is somewhat lower than in 2000, mostly due to the somewhat lower N content of the feeds. Since the N retention hardly differs between both years the N excretion in the urine is lower. The division of the percentage N in urine : N in faeces becomes 1.1% unit lower in 2005 compared to 2000.

A3.4 Hens and roosters of laying varieties ca. 18 weeks and older in battery housing (category 301A)

In this section the calculations for hens in battery systems are examined further. Here also the differences are calculated if only white leghorns or brown laying hens are kept in a battery system.

A3.4.1 Starting points

The start weight of the middle heavy and white laying hens for 1993 is 1,420 respectively 1,215 g (KWIN-V, 1993). For 2005 these weights are 1,520 respectively 1,285 g. The end weight of this category at the end of the laying period is in 1993 for middle heavy and white laying hens 2,050 respectively 1,750 g (KWIN-V, 1993). For 2005 these weights are 1,800 respectively 1,600 g. The length of the laying period is 417 days (399 days actual laying period, 18 days rearing) (KWIN-V, 1993). The division over middle heavy and white laying hens in battery housing is 56:44 (WUM, 1994) and for 2005 50:50 is taken (Cijferinfo Pluimveesector 99/11; PVE, 1999).

The feed uptake of the middle heavy and white laying hens amounts 90 respectively 85 g/day during rearing and 117.5 respectively 110 g/day during the actual laying period for 1993, and for 2005 110 respectively 109.5 g/day is taken (KWIN-V 1993 respectively 2005). Per round the feed uptake in 1993 is on average 42.6 kg per hen present. In 1993 per hen laid on 19.9 (middle heavy) or 20.4 kg (white laying hen) eggs are produced. In this is calculated with another 5 eggs produced during rearing with the same egg weight. The average feed conversion is 2.23 (KWIN-V, 1993), which is based on feed uptake from 20 weeks on and egg production from 17 weeks.

Per round the feed uptake in 2005 is on average 41.1 kg per hen present. In 2005 per hen laid on 20.5 (middle heavy) or 22.3 kg (white laying hen) eggs are produced. In this is calculated with another 5 eggs produced during rearing with the same egg weight. The average feed conversion is 2.02 (KWIN-V, 2005), which is based on feed uptake from 20 weeks on and egg production from 17 weeks.

The loss of animals amounts to 6.3 and 7.3% for middle heavy and white laying hens in 1993 and for 2005 the same values have been taken. The percentage of animals lost is only used for the conversion of delivered hen to average present hen.

The start and laying feeds contain in 1993 on average 29.1 g N/kg (WUM, 1994). For 2005 the average N content in the start and laying feeds was 24.9 g N/kg (Van Bruggen, 2007). The ratio between the laying feeds 1, 2 and 3 over the laying period is 40:40:20, both for 1993 and 2005. There are also businesses where laying feed 2 is used to the end of the laying period instead of switching to laying feed 3. In the calculations this is not taken into account.

The digestibility of the laying hen feeds in 1993 is derived from the feed compositions of Van Niekerk and Reuvekamp (1994; 1995a; 1995b; 1997) and Emous *et al.* (1999). For laying feed 1 there were six observations with an average N digestibility of 84.1%. Of laying feed 2 there were six observations too with an average N digestibility of 83.8%, while for laying feed 3 there were four observations with an average N digestibility of 83.2%. For 2005 we had the disposal of data on laying feed 1 of the first half year of 2006. The average N digestibility was 84.5%. For laying feed 2 the same N digestibility was taken and for laying feed 3 an N digestibility of 84.0% was taken. The N digestibility of the start feed is set equal to that of the laying feed 2.

A3.4.2 Results hens and roosters of laying varieties ca. 18 weeks and older in battery housing
In Tables A3.5a, A3.5b and A3.5c is based on abovementioned starting points an overview given of the N excretion for hens and roosters of laying varieties of ca. 18 weeks and older in batteries.

Table A3.5a N housekeeping (g) by hens and roosters of laying varieties of ca. 18 weeks and older in battery housing (ca. 50% white) in kg N per animal year (category 301A)

Category 301A	1993			2005		
	g N/kg	DC-N (%)	N uptake (g)	g N/kg	DC-N (%)	N uptake (g)
Rearing feed	29.1	79.1	39	27.0	79.1	40
Laying feed 1	29.1	84.1	464	24.9	84.5	380
Laying feed 2	29.1	83.8	464	24.9	84.5	380
Laying feed 3	29.1	83.2	232	24.9	84.0	190
Total uptake			1,200			990
Fixation			350			362
Excretion			850			628
In faeces			196			156
In urine			654			472
In urine (%)			76.9			75.1

Table A3.5b N housekeeping (g) by hens and roosters of laying varieties of ca. 18 weeks and older in battery housing (100% white) in kg N per animal year (category 301A)

Category 301A	1993			2005		
	g N/kg	DC-N (%)	N uptake (g)	g N/kg	DC-N (%)	N uptake (g)
Rearing feed	29.1	79.1	36	27.0	79.1	36
Laying feed 1	29.1	84.1	448	24.9	84.5	380
Laying feed 2	29.1	83.8	448	24.9	84.5	380
Laying feed 3	29.1	83.2	224	24.9	84.0	190
Total uptake			1,155			986
Fixation			345			365
Excretion			810			620
In faeces			189			156
In urine			622			465
In urine (%)			76.7			74.9

The results in Table A3.5a are for businesses with a division of ca. 50% white and 50% middle heavy (brown) laying hens; those in Table A3.5b and A3.5c are for businesses with 100% white respectively 100% brown laying hens. The calculated excretion is expressed in g N per animal year (1 animal that is present the whole year). As such this figure differs from the usual parameters in the sector.

A3.4.3 Discussion laying hens in battery housing
Tables A3.5a, A3.5b and A3.5c show that differences in total N excretion between the various laying varieties do exist, but that there are hardly differences in the share TAN in the excreta. Compared to 1993 the share TAN in the excreta decreased somewhat with on average 1.8% unit. Examined is also what the effect on the excretion of N in faeces and urine is, if the N digestibility is 1% unit higher or lower. Table A3.6 gives the results of this.

Table A3.5c N housekeeping (g) by hens and roosters of laying varieties of ca. 18 weeks and older in battery housing (100% middle heavy; brown) in kg N per animal year (category 301A)

Category 301A	1993			2005		
	g N/kg	DC-N (%)	N uptake (g)	g N/kg	DC-N (%)	N uptake (g)
Rearing feed	29.1	79.1	42	27.0	79.1	44
Laying feed 1	29.1	84.1	477	24.9	84.5	380
Laying feed 2	29.1	83.8	477	24.9	84.5	380
Laying feed 3	29.1	83.2	239	24.9	84.0	190
Total uptake			1,235			994
Fixation			354			358
Excretion			881			636
In faeces			202			157
In urine			679			479
In urine (%)			77.1			75.2

Table A3.6 N uptake and N excretion (g) by hens and roosters of laying varieties of ca. 18 weeks and older in battery housing (ca. 50% white) in kg N per animal year (category 301A)

Category 301A	1993			2005		
	DC-N 1 unit lower	DC-N starting point	DC-N 1 unit higher	DC-N 1 unit lower	DC-N starting point	DC-N 1 unit higher
Total uptake	1,200	1,200	1,200	990	990	990
Excretion	850	850	850	628	628	628
In faeces	208	196	184	166	156	147
In urine	642	654	666	462	472	481
In urine (%)	75.5	76.9	78.3	73.5	75.1	76.7

From Table A3.6 follows that in the dependability of the differences in the N digestibility there are no large shifts in the relative N excretion through the faeces and urine; with a 2% unit difference in N digestibility the relative share in the urine increases with ca. 3% units.

A3.5 Hens and roosters of laying varieties ca. 18 weeks and older in housing other than battery (category 301B)

In section A3.4 some general remarks have been described that also concern this section. Also needs to be mentioned that in estimating the technical results in this housing systems research data of free range housing has been used. In this two types occur, with and without outside access. According to Statistics Netherlands (CBS, 2004) the number of animals is divided equally over both systems and the technical results over both systems are averages (KWIN-V, 1998; 2005).

A3.5.1 Starting points for 1998 and 2005

In the alternative housing (free range) almost completely middle heavy hens are used (Cijferinfo Pluimveesector 99/11; PVE, 1999). Also the data from research concern these hens. Therefore it has been chosen to take only the middle heavy hens for this category, both for 1998 as 2005.

The start weight of the middle heavy laying hens for 1998 and 2005 is 1,470 respectively 1,520 g (KWIN-V, 1998; 2005). The end weight of this category at the end of the laying period for 1998 and 2005 is 1,900 respectively 1,800 g (KWIN-V, 1998; 2005). In 1998 the length of the laying period is 401 days (380 days actually laying period, 21 days rearing) and in 2005 that is 406 (385 actual laying period, 21 days rearing (KWIN-V, 1998; 2005).

The feed uptake is 97.5 g/day during the rearing and 119 g/day during the actual laying period (KWIN-V, 1998), while in 2005 the uptakes are 100 respectively 121 g/day (KWIN-V, 2005). Per round the feed uptake for 1998 is on average 49.6 kg per hen present and 20.28 kg eggs are produced. This production takes place at an average feed conversion of 2.29. For 2005 the feed uptake is on average 48.7 kg per hen present and the egg production 20.19 kg, resulting in an average feed conversion of 2.25. The loss of animals amounts to 8.3% for 1998 and 9.3% for 2005.

The percentage loss of animals is only used for the conversion of delivered hen to average hen present.

The start and laying feeds in 1998 contain on average 26.4 g N/kg (Tamminga *et al.*, 2000). For 2005 the average N content in the start and laying feeds was 24.9 g N/kg (Van Bruggen, 2007). The ratio between the laying feeds 1, 2 and 3 over the laying period is 40:40:20, both for 1993 and 2005. There are also businesses where laying feed 2 is given to the end of the laying period instead of switching to laying feed 3. In the calculations this is not considered.

The digestibility of the laying hen feeds in 1998 is derived from the feed compositions of Van Niekerk and Reuvekamp (1994; 1995a; 1995b; 1997) and Emous *et al.* (1999). For laying feed 1 there were six observations with an average N digestibility of 84.1%. Of laying feed 2 there were also six observations with an average N digestibility of 83.8%, while for laying feed 3 there were four observation with an average N digestibility of 83.2%. For 2005 we had the disposal of data on laying feed 1 of the first half year of 2006. The average N digestibility was 84.5%. For laying feed 2 the same N digestibility as of laying feed 1 is taken and for laying feed 3 84.0% is taken. The N digestibility of the start feed is set equal to that of the rearing feed 2.

A3.5.2 Results hens and roosters of laying varieties ca. 18 weeks and older in housing other than battery

In Table A3.7 is based on abovementioned starting points an overview given of the N excretion for hens and roosters of laying varieties of ca. 18 weeks and older in housing other than batteries. The calculated excretion is expressed in g N per animal year (1 animal that is present the whole year). In this the figure differs from usual parameters in the sector.

Table A3.7 N uptake and excretion (g) by hens and roosters of brown laying varieties ca. 18 weeks and older in housing other than batteries in kg N per animal year (category 301B)

Category 301B	1998				2005			
Uptake	kg feed	g N/kg	DC-N (%)	kg N	kg feed	g N/kg	DC-N (%)	kg N
Rearing feed	1.8	28.6	79.1	51	1.9	27.0	79.1	51
Laying feed 1	16.5	26.4	83.1	436	16.8	24.9	84.5	417
Laying feed 2	16.5	26.4	82.8	436	16.8	24.9	84.5	417
Laying feed 3	8.2	26.4	82.2	218	8.4	24.9	84.5	209
Total	43.0			1,140	43.8			1,094
Fixation				348				357
Excretion				792				736
In faeces				187				173
In urine				605				563
In urine (%)				76.4				76.5

From Table A3.7 follows that the N excretion form 1998 to 2005 decreased somewhat, but that there is no difference in the share TAN in the excreta.

A3.6 Rearing hens and roosters of meat varieties 0 to 19 weeks (category 310)

Category 310 concerns the young parent animals for the broiler sector. Different from the laying sector this is a clearly distinguished category. Differences between hens and roosters have been taken into account. Conversion of parameters took place because in the manure legislation both the hens and roosters are counted, while parameters in some cases are expressed per hen.

A3.6.1 Starting points for 2000 and 2005

The start weight of the rearing parent animals (the chicks) is for both 2000 and 2005 set to 42 g (Van Middelkoop, 2000). The end weight of this category at ca. 19 weeks of age is for roosters and hens in 2000 2,750 respectively 2,000 g (Ross, 2004) and for 2005 the same weights are taken. The length of the rearing period is for 2000 and 2005 calculated to 126 days (KWIN-V, 2000; 2005). The number of roosters at lay on is 15%. On average there are 14.0% roosters per reared hen (KWIN-V, 2000; 2005). At the end of the rearing period selection of the roosters takes place. At lay on for the laying period 10% roosters are deployed. Per rearing period is for 2000 the feed uptake of rearing feed 1 and

2 per hen delivered 2.0 respectively 6.5 kg and per average hen present 1.68 respectively 5.47 kg, resulting in an average feed conversion of 3.49. For 2005 the same values are taken.

The loss of animals in 2000 amounts to 7.0 and 14.0% for hens and roosters and also for 2005. The percentage animals lost is only used for the conversion of delivered hen to average present animal.

The rearing feed contains in 2000 on average 28.3 g N/kg (Tamminga *et al.*, 2000) and in 2005 the average N content of the start and rearing feed is 26.1 g/kg (Van Bruggen, 2007). These contents are copied from those of rearing laying hens, since no data was available for the rearing of broiler parents. The digestibility of the rearing feeds in 2000 is derived from the feed compositions of Van der Haar and Meijerhof (1996) and of a feed supplier. For rearing feed 1 there were two observations (average 80.8%) and for rearing feed 2 seven observations (average 80.7%). For the start feed is based on information from a feed supplier an N digestibility of 84.2% taken. For the rearing feeds 1 and 2 is an average N digestibility taken of 80.7%. Since data on rearing feeds in 2005 are lacking the same digestibilities as in 2000 are used.

A3.6.2 Results rearing hens and roosters of meat varieties 0 to 19 weeks
In Table A3.8 is based on abovementioned starting points an overview given of the N excretion for rearing hens and roosters of meat varieties 0 to 19 weeks. The calculated excretion is expressed in kg N per animal year (1 animal that is present the whole year). In this the figure differs from usual parameters in the sector.

Table A3.8 N uptake and excretion (g) by rearing hens and roosters of meat varieties 0 to 19 weeks in kg N per animal year (category 310)

Category 310	2000			2005		
	g N/kg	DC-N (%)	N uptake (g)	g N/kg	DC-N (%)	N uptake (g)
Rearing feed start	-	-	-	31.0	84.2	38
Rearing feed 1	28.6	80.8	140	28.4	80.8	104
Rearing feed 2	28.6	80.8	453	25.2	80.8	400
Total uptake			593			541
Fixation			200			200
Excretion			393			342
In faeces			114			99
In urine			280			242
In urine (%)			71.1			71.0

From Table A3.8 follows that the N excretion decreased somewhat from 2000 to 2005, but that there is no difference in the share TAN in the excreta.

A3.7 Parents of meat varieties ca. 19 weeks and older (category 311)

Category 311 concerns the parent animals for the broiler sector. Different from the laying sector this is a clearly distinguished category. Differences between hens and roosters are taken into account. Conversion of parameters took place because in the manure legislation both the hens and the roosters are counted, while parameters in some cases are expressed per hen.

A3.7.1 Starting points
The start weight of the hens respectively roosters for 1996 is 1,900 respectively 2,600 g and for 2005 2,000 respectively 2,750 g (Ross, 2004). The end weight of this category at the end of the production period is for hens and roosters for 1996 3,600 respectively 4,800 g and for 2005 3,700 respectively 4,800 g (KWIN-V, 1996; 2005). The length of the production cycle is for 1998 and 2006 calculated to 346 respectively 343 days (KWIN-V, 1996; 2005).

Goal for both 1996 as for 2005 is to have 10% roosters at the start of the laying period. Over the whole period on average 95.51 hens and 8.44 roosters are present. Per laying round is for 1996 the feed uptake on average 3.0 kg pre laying feed and 45.0 kg breeding brood feed per laid on hen (2.9 kg respectively 43.3 kg per average animal present) and 148 brood eggs and 10 consumption eggs of on average 62 grams apiece are produced. This results in 9.27 kg eggs per average present animal.

For 2005 the feed uptake per round is on average 3.30 kg pre laying feed and 44.7 kg breeding brood feed per laid on hen (3.20 kg respectively 43.0 kg per average animal present) and 150 brood eggs and 10 consumption eggs of on average 62 grams are produced. This results in 9.54 kg eggs per average animal present. The loss of animals amounts for 1996 to 1.0 respectively 3.5% for hens and roosters during rearing and 10.0 respectively 35.0% during the laying period. For 2005 the percentages loss of animals during rearing are 1.0 respectively 3.6 and 10.0 respectively 35.0% during the laying period. The percentage animals lost is only used for the conversion of delivered hen to average present animal.

The N content in the pre laying feed and the breeding brood feed for 1996 is calculated by taking the average content of 1992 (WUM, 1994) and that of Tamminga *et al.* (2000). The pre laying feed then contains 31.0 g N/kg and the breeding brood feed 27.8 g N/kg. In 2005 the pre laying feed, breeding brood feed 1 and 2 contained respectively 25.2, 24.3 and 24.2 g N/kg (Van Bruggen, 2007). Of the N digestibility of the feeds in 1996 no data are available. For 2005 for the pre laying feed the N digestibility of the rearing feed 2 (80.8%) was taken. Based on data of a composite feed manufacturer beginning 2008 an N digestibility of the breeding brood feed 1 and 2 of 83.2 respectively 82.3% was calculated. These digestibilities are also taken for the feeds of 1996.

A3.7.2 Results hens and roosters of meat varieties from ca. 19 weeks and older

In Table A3.9 is based on abovementioned starting points an overview given of the N uptake and excretion for hens and roosters of meat varieties from ca. 19 weeks and older. The calculated excretion is expressed in kg N per animal year (1 animal that is present the whole year). In this the figure differs from usual parameters in the sector.

Table A3.9 N housekeeping (g) by hens and roosters of meat varieties ca. 19 weeks and older in kg N per animal year (category 311)

Category 311	1996			2005		
	g N/kg	DC-N (%)	N uptake (g)	g N/kg	DC-N (%)	N uptake (g)
Start feed	31.0	80.8	103	25.2	80.8	92
Breeding brood feed 1	27.8	83.2	614	24.3	83.2	538
Breeding brood feed 2	27.8	82.3	768	24.2	82.3	662
Total uptake			1,484			1,293
Fixation			258			262
Excretion			1,227			1,030
In faeces			259			225
In urine			968			805
In urine (%)			78.9			78.1

From Table A3.9 follows that the N excretion clearly decreases from 1998 to 2005 but that there is hardly difference in the share TAN in the excreta.

A3.8 Broilers (category 312)

A3.8.1 Starting points

The start weight of the broilers is for both 2002 and 2006 set to 42 g (Van Middelkoop, 2000). The end weight of broilers at 43 days of age is for 2002 and 2005 2,100 respectively 2,200 g (KWIN-V, 2003; 2007). Per production round is for 2002 the average feed conversion 1.76 (KWIN-V, 2002), resulting in a feed uptake of on average 3.70 kg. For 2005 the production period is 43 days, the feed conversion on average 1.79, resulting in a feed uptake of 3.94 kg (KWIN-V, 2005).

The broiler feed 1, 2 and 3 for 2002 contained 34.6, 32.0 respectively 30.9 g N/kg. The contents for 2005 are 36.0, 34.1 respectively 33.1 g/kg (Van Bruggen, 2007). Of the broiler feed 1 per production round 300 g is taken up, of broiler feed 2 1,500 g and the remainder is broiler feed 3. There are also businesses where besides compound feed also wheat or corn cob mix is fed additionally but in the calculations this is not taken into account.

The digestibility of the broilers is estimated based on various feed compositions of broiler feed 2 at a composite feed manufacturer in the first half of 2006. This was on average 83.9%. Based on discussions with experts it seems reasonable to raise the N digestibility of broiler feed 1 by 2.5% units, so that it becomes 85.4%. Also is assumed that the N digestibility of broiler feed 3 is 0.5% lower than of broiler feed 2, so that the N digestibility then becomes 83.4%. The digestibilities above are taken for 2005. For 2002 based on discussion with some experts an N digestibility for broiler feed 1, 2 and 3 of 85.1, 84.3 respectively 84.3 is taken.

A3.8.2 Results broilers

In Table A3.10 based on abovementioned assumptions an overview is given of the N excretion for broilers. The calculated excretion is expressed in g N per animal year (1 animal that is present the whole year). In this the figure differs from usual parameters in the sector.

Table A3.10 N housekeeping (g) by broilers in g N per animal year (category 312)

Category 312	2002			2005		
	g N/kg	DC-N	N uptake (g)	g N/kg	DC-N	N uptake (g)
Broiler feed 1	34.6	85.1	87	36.0	85.4	92
Broiler feed 2	32.0	84.3	403	34.1	83.9	434
Broiler feed 3	30.9	84.3	492	33.1	83.4	601
Total uptake			981			1,127
Fixation			479			508
Excretion			502			618
In faeces			153			183
In urine			349			435
In urine (%)			69.5			70.4

A3.8.3 Discussion broilers

From Table A3.10 follows that the N excretion from 2002 to 2005 increased clearly, but also that the share TAN in the excreta increased somewhat.

It has been examined what the effect of an N digestibility 1% unit higher or lower is on the excretion in faeces and urine. Table A3.11 gives the results of this.

Table A3.11 N uptake and N excretion (kg) by broilers in g N per animal year (category 312)

Category 312	2002			2005		
	DC-N 1 unit lower	DC-N starting point	DC-N 1 unit higher	DC-N 1 unit lower	DC-N starting point	DC-N 1 unit higher
Total uptake	981	981	981	1,127	1,127	1,127
Excretion	502	502	502	618	618	618
In faeces	163	153	144	194	183	172
In urine	339	349	359	424	435	446
In urine (%)	67.5	69.5	71.4	68.6	70.4	72.2

From Table A3.11 follows that in the dependability of a difference in N digestibility of 2% units the amount N in urine as percentage of the total N excretion yields a difference of ca. 4% units.

A3.9 General discussion poultry

A3.9.1 Reliability contents of and digestibility of N in chicken feeds and effects on the N excretion

Not for all feeds there is a reliable picture of the correct content of N in feeds for chickens. Often these data are lacking in the various years. Also it is difficult or even not feasible to obtain these contents from compound feed manufacturers. In addition the raw material composition of the feeds is not released by most of the compound feed manufacturers. It is amply known that by whether or not taking up free amino acids in the feeds the N content in the feeds can be lowered, but at the same time it is also possible to take up protein containing raw materials of poorer quality in the feed. Depending on the strategy at the firm both the N content and the N digestibility can vary. It is desirable to collect better underpinned data hereof.

A3.10 Summary poultry

In Table A3.12 a summary is given of the excretion of N by various chicken categories in the reference year and in 2005 in g/year.

Table A3.12 Overview of the excretion of N and % TAN by various chicken categories in the reference year and 2005 (g/year)

Category	Number	Ref. year	N in ref. year	% TAN in ref. year	N in 2005	% TAN in 2005
Rearing laying hens (battery)	300A	1991	389	73.5	307	71.8
Rearing laying hens (ground)	300B	2000	388	73.1	343	72.0
Laying hens (battery)	301A	1993	850	76.9	628	75.1
Laying hens (ground)	301B	1998	792	76.4	736	76.5
Rearing broiler parents	310	2000	393	71.1	342	71.0
Broiler parents	311	1996	1,227	78.9	1,030	78.1
Broilers	312	2002	502	69.5	618	70.4

A3.11 Turkeys

A3.11.1 General

In Table A3.13 data on the average content of N in the animal product and in Table A3.14 the contents of protein and N and the faecal digestibility of N in the various turkey feeds are shown. The contents in the various turkey feeds in 1998 are derived from Veldkamp (1996) and Veldkamp *et al.* (1999) and in 2005 from Jongbloed and Kemme (2005). Also information was obtained from dr. Veldkamp, turkey specialist of ASG (Veldkamp, 2008).

Table A3.13 Weights and contents of N in various turkey categories and in turkey eggs

Livestock category	Weight (g) 1998	Weight (g) 2005	Physiological status	N content (g/kg)	Literature contents
Turkey egg	89	89	-	19.4	WUM, 1994
One-day turkey chick	57	57	-	30.0	LNV, 2004
Turkey for slaughter hen	9,500	9,800	Ca. 16.5 weeks	33.0	LNV, 2004
Turkey for slaughter rooster	18,500	19,500	Ca. 21 weeks	33.0	LNV, 2004

Table A3.14 Overview of the average N contents and digestibility of N in the various turkey feeds for 1998 and 2005

	Reference year			2005	
Feed type	Year	g N/kg	DC-N (%)	g N/kg	DC-N (%)
Start feed	1998	45.8	85.0	44.7	85.0
Turkey feed phase 2	1998	41.4	83.6	40.9	83.6
Turkey feed phase 3	1998	37.4	83.4	35.8	83.4
Turkey feed phase 4	1998	31.3	83.1	29.6	83.1
Turkey feed phase 5	1998	31.3	83.1	26.1	83.1
Turkey feed phase 6	1998	27.6	84.0	24.2	84.0

A3.12 Turkeys for slaughter (category 210)

To assess various technical results of turkeys for slaughter the data of KWIN are used. Furthermore information given by dr. Veldkamp (2008) has been processed.

A3.12.1 Starting points for 1998 and for 2005

The start weight of turkeys for slaughter for both 1998 and 2005 is set to 57 g (Veldkamp, 2008). For 1998 the end weight of the roosters and hens on an age of 147 and 116 days (on average 132 days) is 18.50 respectively 9.50 kg (average 14.00 kg). For 2005 the end weight of the roosters respectively hens on an age of 145 respectively 112 days (on average 128 days) is 19.50 respectively 9.80 kg (average 14.60 kg). Per production period is for 1998 the average feed conversion per kg delivered weight 2.63, resulting in a feed uptake of 36.9 kg per round and 99.9 kg per year. For 2005 the average feed conversion is 2.63, resulting in a feed uptake of 38.7 kg per round and 105.7 kg per year. The division of the feed uptake over the various phases is derived from British United Turkeys (2006).

The N contents in the various feeds for turkeys for slaughter are shown in Table A3.15. The N contents in the feeds for the year 1998 are derived from Veldkamp (1996) and Veldkamp *et al.* (1999) and are averages for each phase. The N contents in the various turkey feeds for 2005 are the same as mentioned by Jongbloed and Kemme (2005). Based on the feed composition according to Veldkamp *et al.* (1999) the digestibility of N in the various feeds for turkeys for slaughter are estimated. The digestibility of N in the distinguished feeds is kept equal for both years (Table A3.15) based on Veldkamp (2008).

A3.12.2 Results turkeys for slaughter

In Table A3.15 is based on abovementioned starting points an overview given of the N excretion for turkeys for slaughter. The calculated excretion is expressed in kg N per animal year (1 animal that is present the whole year). In this the figure differs from usual parameters in the sector.

Table A3.15 N housekeeping (kg) by turkeys for slaughter in kg N per animal year (category 210)

Category 210	1998			2005		
	g N/kg	DC-N (%)	N uptake (g)	g N/kg	DC-N (%)	N uptake (g)
Start feed	45.8	85.0	53	44.7	85.0	54
Turkey feed phase 2	41.4	83.6	134	40.9	83.6	141
Turkey feed phase 3	37.4	83.4	553	35.8	83.4	561
Turkey feed phase 4	31.3	83.1	767	29.6	83.1	768
Turkey feed phase 5	31.3	83.1	992	26.1	83.1	876
Turkey feed phase 6	27.6	84.0	676	24.2	84.0	625
Total uptake			3,175			3,025
Fixation			1,248			1,321
Excretion			1,927			1,704
In faeces			527			502
In urine			1,400			1,202
In urine (%)			72.6			70.5

From the results according to Table A3.15 follows that N excretion has decreased because of the lower N content in the feeds and a higher retention of N. As a result less N is excreted through the urine and share N in urine as percentage of the total N excretion decreased from 72.6 to 70.5%.

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Annex 4 Mineralization and immobilization of nitrogen in manure

Translation of the annex from G.L. Velthof in Velthof *et al.*, 2009.

Part of the organic matter in manure is easily degradable and will already be broken down in the animal house or storage. During this process, CH_4 and CO_2 and depending on the composition of the manure, also NH_4^+ are formed (mineralization). In manure containing straw (high C/N ratio) part of the NH_4^+ will be fixed (immobilized) as organic N.

The method to calculate NH_3 emission described in this report is based on TAN. As a result, changes in TAN during the storage of manure have to be taken into account.

In the literature, only little data is available on mineralization and immobilization of ammonium in manure storages. This is mainly because these processes are hard to determine through a balance method in manure from which also NH_3 is emitted. Another possibility to determine mineralization is the use of ^{15}N labelled N, that is added to the ration of the animal or the manure.

In an incubation study of Sommer *et al.* (2007) the N mineralization was low at 10 °C, for both cattle and pig slurry. The manure has been collected fresh and was stored frozen, until the start of the incubation study. The mineralization increased strongly at increasing temperature. About 80% of the organic N was mineralized at 15-20 °C for 100-200 days. Mineralization was higher in pig manure than in cattle manure.

In an incubation study of Sørensen *et al.* (2003), mineralization of 9-50% of the organic N in cattle slurry was found. The fresh manure was incubated at 8 °C for 16 weeks first, and then for 4 weeks at 15 °C.

Processing of data from an incubation study of Velthof *et al.* (2005) shows that the N mineralization of organic N of pig slurry at high temperature (90 days at 35 °C) was on average 15%, with a variation of -11 to +30% (depending of the ration). The manure was collected fresh and stored frozen, until the start of the incubation study.

In an incubation study with pig manure to which ^{15}N labelled urea was added (Beline *et al.*, 1998) the N mineralization was 19% of the organic N during 84 days at 20 °C. The manure was collected from a farm and thus been stored for a while (it is not clear how long the storage period was).

In models used in England and Germany for calculation of ammonia emissions on the national scale the N mineralization is set to 10% of the organic N (with reference to the research of Beline *et al.*, 1998). In the models used by Denmark and Switzerland, mineralization is not (yet) taken into account.

In the methodology described in this report, it is assumed that 10% of the organic N in slurry stored in the animal house mineralizes. This might be a conservative assumption. Given the uncertainties only mineralization in the animal houses is calculated and not in the outside storage. Also in the outside storage mineralization can occur, but this is possibly lower since the easily degradable organic N will mineralize quickly after excretion in the animal house.

For solid manure except poultry manure, 25% immobilization is assumed. In poultry manure, both solid and slurry, and slurry manure of other animals (rabbits and fur-bearing animals) no mineralization or immobilization takes place. It is recommended to conduct further research into (net) mineralization in cattle and pig slurry, since this has an effect on calculated NH_3 emissions from the animal house, manure storage and manure application.

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Annex 5 Emission factors for NH_3 from animal housing of cattle

In this annex the emission factors in kg NH_3 per animal place are given that form the basis for the calculation of emission factors with respect to the TAN excretion (section 5.2).

Dairy cows
In the calculation model NEMA the N excretion is divided over the winter and grazing period. During the grazing period dairy cows spend part of their time in the animal house and another part on pasture land. The N excretion of the grazing period is therefore split into excretion in the animal house and during grazing. To connect to the N excretion the year round emission factors are split into factors for the winter period and for time spent in the animal house in unlimited (day and night) and limited (daytime) grazing, see also Van Bruggen *et al.*, 2011 (par. 5.4.2).

In Ogink *et al.* (2014) a current emission factor of 13.0 kg NH_3 per animal place is calculated for dairy cattle kept continuously indoors in traditional housing systems. These are cubicle housings with slatted floors as walking area and manure storage below the grates (Rav-code A1.100). Decrease in emissions per hour of grazing is determined to be 2.61%. On a yearly basis the procentual emission reduction then is:

2.61% x (number of grazing hours per day) x (number of grazing days) / 365 (A5.1)

Based on the reference value of 13.0 kg NH_3 per animal place and above formula, in Table A5.1 emission factors are calculated for the winter period and for the time spent in the animal house during the grazing period for each grazing system. Ogink *et al.* (2014) do no split the year round emission. The calculation of the emission reduction by grazing of the working group NEMA differs somewhat from the calculation in Ogink *et al.* (2014). The working group NEMA takes the average number of grazing days in the years emission measurements took place (2007-2012) as the starting point, where in Ogink *et al.* (2014) the length of the grazing period of 2012 and a weighted average number of hours grazing per day are used.
In the calculation of the NH_3 emission of dairy cattle housings an increase in emission per animal place from 11.0 kg NH_3 in 2001 to 13.0 kg in the measurement period 2007-2012 is assumed.

Table A5.1 Emission factors for traditional dairy housing (kg NH_3/animal place), 2007-2015

	Grazing period (days)	Hours grazing per day	Emission reduction (kg NH_3)	Grazing period (kg NH_3)	Winter period (kg NH_3)	Year-round (kg NH_3)
	A[1]	B[2]	C[3]	D[4]	E[5]	F[6]
Traditional dairy housing/cubicle system						
Grazing system						
continuously indoors	169	0	0.00	6.02	6.98	13.00
limited grazing	169	8	1.26	4.76	6.98	11.74
unlimited grazing	169	20	3.14	2.88	6.98	9.86

[1] Source WUM-Statistics Netherlands: average length of the grazing period in the measurement period 2007-2012.

[2] Source: Statistics Netherlands-research Grassland use 2008.

[3] 2.61% * B x (A/365) x (13.0 kg NH_3).

[4] (A/365) x (13.0 kg NH_3) – C.

[5] ((365-A)/365) x (13.0 kg NH_3).

[6] D + E.

For the emission year 2016 the hours grazing per day were reconsidered, limited grazing was set to 7 and unlimited grazing to 19 hours leading to year-round emission factors of 11.90 and 10.01 kg NH_3/animal for limited and unlimited grazing respectively.

The emission factors for low emission housing systems (low emission techniques in a traditional housing setup) are adjusted based on the proportion between the new and old factor for traditional housing according to Ogink *et al.* (2014). In continuously indoors this means multiplication with factor 13.0/11.0 and in limited grazing multiplication with factor 11.74/9.5.

The average emission factor for low emission cubicle housing is derived from information in environmental permits (Van Bruggen *et al.*, 2011 p. 25 and Van Bruggen *et al.*, 2013 annex 1). The new year round emission factor for low emission housing with limited grazing then becomes: (11.74/9.5) x 7.5 = 9.27 and for continuously indoors: (13.0/11.0) x 8.8 = 10.40. In Van Bruggen *et al.* (2011) the year round emission factor is divided over winter and grazing period based on the proportion between winter and grazing period in traditional housing with limited grazing. This means that in low emission cubicle housing 5.5 kg NH_3 is emitted during the winter period: (6.98/11.74) x 9.27. For low emission cubicle housing with unlimited grazing no year round emission can be calculated based on environmental permits and is therefore not considered.

In Table A5.2 an overview is given of the emission factors for low emission housing of dairy cattle. Compared to Van Bruggen *et al.* (2014) the emission factor of tie-stall housing has also been adjusted in the way proposed by Ogink *et al.* (2014): 4.3 x (13.0/11.0).

Table A5.2 Emission factors for low emission dairy housing (kg NH_3/animal place), 2011-2014

	Winter period (kg NH_3)	Grazing period (kg NH_3)	Year-round (kg NH_3)
Low emission cubicle housing			
Grazing system			
continuously indoors	5.51	4.89	10.40
limited grazing	5.51	3.76	9.27
Tie-stall with slurry	3.02	2.06	5.08

For the emission years 2015 and 2016, information from the Agricultural census on low emission cubicle housing was available. With continuously indoors year-round emission was 10.02 respectively 9.22 kg NH_3/animal and limited grazing was calculated to be 9.05 respectively 8.44 kg NH_3/animal.

The emission factors in Tables A5.1 and A5.2 are converted into emission factors in per cent of the TAN excretion in the winter and grazing periods using the method described in section 5.2.

Other cattle excluding veal calves

Ogink *et al.* (2014) propose to calculate NH_3 emission factors per animal place for other cattle categories with the formula:

(TAN excretion in the animal house of livestock category)/(TAN excretion in the animal house dairy cattle) x 13.0 (A5.2)

This therefore means that the emission factor for traditional housing compared to the TAN excretion for all cattle categories is equal. In NEMA emission factors are calculated compared to the TAN excretion including 10% mineralization of organic N. Ogink *et al.* (2014) however do not consider the 10% mineralization of organic N and as a result emission factors calculated with above formula differ somewhat because the percentage organic N differs between cattle categories. To prevent these differences the calculation in Ogink *et al.* (2014) is applied on TAN excretion including 10% mineralization of organic N.

In the calculation of the NH_3 emission of dairy cattle housings an increase in emission per animal place from 11.0 kg NH_3 in 2001 to 13.0 kg in the measurement period 2007-2012 is assumed. By relating the emission factor for other cattle to that of dairy cows this means that for other cattle a comparable development has taken place in which the emission has increased over time.

In Table A5.3 the calculation of the emission factors is presented.

Table A5.3 Emission factors NH_3-N for other cattle categories in % of TAN excretion (including 10% net mineralization)

	1990-2001	2002	2003	2004	2005	2006	from 2007 on
Emission factor compared to TAN excretion	11.03	11.57	12.11	12.65	13.19	13.73	14.27

For the different cattle categories is based on the TAN excretion in the 2007-2012 period and the emission factors in Table A5.3, the subsequent emission calculated in kg NH_3 per animal place. This calculated emission is compared to the emission factor in the Rav.

Table A5.4 Emission factors NH_3-N for other cattle categories in % of TAN excretion (including 10% net mineralization)

	1990-2001	2002	2003	2004	2005	2006	2007-2015	2016
	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place
Female young stock - regular	3.3	3.5	3.6	3.8	4.0	4.1	4.3	4.3
Female young stock – low emission	1.5	1.5	1.6	1.7	1.8	1.8	1.9	1.8
Suckling-, fattening- and grazing cows	3.4	3.5	3.7	3.9	4.0	4.2	4.4	4.4
Bulls for service including male young stock	7.5	7.9	8.3	8.7	9.0	9.4	9.8	9.8
Meat bulls 1 year and over	4.0	4.2	4.4	4.6	4.8	5.0	5.2	5.2

Meat calves

In Groenestein *et al.* (2014) emission factors for meat calves are reconsidered in which separate emission factors are proposed for white veal calves and rosé veal calves. The factor for both categories was 2.5 kg NH_3 per animal place in the reference year 1998 with an occupancy rate of 0.93. The husbandry of meat calves and management thereof have evolved such that the available older measurement series are no longer representative of current practice. The new emission factors are derived from the emission factor of dairy cows (13.0 kg NH_3/animal place) in which differences in TAN excretion, size of emitting surfaces (Groenestein *et al.*, 2014) and the contribution of the grates and slurry pit to the emission of the animal house are taken into account. This method therefore differs from the method used in determining the emission factors for other cattle in above text. The new reference year is 2012.

The new factors are 3.1 and 3.7 kg NH_3 per animal place respectively for white veal calves and rosé veal calves, at an occupancy rate of 0.93 for white veal calves and 0.96 for rosé veal calves.

The emission factor for NH_3-N compared to the TAN excretion of white veal calves, including 10% mineralization of organic N, amounts to 28.2% in the reference year 1998. As a result of the higher TAN excretion in the new reference year 2012 belonging to the new emission factor per animal place the emission factor increases to 28.6%.

For rosé veal calves the emission factor compared to the TAN excretion, including 10% mineralization of organic N, is 13.2% in the reference year 1998. The revised emission of 3.7 kg NH_3 per animal place yields an emission factor of 22.9% compared to the TAN excretion in the reference year 2012. Between 1998 and 2012 the emission factor is gradually increased through interpolation. The occupancy rate is increased from 0.93 to 0.96.

Since between the reference years 1998 and 2012 a gradual change in management took place, the emission factor is being interpolated. For meat calves two different methods for interpolation between 1998 and 2012 are possible: interpolation of the proposed Rav factor or interpolation of the emission factor compared to the TAN excretion. Interpolation of the proposed Rav factor means for white veal calves a gradual increase from 2.5 kg NH_3 to 3.1 kg NH_3 and for rosé veal calves an increase from 2.5 to 3.7 kg NH_3 per animal place. In the second method of interpolation the emission factor compared to the TAN excretion is gradually adjusted. For white veal calves this means the emission factor increases from 28.2 to 28.6% and for rosé veal calves a gradual increase from 13.2 to 22.9%.

Choice was made to interpolate the emission factor on the basis of net TAN excretion. With interpolation of the proposed Rav factor yearly fluctuations in the emission factor compared to the TAN excretion would occur, because TAN excretion also have yearly fluctuations. The latter is not logical since one would expect the emission factor compared to the TAN excretion to be constant or gradually changing because of changing management, but not to fluctuate yearly.

The emission factor for low emission housing was previously established to be 0.60 kg NH_3 per animal place based on the shares of various types of air scrubbers in the environmental permits of provinces. This meant an average emission reduction of 76% compared to the regular emission factor of 2.5 kg NH_3 per animal place. With the same percentage reduction the emission factor for low emission housing in white veal calves becomes 0.24 x 3.1 = 0.74 kg NH_3 per animal place and in rosé veal calves 0.24 x 3.7 = 0.89 kg NH_3 per animal place. Based on information from the Agricultural census, emission factors of 0.47 for 2015 and 0.34 kg NH_3/animal for 2016 were used for white veal calves. In rosé veal, emission factors were 0.56 and 0.41 kg NH_3/animal for 2015 and 2016, respectively.

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Annex 6 Emission factors for NH_3 from animal housing of pigs

In this annex the emission factors in kg NH_3 per animal place are given that form the basis for the calculation of emission factors relative to the TAN excretion (section 5.2).

Table A6.1 Emission factors for traditional pig housing (kg NH_3 per animal place)

Sows with piglets	8.3
Open and sows in pig	4.2
Weaned piglets	
Pen surface ≤ 0.35 m^2/animal place	0.60
Pen surface > 0.35 m^2/animal place	0.75
Fattening and rearing pigs	
Slurry pit under complete animal place, pen surface 0.8 m^2/animal place	5.0
Slurry pit under complete animal place, pen surface 1.0 m^2/animal place	6.1
Slurry pit under part of the animal place, pen surface 0.8 m^2/animal place	3.4
Slurry pit under part of the animal place, pen surface 1.0 m^2/animal place	4.0
Boars for service	5.5

Table A6.2 Emission factors for reduced emission housing of sows with piglets (kg NH_3 per animal place)

	EF	1990-2004[1)]	2005-2006[2)]	2007-2010[3)]	2011-2012[4)]	2013-2014[5)]	2015[6)]	2016[7)]
	kg NH_3/ animal place	fraction (fr.)	fr.	fr.	fr.	fr.	fr.	fr.
Air scrubbers								
Biological air scrubber system 70% emission reduction	2.5		0.25	0.16	0.11	0.09		
Chemical air scrubber system 70% emission reduction	2.5		0.37	0.42	0.28	0.20		
Chemical air scrubber system 95% emission reduction	0.42		0.38	0.33	0.30	0.26		
Combined air scrubber system 85% emission reduction chemical and water washer	1.3		-	0.06	0.18	0.17		
Combined air scrubber system 70% emission reduction chemical and water washer, biofilter	2.5		-	0.00	0.01	0.01		
Combined air scrubber system 85% emission reduction chemical and water washer, biofilter	1.3		-	0.02	0.03	0.03		
Combined air scrubber system 85% emission reduction with water curtain and biological washer	1.3		-	-	0.10	0.24		

	EF	1990-2004[1]	2005-2006[2]	2007-2010[3]	2011-2012[4]	2013-2014[5]	2015[6]	2016[7]
	kg NH_3/ animal place	fraction (fr.)	fr.	fr.	fr.	fr.	fr.	fr.
Average emission factor (kg NH_3/animal place)		**N/A**	**1.7**	**1.7**	**1.5**	**1.4**	**1.4**	**1.4**
Floor/slurry pit adjustment								
Rinsing gully system, rinsing with slurry	3.3		0.06	0.05	0.05	0.05		
Level coated pit floor with rack and pinion shove system	4.0		0.03	0.01	0.01	0.00		
Manure shove with coated sloping pit floor and urine gully	3.1		0.03	0.02	0.01	0.01		
Manure gully with manure discharge system	3.2		0.06	0.05	0.04	0.03		
Shallow slurry pits with manure and water canal	4.0		0.35	0.24	0.22	0.22		
Shovels in manure gully	2.5		0.05	0.04	0.02	0.02		
Cool deck system	2.4		0.12	0.10	0.09	0.08		
Manure pan/- box under farrowing pen	2.9		0.06	0.06	0.08	0.08		
Manure pan with water and manure canal under farrowing pen	2.9		0.16	0.19	0.18	0.16		
Water canal combined with separate manure canal or manure box	2.9		0.08	0.22	0.30	0.33		
Average emission factor (kg NH_3/animal place)		**4.15**	**3.3**	**3.2**	**3.1**	**3.1**	**3.2**	**3.2**

1) The emission reduction in this period is set to 50% compared to traditional housing (Van der Hoek, 2002).

2) Source: environmental permits in the province Noord-Brabant on 01-01-2005.

3) Source: environmental permits in the province Noord-Brabant on 01-01-2009.

4) Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2012.

5) Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2014.

6) Source: agricultural census 2016.

7) Source: agricultural census 2017.

Table A6.3 Emission factors for reduced emission housing of open and sows in pig (kg NH_3 per animal place)

	EF	1990-2004$^{1)}$	2005-2006$^{2)}$	2007-2010$^{3)}$	2011-2012$^{4)}$	2013-2014$^{5)}$	2015$^{6)}$	2016$^{7)}$
	kg NH_3/ animal place	fraction (fr.)	fr.	fr.	fr.	fr.	fr.	fr.
Air scrubbers								
Biological air scrubber system 70% emission reduction	1.3		0.22	0.15	0.11	0.09		
Chemical air scrubber system 70% emission reduction	1.3		0.42	0.45	0.29	0.22		
Chemical air scrubber system 95% emission reduction	0.21		0.38	0.33	0.31	0.29		
Combined air scrubber system 85% emission reduction chemical and water washer	0.63		-	0.05	0.13	0.12		
Combined air scrubber system 70% emission reduction with water washer, chemical washer and biofilter	1.3		-	-	0.01	0.01		
Combined air scrubber system 85% emission reduction chemical and water washer, biofilter	0.63		-	0.01	0.03	0.03		
Combined air scrubber system 85% emission reduction water curtain and biological washer	0.63		-	0.00	0.11	0.23		
Average emission factor (kg NH_3/animal place)		**N/A**	**0.90**	**0.90**	**0.77**	**0.72**	**0.69**	**0.66**
Floor/slurry pit adjustment								
Narrow shallow manure canals with metal three sided grates and sewerage (individual housing)	2.4		0.28	0.24	0.25	-		
Manure gully with combined grates and frequent manure disposal (individual housing)	1.8		0.06	0.05	0.04	-		
Rinsing gully system with slurry (individual and group)	2.5		0.14	0.09	0.09	0.12		
Shovels in manure gully (individual housing)	2.2		0.02	0.01	0.01	-		
Cool deck system 115% cooling surface (individual and group)	2.2		0.12	0.08	0.07	0.10		
Cool deck system 135% cooling surface (individual and group)	2.2		0.12	0.14	0.11	0.15		
Group housing with feeding cubicles or feeding stations, without straw bed, tilting pit walls, metal three sided grate	2.3		0.12	0.20	0.17	0.22		
Group housing with feeding cubicles or feeding stations, without straw bed, tilting pit walls, other material grate	2.5			0.02	0.06	0.12		
Walk about housing with sow feeding station and straw bed (group)	2.6		0.14	0.15	0.20	0.28		
Average emission factor (kg NH_3/animal place)		**2.1**	**2.3**	**2.3**	**2.4**	**2.4**	**2.6**	**2.4**

1) The emission reduction in this period is set to 50% compared to traditional housing (Van der Hoek, 2002).

2) Source: environmental permits in province Noord-Brabant on 01-01-2005.

3) Source: environmental permits in province Noord-Brabant on 01-01-2009.

4) Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2012.

5) Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2014.

6) Source: agricultural census 2016.

7) Source: agricultural census 2017.

Table A6.4 Emission factors for reduced emission housing of weaned piglets (kg NH_3 per animal place)

	EF	1990-2004 1)	2005-2006 2)	2007-2010 3)	2011-2012 4)	2013-2014 5)	2015 6)	2016 7)
	kg NH_3/ animal place	fraction	fraction	fraction	fraction	fraction	fraction	fraction
Air scrubbers								
Biological air scrubber system 70% emission reduction	0.18		0.23	0.14	0.10	0.08		
Chemical air scrubber system 70% emission reduction	0.18		0.38	0.38	0.23	0.17		
Chemical air scrubber system 95% emission reduction	0.03		0.39	0.39	0.28	0.22		
Combined air scrubber system 85% emission reduction chemical and water washer	0.09		-	0.06	0.19	0.16		
Combined air scrubber system 70% emission reduction with water washer, chemical washer and biofilter	0.18		-	0.01	0.02	0.02		
Combined air scrubber system 85% emission reduction with water washer, chemical washer and biofilter	0.09		-	0.02	0.04	0.03		
Combined air scrubber system 85% emission reduction water curtain and biological washer	0.09		-	0.00	0.14	0.30		
Various combinations of low emission built housing with air scrubbers	ca. 0.03		-	-	0.01	0.01		
Average emission factor (kg NH_3/animal place)		**N/A**	**0.12**	**0.11**	**0.09**	**0.10**	**0.10**	**0.10**
Floor/slurry pit adjustment								
Level coated pit floor with rack and pinion shove system	0.18		0.01	0.01	0.02	0.02		
Rinsing gully system with slurry and partly slatted floor	0.21		0.07	0.05	0.03	0.03		
Manure capture in water combined with a manure disposal system	0.13		0.40	0.46	0.50	0.50		
Shallow slurry pits with water and manure channel of max. 0.13 m^2 per animal place	0.26		0.09	0.07	0.08	0.08		
Shallow slurry pits with water and manure channel of max. 0.19 m^2 per animal place	0.33		0.01	0.00	0.01	0.01		
Half grate with decreased manure surface	0.34		0.01	0.01	0.01	0.01		
Manure collection in and rinsing with acidified liquid fully slatted floor	0.16		0.02	0.01	0.01	0.00		
Manure collection in and rinsing with acidified liquid party slatted floor	0.22		0.01	0.00	0.00	0.00		
Separated discharge manure and urine through tilting manure belt	0.20		0.01	0.00	0.00	0.00		
Cool deck system (150% cooling surface)	0.15		0.12	0.09	0.08	0.09		
Rearing pen with tilting pit wall max. 0.07 m^2 emitting surface, regardless of group size	0.17		0.01	0.02	0.03	0.03		
Rearing pen with tilting pit wall > 0.07 m^2 < 0.10 m^2 emitting surface, up to 30 piglets	0.21		0.01	0.02	0.04	0.07		

	EF	1990-2004[1]	2005-2006[2]	2007-2010[3]	2011-2012[4]	2013-2014[5]	2015[6]	2016[7]
	kg NH_3/ animal place	fraction	fraction	fraction	fraction	fraction	fraction	fraction
Rearing pen with tilting pit wall > 0.35 m^2 emitting surface > 0.07 m^2 < 0.10 m^2, from 30 piglets on	0.18		0.12	0.15	0.11	0.10		
Fully slatted with water and manure canals eventually with tilted pit wall, emitting surface < 0.10 m^2	0.20		0.13	0.09	0.09	0.09		
Average emission factor (kg NH_3/animal place)		**0.30**	**0.17**	**0.17**	**0.17**	**0.17**	**0.18**	**0.18**

[1] The emission reduction in this period is set to 50% compared to traditional housing (Van der Hoek, 2002).

[2] Source: environmental permits in province Noord-Brabant on 01-01-2005.

[3] Source: environmental permits in province Noord-Brabant on 01-01-2009.

[4] Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2012.

[5] Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2014.

[6] Source: agricultural census 2016.

[7] Source: agricultural census 2017.

Table A6.5 Emission factors for reduced emission housing of fattening pigs and young breeding pigs (kg NH_3 per animal place)

	EF		1990-2004[1]		2005-2006[2]		2007-2010[3]		2011-2012[4]		2013-2014[5]		2015[6]		2016[7]	
	kg NH_3/ animal place		fraction		fraction		fraction		fraction		fraction		fraction		fraction	
	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2
Air scrubbers																
Biological air scrubber system 70% emission reduction	1.0	1.2			0.22		0.12		0.10		0.10					
Chemical air scrubber system 70% emission reduction	1.0	1.2			0.40		0.40		0.25		0.19					
Chemical air scrubber system 95% emission reduction	0.17	0.20			0.38		0.40		0.30		0.28					
Air scrubber, other than biological or chemical	0.51	0.60			-		0.08		0.34		0.42					
Various combinations of low emission built animal houses with air scrubbers	ca. 0.3	ca. 0.3			-		-		0.00		0.01					
Average emission factor (kg NH_3/animal place)			**N/A**	**N/A**	**0.70**	**0.82**	**0.64**	**0.76**	**0.59**	**0.69**	**0.57**	**0.68**	**0.55**	**0.53**	**0.65**	**0.63**

	EF		1990-2004 1)		2005-2006 2)		2007-2010 3)		2011-2012 4)		2013-2014 5)		2015 6)		2016 7)	
	kg NH_3/ animal place		fraction		fraction		fraction		fraction		fraction		fraction		fraction	
	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2
Floor/slurry pit adjustment																
Manure collection in and rinsing with NH_3 poor liquid	1.8	2.1			0.10		0.05		0.03		0.02					
Cool deck system 170% and metal three sided grate floor	1.9	2.3			0.13		0.08		0.04		0.03					
Manure collection in formaldehyde-liquid manure solution and metal three sided grate	1.1	1.3			0.04		0.04		0.01		0.01					
Manure collection in water and metal three sided grate	1.5	1.8			0.01		0.01		0.01		0.01					
Cool deck system 200% and metal grate, emitting surface max. 0.8 m^2	1.7	2.0			0.14		0.11		0.07		0.07					
Cool deck system 200% and metal grate, emitting surface max. 0.5 m^2	1.4	1.6			0.00		0.00		0.00		0.00					
Cool deck system 200% and other than metal grate, emitting surface max. 0.6 m^2	1.8	2.1			0.04		0.05		0.04		0.03					
Cool deck system 200% and other than metal grate, 0.6 m^2 < emitting surface < 0.8 m^2	2.7	3.1			0.00		0.00		0.00		0.00					
Water-manure channel, tilting pit wall, metal three sided grate, emitting surface max. 0.18 m^2	1.2	1.2			0.20		0.17		0.24		0.24					
Water-manure channel, tilting pit wall, metal three sided grate, 0.18 m^2 < emitting surface < 0.27 m^2	1.7	1.7			0.02		0.03		0.06		0.07					
Water-manure channel, tilting pit wall, grate other than metal, emitting surface max. 0.18 m^2	1.9	1.9			0.15		0.34		0.37		0.40					
Water-manure channel, tilting pit wall, grate other than metal, 0,18 m^2 < emitting surface < 0.27 m^2	2.3	2.3			0.04		0.03		0.03		0.04					
Spherical floor pen with concrete spill grate and metal three sided grate	1.7	2.3			0.02		0.02		0.02		0.02					

	EF kg NH_3/ animal place		1990-2004[1] fraction		2005-2006[2] fraction		2007-2010[3] fraction		2011-2012[4] fraction		2013-2014[5] fraction		2015[6] fraction		2016[7] fraction	
	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2	0.8 m^2	1.0 m^2
Pen with separate manure channels	2.1	2.1			0.01		0.01		0.01		0.01					
Rinsing gully system with metal three sided grates	1.4	1.6			0.03		0.02		0.02		0.02					
Rinsing gully system with other than three sided grates	2.0	2.3			0.07		0.06		0.04		0.04					
Floating balls in the manure	ca. 3.3	ca. 4.0			-		-		0.00		0.01					
Average emission factor (kg NH_3/animal place)			**2.1**	**N/A**	**1.7**	**1.9**	**1.7**	**1.8**	**1.7**	**1.8**	**1.7**	**1.8**	**1.7**	**1.8**	**1.7**	**1.8**

[1] The emission reduction in this period is set to 50% compared to traditional housing (Van der Hoek, 2002).

[2] Source: environmental permits in province Noord-Brabant on 01-01-2005.

[3] Source: environmental permits in province Noord-Brabant on 01-01-2009.

[4] Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2012.

[5] Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2014.

[6] Source: agricultural census 2016.

[7] Source: agricultural census 2017.

Table A6.6 Emission factors for reduced emission housing of boars (kg NH_3 per animal place)

	EF	1990-2004[1]	2005-2006[2]	2007-2010[3]	2011-2012[4]	2013-2014[5]	2015[6]	2016[7]
	kg NH_3/ animal place	fraction	fraction	fraction	fraction	fraction	fraction	fraction
Air scrubbers								
Biological air scrubber system 70% emission reduction	1.7		0.22	0.16	0.08	0.07		
Chemical air scrubber system 70% emission reduction	1.7		0.47	0.50	0.48	0.27		
Chemical air scrubber system 95% emission reduction	0.28		0.31	0.26	0.19	0.22		
Combined air scrubber system 85% emission reduction chemical and water washer	0.83		-	0.05	0.15	0.15		
Combined air scrubber system 70% emission reduction with water washer, chemical washer and biofilter	1.7		-	0.01	0.02	0.02		
Combined air scrubber system 85% emission reduction with water washer, chemical washer and biofilter	0.83		-	0.01	0.02	0.01		

	EF	1990-2004[1]	2005-2006[2]	2007-2010[3]	2011-2012[4]	2013-2014[5]	2015[6]	2016[7]
	kg NH_3/ animal place	fraction	fraction	fraction	fraction	fraction	fraction	fraction
Combined air scrubber system 85% emission reduction water curtain and biological washer	0.83		-	-	0.06	0.26		
Average emission factor (kg NH_3/animal place)		**1.65**	**1.3**	**1.3**	**1.2**	**1.0**	**1.1**	**1.1**
Floor/slurry pit adjustment through floating balls in the manure	3.9							

[1] The emission reduction (air scrubber) in this period is set to 70% compared to traditional housing (Van der Hoek, 2002).

[2] Source: environmental permits in province Noord-Brabant on 01-01-2005.

[3] Source: environmental permits in province Noord-Brabant on 01-01-2009.

[4] Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2012.

[5] Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2014.

[6] Source: agricultural census 2016.

[7] Source: agricultural census 2017.

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Annex 7 Emission factors for NH_3 from animal housing of poultry

In this annex the emission factors in kg NH_3 per animal place are given that form the basis for the calculation of emission factors relative to the TAN excretion (section 5.2).

Laying hens younger than ca. 18 weeks
In Table A7.1 the housing systems are depicted according to the classification of the Agricultural census. For some systems that comprise of several subsystems an emission factor is derived using information in environmental permits.

To the battery cage systems with slurry and manure belt also the compact battery is counted with an emission factor of 0.011 kg NH_3/animal place. The share of this system in environmental permits is negligibly small with 0.1%.

Table A7.1 (Derived) emission factors for laying hens under 18 weeks (kg NH_3 per animal place)

	1990-2010[1]	**2011-2012[2]**	**2013-2014[3]**	**2015[4]**	**2016[5]**
	kg NH_3/animal place	**kg NH_3/animal place**	**kg NH_3/animal place**	**kg NH_3/animal place**	**kg NH_3/animal place**
Battery cage with slurry					
Open storage	0.045	0.045	0.045	0.045	0.045
Manure belt	0.020	0.020	0.020	0.020	0.020
Battery cage with solid manure					
Manure belt, forced manure drying 0.2 m^3/animal/hour	0.020	0.020	0.020	0.020	0.020
Manure belt, forced manure drying 0.4 m^3/animal/hour	0.006	0.006	0.006	0.006	0.006
Manure belt, forced manure drying 0.4 m^3/animal/hour with air scrubber	0.001	0.001	0.001	0.001	0.001
Other battery cage solid manure	0.020	0.020	0.020	0.016	0.016
Ground housing without manure aeration	0.170	0.170	0.170	0.170	0.170
Ground housing with air scrubber	-	-	-	0.035	0.042
Aviary system					
Aviary housing without forced manure drying	0.050	0.050	0.050	0.050	0.050
Aviary housing with forced manure drying	0.030	0.029	0.028	0.028	0.028
Ground/aviary housing with air scrubber	0.017	0.009	0.011	-	-
Other housing	0.139	0.157	0.094	0.106	0.108

[1] Source: environmental permits in province Noord-Brabant on 1-1-2009.

[2] Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2012.

[3] Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2014.

[4] Source: agricultural census 2016.

[5] Source: agricultural census 2017.

It is not clear which systems have been filled in by businesses under 'other battery cage housing solid manure' in the Agricultural census of 2008. To the other battery cage systems with solid manure belong the channel animal house (E1.4) and the battery cage system with manure belt aeration and above laying drying tunnel (E1.6). Although it concerns over 7% of the animal places in the Agricultural census of 2008, systems mentioned hardly occur in the environmental permits. Possibly it concerns businesses with manure belt aeration with the aeration turned off but producing solid manure after all through after drying, and therefore have filled in battery cage housing with solid manure (Ellen, 2010). The emission factor of manure belt with forced manure drying 0.2 m^3 per hour is applied as minimal value.

The emission factor in the Rav applies to situations in which the manure is disposed of from the business immediately or stored for a maximum of two weeks in a covered container. In other cases an additional emission factor for post-processing techniques like after drying or other storage applies. The emission factor for the post-processing technique is to be added to the emission factor of the animal housing type. For rearing hens from the environmental permits an average additional emission factor for after drying of 0.005 kg NH_3 is derived.
Although in animals with ground housing in the Agricultural census in some cases a post-processing technique is applied, this is not accounted for. The Rav does not provide an additional emission factor for post-processing techniques in ground housing.

Laying hens
In Table A7.2 the housing systems are depicted according to the classification of the Agricultural census. For some systems that consist of several subsystems an emission factor is derived using information in environmental permits.

It is assumed that the enriched cages and colony housing, both with manure belt aeration, have been filled in with battery cage housing with forced manure drying (0.7 m^3/hour) by businesses.
To the other battery cage systems with solid manure belong the canals animal house (E2.4 and the battery cage system with manure belt aeration and above lying drying tunnel (E2.6). These systems hardly occur. In other battery cage housing with solid manure it concerns most likely businesses with manure belt drying that have switched off the aeration. Possibly part of these businesses have after drying so that they produce solid manure after all (Ellen, 2010). For the share animals with housing type other battery cage solid manure the emission factor of manure belt with forced manure drying 0.042 m^3 per hour is applied as minimal value.

In Table A7.2 also the emission factors for systems consisting of several variations are derived. Air scrubbers hardly occur and are not considered further.

Table A7.2 (Derived) emission factors for laying hens (kg NH_3 per animal place)

	1990-2000	2001-2007	2008-2010[1)]	2011-2012[2)]	2013-2014[3)]	2015[4)]	2016[5)]
	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place
Battery cage with slurry							
Open storage	0.083	0.100	0.100	0.100	0.100	0.100	0.100
Manure belt	0.035	0.042	0.042	0.042	0.042	0.042	0.042
Battery cage with solid manure							
Manure belt, forced manure drying 0.5 m^3/animal/hour	0.035	0.042	0.042	0.042	0.042	0.042	0.042
Manure belt, forced manure drying 0.7 m^3/animal/hour	0.010	0.012	0.012	0.012	0.012	0.012	0.012
Manure belt, forced manure drying 0.7 m^3/animal/hour with air scrubber	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Other battery cage solid manure	0.035	0.042	0.042	0.042	0.042	0.031	0.032

	1990-2000	2001-2007	2008-2010[1]	2011-2012[2]	2013-2014[3]	2015[4]	2016[5]
	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place
Ground housing							
Ground housing without manure aeration (including 0.1% with air scrubber)	0.315	0.315	0.402	0.402	0.402	0.402	0.402
Perfo system	0.110	0.110	0.140	0.140	0.140	0.140	0.140
Manure aeration	0.125	0.125	0.160	0.160	0.160	0.170	0.170
Manure belts	0.068	0.068	0.087	0.091	0.092	0.098	0.101
Aviary housing							
Aviary housing without forced manure drying	0.090	0.090	0.090	0.090	0.090	0.090	0.090
Aviary housing without forced manure drying	0.100	0.100	0.100	0.098	0.098	0.109	0.110
Aviary housing with forced forced manure drying	0.062	0.062	0.062	0.058	0.058	0.059	0.061
Other housing	0.290	0.290	0.370	0.295	0.101	-	-

[1] Source: environmental permits in province Noord-Brabant on 1-1-2009.

[2] Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2012.

[3] Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2014.

[4] Source: agricultural census 2016.

[5] Source: agricultural census 2017.

The emission factor in the Rav applies to situations in which the manure is disposed of immediately from the business or is stored for a period of at most two weeks in a covered container. In other cases an additional emission factor for post-processing techniques like after drying or other storage applies. The emission factor of the post-processing technique is to be added to the emission factor of the animal housing type. Based on information in environmental permits the average additional emission factor for after drying is 0.010 kg NH_3 up to 2010 and for the years after 0.008 kg NH_3 per animal place.

Broiler parents to ca. 19 weeks

In Table A7.3 the animal housing systems are depicted according to the classification in the Agricultural census. For some systems that consist of several subsystems an emission factor is derived using information in environmental permits.

In Table A7.3 also the emission factors for other low emission housing are presented.

Table A7.3 Emission factors for broiler parents under 19 weeks (kg NH_3 per animal place)

	1990-2010	2011-2012[1]	2013-2014[2]	2015[3]	2016[4]
	kg NH_3/animal place	kg NH_3/animal place	kg NH_3/animal place	kg NH_3/animal place	kg NH_3/animal place
Traditional housing	0.122	0.122	0.122	0.122	0.122
Air scrubber/biofilter	-	0.012	0.012	0.016	0.016
Other low emission housing	-	0.057	0.052	0.050	0.048

[1] Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2012.

[2] Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2014.

[3] Source: agricultural census 2016.

[4] Source: agricultural census 2017.

Broiler parents
In Table A7.4 the housing systems are depicted according to the classification of the Agricultural census. For some systems consisting of several subsystems an emission factor is derived using information in environmental permits.

In Table A7.4 also emission factors for systems consisting of several variations are derived.

Table A7.4 Derived emission factors for broiler parents (kg NH_3 per animal place)

	1990-2007	2008-2010[1)]	2011-2012[2)]	2013-2014[3)]	2015[4)]	2016[5)]
	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place
Traditional housing	0.580	0.456	0.456	0.456	0.456	0.456
Enriched cage/group cage	0.080	0.063	0.063	0.063	0.063	0.063
Aviary housing with forced manure drying	0.170	0.134	0.131	0.127	0.127	0.128
Ground housing with manure aeration from above	0.250	0.196	0.196	0.196	0.196	0.196
Ground housing with vertical hoses in the manure or through tubes underneath the bin	0.435	0.342	0.342	0.342	0.342	0.342
Perfo system	0.230	0.181	0.181	0.181	0.181	0.181
Air scrubber systems	0.245	0.192	0.192	0.192	0.192	0.192
Ground housing with manure belts	0.255	0.202	0.200	0.200	0.242	0.205

1) Source: environmental permits in province Noord-Brabant on 1-1-2009.

2) Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2012.

3) Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2014.

4) Source: agricultural census 2016.

5) Source: agricultural census 2017.

The emission factor in the Rav applies to situations in which the manure is removed from the farm directly or stored for a period of no more than two weeks in a covered container. In the remaining cases an additional emission factor for post-processing techniques like after drying or other storage applies. The emission factor of the post-processing technique has to be added to the emission factor of the housing type. Based on the information in environmental permits the average additional emission factor for after drying amounts to 0.010 kg NH_3 up to 2010 and in the years after 0.008 kg NH_3 per animal place.

Broilers
In Table A7.5 the housing systems are depicted according to the classification of the Agricultural census. For some systems consisting of several subsystems an emission factor is derived using information in environmental permits.

In Table A7.5 also emission factors for systems consisting of several variations are derived.

Ducks for slaughter
In ducks for slaughter only traditional housing occurs with an emission factor of 0.210 kg NH_3 per animal place.

Table A7.5 (Derived) emission factors for broilers (kg NH_3 per animal place)

	1990-2010[1)]	2011-2012[2)]	2013-2014[3)]	2015[4)]	2016[5)]
	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place
Traditional housing	0.068	0.068	0.068	0.068	0.068
Floor with litter drying	0.008	0.009	0.009	0.005	0.006
Storey systems	0.011	0.012	0.011	0.029	0.024
Air scrubber systems	0.008	0.010	0.010	0.010	0.010
Ground housing with floor heating and cooling	0.038	0.038	0.038	0.038	0.038
Mixed air ventilation, warmth heaters and fans, air blending	0.031	0.032	0.031	0.030	0.021

1) Source: environmental permits in province Noord-Brabant on 1-1-2009.

2) Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2012.

3) Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2014.

4) Source: agricultural census 2016.

5) Source: agricultural census 2017.

Turkeys for slaughter

In Table A7.6 the housing systems are presented according to the classification of the Agricultural census. For some systems consisting of several subsystems an emission factor is derived using information of environmental permits.

In Table A7.6 also emission factors for systems consisting of several variations are derived.

Table A7.6 (Derived) emission factors for turkeys (kg NH_3 per animal place)

	1990-2007	2008-2010[1)]	2011-2012[2)]	2013-2014[3)]	2015[4)]	2016[5)]
	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place	kg NH_3/ animal place
Traditional housing	0.680	0.932	0.932	0.932	0.932	0.932
Low emission housing	0.493	0.493	0.411	0.404	0.383	0.374

1) Source: environmental permits in province Noord-Brabant on 01-01-2009.

2) Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2012.

3) Source: environmental permits in provinces: Overijssel, Gelderland, Utrecht, Noord-Brabant and Limburg on 01-01-2014.

4) Source: agricultural census 2016.

5) Source: agricultural census 2017.

Annex 8 Animal house occupancy fractions

To convert emissions from animal housings in kg NH_3 per animal place to an emission factor in kg NH_3 per animal, the animal house occupancy fractions are needed. For instance an emission of 10.0 kg NH_3 per animal place at an occupancy fraction of 0.9 yields an emission of 10.0 / 0.9 = 11.1 kg NH_3 per animal entered in the Agricultural census. Table A8.1 presents reference year, occupancy fraction and period to which these apply (reporting period).

Table A8.1 Animal house occupancy (fraction) and reference year

	Reporting period	Reference year[1)]	Animal house occupancy (fraction)
Dairy cows	1990-2001	2001	0.9
Dairy cows	2002-2016	2007-2012	1.0
Other cattle excluding meat calves	1990-2016	2007-2012	1.0
Meat calves, for white veal production	1990-1998	1998	0.93
Meat calves, for white veal production	1999-2016	2012	0.93
Meat calves, for rosé meat production	1990-1998	1998	0.93
Meat calves, for rosé meat production	1999-2016	2012	0.96
Female sheep	1990-2016	1991	1.0
Milk goats	1990-2016	1998	1.0
Horses, ponies and mules	1990-2016	1997	1.0
Fattening pigs and rearing pigs	1990-2016	2008-2009	0.97
Sows	1990-2016	1994	[2)]
Boars for service	1990-2016	1991	0.9
Broiler parents < 18 weeks	1990-2016	2008	0.83
Broiler parents ≥ 18 weeks	1990-2007	1996	0.87
Broiler parents ≥ 18 weeks	2008-2016	2008	0.87
Laying hens < 18 weeks			
battery cage slurry, dry manure 0.2 m^3/h, other battery and other housing	1990-2016	1991	0.9
battery cage dry manure 0.4 m^3/h	1990-2016	1996	0.9
free range housing without manure aeration and aviary with manure drying	1990-2016	2000	0.9
aviary without manure drying and air scrubber	1990-2016	1998	0.9
Laying hens ≥ 18 weeks			
battery slurry with open storage, battery dry	1990-2016	1996	0.95

	Reporting period	Reference year[1]	Animal house occupancy (fraction)
manure 0.7 m^3/h and deep pit			
battery slurry 2/week mucking, dry manure 0.5 m^3/h, other battery	1990-2016	1991	0.95
floor housing and other housing	1990-2007	1996	0.95
floor housing and other housing	2008-2016	2008	0.95
aviary without manure drying	1990-2016	1998	0.95
aviary manure drying	1990-2016	2001	0.95
Broilers			
traditional, litter drying, storey system with slatted floor and aeration, air scrubber	1990-2016	2002	0.81
ground housing with floor heating and - cooling	1990-2016	1997-1998	0.81
mixed air ventilation	1990-2016	2005	0.81
Ducks	1990-2016	2000	0.84
Turkeys			
traditional	1990-2007	1998	0.95
traditional	2008-2016	2008	0.95
low emission	1990-2016	2008	0.95
Rabbits (mother animals)	1990-2016	1998	1.0
Rabbits for slaughter	1990-2016	1998	0.85
Fur-bearing animals (mother animals)	1990-2016	1991	0.9

1) The reference year is the year or period that corresponds with the year or the period in which the emission factor in kg NH_3 per animal place is taken up in the Rav respectively is measured.

2) Per breeding sow present: 0.25 sow with piglets; 0.83 open and sows in pig and 2.8 weaned piglet per breeding sow.

Annex 9 Manure storage outside the animal house

Table A9.1 Manure storage outside animal housing (% of produced manure)

	1990-2004[1]	2005[2]	2006[2]	2007[2]	2008[2]	2009[2]	2010-2011[3]	2012[3]	2013[4]	2014[5]	2015[6]	2016[7]
Cattle slurry	25	27	27	27	27	27	24	24	23	23	23	23
Pig slurry	10	15	15	15	15	15	21	21	19	19	19	19
Poultry slurry	15	88	88	88	88	88	100	100	100	100	100	100
Slurry of fur-bearing animals	50	50	50	50	50	50	50	50	50	50	50	50
Solid manure of grazing animals, pigs and rabbits	100	100	100	100	100	100	100	100	100	100	100	100
Solid poultry manure												
deep pit housing	100	100	100	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
pre-dried belt manure (battery cage and aviary)	100	100	100	100	100	100	100	100	100	100	100	100
aviary without post-drying	100	100	100	100	100	100	100	100	100	100	100	100
post-dried manure	100	100	100	100	100	100	100	100	100	100	100	100
laying poultry – litter manure	100	90	60	40	0	0	0	40	40	45	35	35
broiler manure	100	85	65	70	40	35	25	25	30	35	20	25
duck manure	100	100	100	100	85	90	95	95	100	85	70	65
turkey manure	100	75	5	95	0	0	0	0	0	0	25	30

[1] Agricultural census 1993.

[2] Agricultural census 2007 and registered manure transports.

[3] Agricultural census 2010 and registered manure transports.

[4] Agricultural census 2014 and registered manure transports.

[5] Agricultural census 2015 and registered manure transports.

[6] Agricultural census 2016 and registered manure transports.

[7] Agricultural census 2017 and registered manure transports.

Table A9.2 Covered manure storages (% of stored manure outside animal housing)

	1990[1]	1991[1]	1992-1996[2]	1997-2004[3]	2005-2016[4]
Cattle slurry	25	25	67	97	100
Pig slurry	70	75	82	100	100
Poultry slurry					
open storage	60	70	78	100	100
manure belt disposal	0	17	78	100	100

[1] Van der Hoek (1994).

[2] Agricultural census 1993.

[3] Van der Hoek (2002).

[4] Hoogeveen *et al.* (2010).

N.B. Other manure storages are not covered.

Table A9.3 NH_3 emission factors from manure storages outside animal housing (% stored manure)

	1990-2004[1]		2005-2016[2]
	covered	uncovered	covered
Cattle slurry	0.96	4.80	1.00
Fattening pig slurry	1.66	8.30	2.00
Breeding pig slurry	2.36	11.80	2.00
Manure of fur-bearing animals and rabbits	2.00		2.00
Poultry slurry			
open storage	2.80	14.00	1.00
manure belt disposal	0.90	4.50	1.00
Solid grazing animal manure	0.49	2.45	2.00
Solid pig manure	N/A	N/A	2.00
Solid poultry manure			
deep pit	N/A	4.20	4.20
pre-dried belt manure battery cage housing	N/A	5.30	*
aviary housing	N/A	9.50[3]	*
post-dried manure	N/A	0.00	0.00
laying poultry – litter manure	N/A	3.00	2.50
meat poultry – litter manure	N/A	2.70	2.50
*Pre-dried belt manure and aviary manure			kg NH_3 per animal place
laying hens < 18 weeks			0.025
laying hens ≥ 18 weeks			0.050
broiler parents			0.075

[1] Van der Hoek (2002).

[2] Oenema *et al.* (2000).

[3] Hoogeveen *et al.* (2006).

Emission factors for N_2O, NO_x and N_2 from animal housing are usually expressed as percentage of the N excretion (Oenema *et al.*, 2000). Nitrogen emissions as NO_x and N_2O from manure management are described in Chapters 6 and 7. For NH_3 the emission factors are based on TAN. In line with the TAN flow, the emission factors for N_2O, NO_x and N_2 have to be converted to percentages of TAN in order to determine the amount of TAN entering outside manure storages. Section 5.2 describes this conversion along with the emission factors for NH_3 from animal housing.

The emission factor as percentage of the amount of TAN present at the start of the storage period is calculated from the proportion of the total amount of TAN that is excreted and mineralized in the animal house. For all livestock categories (i) and manure management systems (j), following calculations are performed:

$EF\ NH_3\text{-}N\ storage_{ij} = EF\ NH_3\ storage_{ij} \times ((N\ excretion_i - N\ losses\ animal\ housing_{ij}) / (TAN\ input_{ij} - N\ losses\ animal\ housing_{ij}))$ (A9.1)

In which

EF NH_3-N $storage_{ij}$: NH_3 emission factor (% of TAN) for outside storages of livestock category (i) and manure management system (j)

EF NH_3 $storage_{ij}$: NH_3 emission factor (% of N stored) for outside manure storage of livestock category (i) and manure management system (j)

N losses animal housingij: Sum of NH_3-N, N_2O-N, NO_x-N and N_2-N losses (kg N/year) from animal houses for livestock category (i) and manure management system (j)

Also in manure storages emissions of N_2, N_2O and NO_x occur, but as emission factors for these include both animal housing and manure storage according to the IPCC Guidelines, these are not calculated separately. Emissions from manure storages are therefore included in the EFs described in section 5.3 (equation 5.5).

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Annex 10 Emission factors for calculation direct nitrous oxide emissions from agricultural soils (including grazing)

Marian van Schijndel and Sietske van der Sluis (PBL), 2011

For fertilization with inorganic N fertilizers and animal manure and for grazing emission factors have been established and applied in the NIR 2011. For an overview see Table A10.1. This memorandum describes the derivation of the (weighted average) emission factors that are applied in the NIR 2011 for the period from 1990 to now in the ER-calculations of direct N_2O emissions from agricultural soils (including grazing).

Table A10.1 N_2O-N emission factors (% of the N supply) for calculation of direct N_2O emissions from agricultural soils and of N_2O emissions as a result of grazing (based on Velthof and Mosquera, 2011b and Van der Hoek *et al.*, 2007). The marked emission factors are applied since the NIR 2011 (Van der Maas *et al.*, 2011).

N_2O-emission factor (%)		grassland	arable land	Weighted average all land use and soils	Was previously (1)*	remarks
Animal manure emission low	All soils			0.9	2 (1.7)	1990: 1.5 2008: 1.9
	Mineral soils	0.3	1.3		Like all soils	
	Peat soils	1	N/A		Like all soils	
Animal manure surface application	All soils			0.4	1 (0.9)	
	Mineral soils	0.1	0.6		1 (0.8)	1990: 0.8 1999: 0.9
	Peat soils	0.5	N/A		2 (1.6)	1990: 1.5 1995: 1.7
Inorganic N fertilizer	All soils			1.3	1 (1.04)	
	Mineral soils	0.8	0.7		nitrate containing 1 (0.97) ammonium containing 0.5 (0.48)	varying over the years
	Peat soils	3	N/A		nitrate containing 2 (1.94) ammonium containing 1 (0.97)	varying over the years
Grazing	All soils			3.3	1.68 (1.56)	
	Mineral soils	2.5	N/A			
	Peat soils	6.0	N/A			

N_2O-emission factor (%)		grassland	arable land	Weighted average all land use and soils	Was previously (1)*	remarks
					1 (0.93)	faeces
					2 (1.86)	urine
Histosols	Peat soils	**	N/A	**	2	No adjustment
Crop residues	Mineral soils	N/A	**	**	1	No adjustment
Nitrogen fixation	Mineral soils	N/A	**	**	1	No adjustment
Sewage sludge	????				1	No adjustment

(1) Van der Hoek *et al.*, 2007.

* Between brackets the emission factors related to total gross N supply to soil (without deducting NH_3-N in fertilizing). In the old method the N_2O-N was calculated based on net N supply to soil, i.e. after deduction of NH_3-N. In the new method no NH_3-N deduction is applied anymore. Reason is that this also not happens in the N_2O measurements in field experiments.

** No (new) data available.

1. Reason revision N_2O-N emission factors

In 1994 based on laboratory scale experiments country-specific emission factors for the direct N_2O emission from agricultural soils were derived (Kroeze, 1994) for the distinguished sources.
The N_2O-N emission factor for low emission manure application and surface spreading were respectively 2 and 1% of the N supply to the soil. Thus the emission factor for low emission manure application was compared to surface spreading a factor 2 higher. In 1997 this was summarized in a methodology description (Spakman *et al.*, 1997). For surface spreading the country-specific N_2O-N emission factor was somewhat lower than the IPCC 1996 default (1% versus 1.25% of the N supply).

For the NIR 2005 (Klein Goldewijk *et al.*, 2005) the methodology was developed further and adjusted (Van der Hoek *et al.*, 2007). Amongst others the emission factor for inorganic N fertilizer is refined based on research of Velthof *et al.*, 1997. This refinement comprised that for a separate category inorganic N fertilizers (ammonium containing inorganic N fertilizers that do not contain nitrate) a 50% lower emission factor was applied than used before for all kinds of inorganic N fertilizer.

Based on field experiments in the Netherlands there seemed to be indications that the N_2O-N emission factor for low emission manure application was lower than the 2% of the N supply used (Velthof *et al.*, 2003 and Van Groeningen *et al.*, 2004). This led to the question whether low emission manure application in practice indeed had a higher N_2O-N emission factor than surface spreading. An overview of Dutch and international research results published after the publication of Kroeze in 1994 (Kuikman *et al.*, 2006) offered insufficient reason to adjust and/or further refine the emission factors for low emission manure application and surface spreading (Van der Hoek *et al.*, 2007). In the Netherlands only a very limited number of comparative experiments had been carried out between surface spreading and low emission manure application. These resulted in relatively low emission factors (< 0.1% of the N supply) for both application techniques (Velthof *et al.*, 1997). Results of international comparative field experiments showed that the nitrous oxide emissions for low emission manure application were mostly higher than for surface spreading. However it was not possible to derive long year average N_2O-N emission factors and adjust these for Dutch circumstances. It was concluded that more research was needed (see also the NIR 2006; Brandes *et al.*, 2006).

Between 2007 and 2010 in the Netherlands 2 to 3 year lasting comparative field experiments have been conducted to map the N_2O emissions for surface spreading and low emission manure application, in which for comparison also the fertilization with inorganic N fertilizer was researched (Velthof *et al.*, 2010 and Velthof and Mosquera, 2011a). It was found that low emission manure application has higher N_2O-N emission factors than surface spreading.

The emission factors derived based were lower than the emission factors used for both fertilization techniques, and there were differences in the N_2O-N emission factors between grassland and arable land and between animal manure and inorganic N fertilizer. These findings were the incentive to follow-up research. Based on all available Dutch and other NW European measurements of N_2O emission factors starting from the beginning of the nineties it was recommended to adjust the emission factors for manure application and inorganic N fertilizer use (Velthof and Mosquera, 2011b). PBL Netherlands Environmental Assessment Agency has reviewed the statistical analysis performed by Velthof and Mosquera on behalf of the Emission Registration (see annex 2 of this Annex).

2. Motivation for calculating weighted average emission factors

Table 1 distinguishes for animal manure low emission manure application and surface fertilization. Further for animal manure, inorganic N fertilizer and grazing there are separate emission factors for mineral soils, peat soils, grassland and arable land (see data in italics) as determined by Velthof and Mosquera, 2011b.

Data series N supply to soil

Based on the historical data for N supply to grassland and arable land (part of the manure and NH_3 calculation for the Emission Registration, see for instance Hoogeveen *et al.*, 2010) for four soil types a yearly and multiannual weighted average emission factor can be calculated (Table 1a up to c in annex 1, this Annex). For this the data series of 1990-2005 is used, because the data 2006-2008 show a trend break with the data of 1990-2005. Especially there is a factor 8 to 15 increase in the supply of respectively inorganic N fertilizer and animal manure to arable land on peat soil. Also there is almost a bisection in the supply of N in manure (through fertilization and grazing) to grassland on peat.

This correlates to specific data becoming available on the cultivation of crops on several soil types through the Agricultural census since 2006. Up to 2006 this information was not available and crops were allocated to soil types. Grassland was situated on peat soil as much as possible and only in case of too little grassland also arable land was situated on peat soil. The supply of manure to arable land on peat soil was as a result of this limited to << 1% and deemed negligible.

In the assumption that the supply of manure to arable land is negligible, use of the whole data series (1990-2008) leads to a weighted average emission factor that is circa 0.1% lower than in using the data series 1990-2005. For the current emission calculations the data series of 1990-2005 is used to prevent underestimation of the emissions.

From the new information that is available over the period 2006-2008 it turns out that the supply of manure on arable land on peat soil is circa 1 to 2% higher. At this moment it is unknown whether including the supply of manure to arable land on peat leads to significant higher N_2O emission factors. There is no N_2O emission factor available for fertilization of arable land on peat with animal manure or inorganic N fertilizer.

A sensitivity analysis shows that including the supply of manure to arable land on peat does not lead to a higher weighted average emission factor.

Only with an emission factor that is a factor 6 to 8 higher for supply of animal manure to arable land on peat the weighted average emission factor becomes 0.1% point higher. For inorganic N fertilizer this is only the case when the emission factor is a factor 40 higher.

Experiments on grassland show that the emission factor for peat soils is often a factor 3 to 5 higher than the emission factor for mineral soils. Assuming this increase also applies to arable land it is assumed that the weighted average emission factor is correct.

Variation in N supply to soil

The share of the N supply to arable land coming from animal manure is for the whole period of 1990 until now on average circa 48%, this share varies between 36 and 57%.

Deviation of the average is therefore at maximum around 25%. For grassland the average N supply from animal manure is circa 52%, this varies between 43 and 64%. Deviation of the average is therefore at maximum around 20%. For grassland on peat soils an average N supply of circa 11% (9-14%) applies.

The share of the N supply to arable land coming from inorganic N fertilizer is for 1990 until now on average 27%, in which this share varies between circa 23 to circa 41%. Deviation of the average is therefore at maximum around 50%. For grassland the average N supply coming from inorganic N fertilizer is circa 73%, in which this share varies between circa 59 to 77%. Deviation from the average is therefore at maximum around 20%.

The variation in the shares of the N supply to arable land versus grassland therefore is tens of per cents. Also for the emission factors derived for the various sources the uncertainty is tens of per cents (see standard deviations in Velthof and Mosquera, 2011b).

The uncertainties in the emission factors and in the yearly N supply to mineral versus organic soils with grassland and arable land do not make it necessary to conduct yearly calculation for the distinguished sources. Also for the supply of N_2O emission figures in international reports disaggregated emission factors are not necessary. From 2011 on the disaggregated data on N supply possibly will not become available yearly[1]. For these reasons multiannual weighted average emission factors are derived for surface spreading, for low emission manure application, for application of inorganic N fertilizers and for grazing.

Weighted average emission factors

Animal manure

For animal manure the (multiannual weighted average) N_2O emission factor for surface spreading and low emission manure application is respectively 0.4% and 0.9% of the N supply to soil. That is circa a factor 2 lower than the value applied up to now. This applies to surface spreading (decrease from circa 1 to 0.4% of the N supply) as well as low emission manure application (decrease from circa 2 to 0.9% of the N supply).

There is a significant difference in emission factors for low emission manure application and surface spreading. For low emission manure application the N_2O-N emission factor is a factor 2 higher than for surface spreading, namely 0.9% versus 0.4% of the N supply (Velthof *et al.*, 2010). The share of N in surface spreading decreases strongly between 1990 and 1995 (from 100 to 5%). This makes it necessary to calculate these sources separately in the yearly emission calculations and thus to differentiate separate emission factors for surface spreading and low emission manure application.

Inorganic N fertilizer

For inorganic N fertilizer the (multiannual weighted average) N_2O-N emission factor is circa 30% higher than the value applied up until now (from circa 1 to 1.3% of the N supply). Reason is that especially for grassland on peat soils the emission factor based on measurement turns out to be higher than assumed (3% instead of 2%).

Also no longer a lower emission factor for ammonium containing (nitrate free) inorganic N fertilizer is applied, because the available measurements do not provide sufficient basis for different factors. In the Netherlands very few measurement were done; only 3 comparative experiments with a duration of more than 8 months. In 1 of the 3 experiments there seems to be a lower emission factor for the ammonium containing (nitrate fee) inorganic N fertilizer. In the other 2 experiments there is no difference or the emission factor is even higher. Also literature research into international measurements does not provide a definite answer (Velthof and Mosquera, 2011b).

Grazing

For grazing the (multiannual weighted average) emission factor is circa a factor 2 higher based on measurements (urine/dung data in Appendix 1 of Velthof and Mosquera, 2011b); it increases from circa 1.7 to 3.3% N_2O-N of the N supply.

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[1] This as result of the transition to a new calculation methodology for the yearly national NH_3 calculations (Velthof *et al.*, 2009 and Van Bruggen *et al.*, 2011). The previously yearly used MAMBO model for the NH_3 calculations will be applied by the ER possibly only for the purpose of regionalization. This will likely be less frequent than yearly, for instance 3 yearly.

Other sources
For the emission factor of the smaller sources crop residues, N fixation, histosols and sewage sludge the 'old' values still apply because no new data is available. For histosols the emission factor is 2%. This is consistent with the average of the new emission factors that apply for grassland on peat soils for inorganic N fertilizer and low emission manure application (respectively 3 and 1%). For crop residues and nitrogen fixation the emission factor is 1%. This is consistent with the average of the emission factors that apply for arable land on mineral soils for inorganic N fertilizers and low emission manure application (respectively 1 and 1.3%).

Comparison to IPCC defaults
The new emission factor for low emission manure application of 0.9% is lower than the IPCC 1996 default of 1.25%, but is approximately around the **new** IPCC 2006 default of 1%. For surface spreading the emission factor is a factor 2 lower than the IPCC 2006 default.

The new emission factor for inorganic N fertilizer is somewhat higher than the IPCC 1996 default (1.3 versus 1.25%). In comparison to the **new IPCC 2006 default** of 1% of the N supply the country-specific value is circa 30% higher.

The new emission factor for grazing is 3.3% of the N supply and with that circa 65% higher than the IPCC 1996 and IPCC 2006 defaults of 2%.

Uncertainties in weighted average emission factors
Velthof and Mosquera (2011b) give uncertainties for the emission factors for animal manure, inorganic N fertilizer and grazing. For the calculation of the uncertainty of the weighted average emission factors an expert judgement (Luesink) was made on the uncertainty if the amount of manure going to different soil types and land use.

Animal manure

Agricultural soil	Manure to soil	U manure to soil	EF (%)	U EF
Low emission (total x2)				70%
Organic grassland	21.6	40%	1.0	45%*
Mineral grassland	106.5	40%	0.3	33%
Mineral arable land	108.7	40%	1.3	23%
surface spreading (total x2)				81%
Organic grassland	1.1	40%	0.5	45%*
Mineral grassland	5.5	40%	0.1	20%
Mineral arable land	5.6	40%	0.6	33%

* Velthof and Mosquera (2011b) do not give an uncertainty. The highest uncertainty of the other emission factors in taken, rounded at 5%.

Inorganic N fertilizer

Agricultural soil	Inorganic fertilizer to soil	U inorganic fertilizer to soil	EF (%)	U EF
Organic grassland	18.8	20%	3.0	20%
Mineral grassland	123.2	20%	0.8	13%
Mineral arable land	83.4	20%	0.7	43%
Total (2x)				37%

Grazing

Agricultural soil	Manure deposited in pastures	U manure deposited in pastures	EF (%)	U EF
Organic grassland	12.0	20%	3.0	38%
Mineral grassland	64.3	20%	0.8	31%
Total (2x)				64%

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ANNEX 1

Table 1a Calculation weighted average N_2O-N emission factor for application animal manure based on N in animal manure to soil*

		N supply (kg N) to	N supply (kg N) to	share N supply to	share N supply to	N_2O-N emission factor (% of N supply)	
year	soil	arable land	grassland	arable land**	grassland	low emission manure application	surface spreading
1980	mineral	124,056,517	131,190,515	43%	46%	0.8	0.4
	peat	12,025	31,254,013		11%		
1984	mineral	149,064,760	121,560,842	50%	40%	0.9	0.4
	peat	39,840	29,774,908		10%		
1985	mineral	163,478,854	118,770,657	52%	38%	0.9	0.4
	peat	48,463	29,830,481		10%		
1987	mineral	177,840,312	109,262,083	56%	35%	0.9	0.4
	peat	65,403	29,254,982		9%		
1988	mineral	164,940,815	131,212,093	51%	40%	0.9	0.4
	peat	135,656	29,503,622		9%		
1989	mineral	175,935,382	120,319,586	54%	37%	0.9	0.4
	peat	190,745	28,275,924		9%		
1990	mineral	186,513,236	113,568,424	57%	35%	0.9	0.4
	peat	227,961	28,102,535		9%		
1991	mineral	160,111,819	149,104,352	46%	43%	0.8	0.4
	peat	212,422	36,882,599		11%		
1992	mineral	190,789,097	148,340,643	51%	40%	0.9	0.4
	peat	272,982	35,694,657		10%		
1993	mineral	168,860,398	172,584,027	44%	45%	0.8	0.4
	peat	290,342	42,588,332		11%		
1994	mineral	161,482,717	172,727,227	43%	46%	0.8	0.4
	peat	312,744	39,521,343		11%		
1995	mineral	127,921,589	175,486,807	36%	50%	0.8	0.3
	peat	416,212	47,621,425		14%		
1996	mineral	183,453,286	157,935,264	48%	41%	0.9	0.4
	peat	1,599,323	42,963,547		11%		
1997	mineral	161,978,074	133,007,449	49%	40%	0.9	0.4
	peat	1,193,763	37,554,142		11%		
1998	mineral	126,756,610	145,544,393	41%	47%	0.8	0.4
	peat	447,910	37,769,955		12%		
1999	mineral	163,289,415	129,991,784	50%	40%	0.9	0.4

		N supply (kg N) to	N supply (kg N) to	share N supply to	share N supply to	N_2O-N emission factor (% of N supply)	
year	soil	arable land	grassland	arable land**	grassland	low emission manure application	surface spreading
	peat	215,418	35,090,459		11%		
2000	mineral	143,240,045	114,417,747	49%	39%	0.9	0.4
	peat	341,562	32,961,633		11%		
2001	mineral	131,772,857	124,241,918	45%	43%	0.8	0.4
	peat	230,807	36,298,625		12%		
2002	mineral	122,698,262	119,650,533	44%	43%	0.8	0.4
	peat	209,634	35,621,517		13%		
2003	mineral	126,006,911	117,602,005	45%	42%	0.8	0.4
	peat	164,073	35,520,456		13%		
2004	mineral	124,227,089	105,717,392	47%	40%	0.9	0.4
	peat	212,829	35,597,614		13%		
2005	mineral	117,023,028	104,205,390	46%	41%	0.9	0.4
	peat	251,242	35,832,769		14%		
2006	mineral	101,398,282	114,285,064	42%	48%	0.8	0.4
	peat	3,243,483	23,273,421		10%		
2007	mineral	111,809,202	117,300,043	44%	46%	0.8	0.4
	peat	3,634,559	23,164,601		9%		
2008	mineral	114,272,963	112,003,903	45%	45%	0.8	0.4
	peat	4,184,001	22,771,321		9%		
avg 1980-2005***				48%	41%	0.9	0.4
					11%		
avg 1980-2008				47%	42%	0.8	0.4
					11%		

Table 1b Calculation weighted average N_2O emission factor for application inorganic N fertilizer based on N in inorganic N fertilizer to soil*

		N supply (kg N) to	N supply (kg N) to	share N supply to	share N supply to	N_2O-N emission factor (% of N supply)
year	soil	arable land	grassland	arable land**	grassland	
1980	mineral	106,970,124	321,290,597	22%	68%	1.2
	peat	845,784	47,364,270		10%	
1984	mineral	115,242,899	306,592,441	25%	65%	1.2
	peat	669,448	46,453,094		10%	
1985	mineral	121,629,145	321,528,042	25%	65%	1.2
	peat	980,333	51,032,821		10%	
1987	mineral	117,364,458	321,205,471	24%	65%	1.2
	peat	1,176,447	54,196,495		11%	
1988	mineral	103,843,410	285,610,253	23%	64%	1.3
	peat	567,437	58,982,461		13%	
1989	mineral	109,035,951	271,123,012	25%	62%	1.2
	peat	628,476	53,700,679		12%	
1990	mineral	93,955,348	258,779,664	23%	64%	1.3
	peat	587,758	50,443,644		13%	
1991	mineral	95,188,438	247,537,905	24%	63%	1.2
	peat	558,547	48,700,413		12%	
1992	mineral	95,575,147	239,788,209	25%	63%	1.3
	peat	606,476	47,919,077		13%	
1993	mineral	90,046,707	242,183,075	24%	64%	1.3
	peat	572,620	49,155,969		13%	
1994	mineral	93,444,169	224,305,307	26%	62%	1.3
	peat	735,972	45,573,592		13%	
1995	mineral	105,665,020	252,386,044	27%	64%	1.2
	peat	719,180	38,860,446		10%	
1996	mineral	103,559,665	220,116,636	27%	58%	1.3
	peat	1,503,317	56,088,691		15%	
1997	mineral	92,783,862	236,991,849	25%	63%	1.2
	peat	1,235,110	46,040,338		12%	
1998	mineral	93,406,574	247,455,602	24%	65%	1.2
	peat	436,096	42,469,506		11%	
1999	mineral	91,272,134	239,316,122	24%	64%	1.2
	peat	414,525	42,111,274		11%	
2000	mineral	94,109,506	199,931,253	28%	61%	1.2
	peat	452,482	36,361,014		11%	
2001	mineral	99,873,727	141,112,710	36%	51%	1.3
	peat	426,707	37,024,246		13%	
2002	mineral	87,422,680	146,382,600	32%	54%	1.3
	peat	367,928	37,970,173		14%	
2003	mineral	86,331,855	148,396,464	32%	55%	1.3
	peat	380,570	35,186,448		13%	
2004	mineral	86,696,990	148,801,581	31%	54%	1.3
	peat	346,690	41,245,514		15%	
2005	mineral	87,869,786	129,741,007	34%	51%	1.3
	peat	353,314	38,008,391		15%	
2006	mineral	105,470,705	132,928,979	41%	51%	1.2
	peat	2,874,346	21,094,967		8%	
2007	mineral	83,018,237	128,571,402	36%	56%	1.2

year	soil	N supply (kg N) to arable land	N supply (kg N) to grassland	share N supply to arable land**	share N supply to grassland	N_2O-N emission factor (% of N supply)
	peat	2,165,854	18,554,082		8%	
2008	mineral	83,433,097	123,167,371	37%	55%	1.2
	peat	1,913,870	18,795,236		8%	
avg 1990-2005***				27%	60%	1.3
					13%	
avg 1990-2008				28%	60%	1.2
					12%	

Table 1c Calculation weighted average N_2O emission factor for grazing based on N in pasture manure to soil*

year	N supply (kg N) to mineral	N supply (kg N) to peat	N_2O-N emission factor (% of N supply)
1980	107,508,357	24,674,512	3.2
1984	119,347,758	27,232,572	3.2
1985	121,731,826	28,144,527	3.2
1987	123,537,968	28,990,668	3.2
1988	115,887,919	27,259,575	3.2
1989	115,780,711	27,211,678	3.2
1990	121,894,046	28,534,860	3.2
1991	124,259,557	29,059,000	3.2
1992	119,230,167	28,189,410	3.2
1993	119,802,693	28,642,606	3.2
1994	110,172,205	26,420,847	3.2
1995	110,190,780	26,542,838	3.2
1996	112,515,810	30,676,162	3.2
1997	105,550,182	32,090,792	3.3
1998	94,709,103	28,909,070	3.3
1999	81,121,551	25,597,115	3.3
2000	74,318,394	23,178,293	3.3
2001	75,716,792	23,705,551	3.3
2002	60,076,981	19,368,654	3.4
2003	61,799,968	19,573,558	3.3
2004	60,023,293	21,370,347	3.4
2005	59,810,261	21,389,229	3.4
2006	66,689,712	12,502,196	3.1
2007	60,286,513	11,358,872	3.1
2008	64,312,534	11,955,203	3.0
avg 1990-2005***			3.3
avg 1990-2008			3.2

* N to soil after subtraction of NH_3-N during application because data without subtraction of NH_3-N for N to peat respectively mineral soils are not available; in the emission calculations the weighted average emission factors however are related to the total gross N supply to soil (without subtraction of NH_3-N during application). Assumption is that the differences in evaporation of NH_3 in arable land and grassland are so small that these will not influence the division of the gross N supply over grassland and arable land.

1980-1997: MestAmm data LEI

1997-2005: MAM data LEI

2006-2008: MAMBO data LEI

** In calculation of the shares N to arable land and grassland the N supply to arable land on peat is neglected. The share is relatively small (< 0.2%) and for this source no emission factors are available.

*** The data 2006-2008 show a break in the trend with the data 1980-2005. Especially there is a factor 8 to 15 increase in the supply of respectively inorganic N fertilizer and animal manure to arable land on peat. Also there is almost a halving in the supply of N in manure (through fertilization and grazing) to grassland on peat. This correlates to specific data becoming available on the cultivation of crops on several soil types through the Agricultural census from 2006 on.

In the assumption that the supply of manure to arable land is negligible, use of the whole data series (1990-2008) leads to a weighted average emission factor that is circa 0.1% point lower than in use of the data series 1990-2005. For the emission calculation the weighted average emission factor based on the data series 1990-2005 is used to prevent underestimation of the emissions. From a sensitivity analysis follows that there is a reasonable chance that weighing in the supply of manure to arable land on peat does not lead to an even higher weighted average emission factor.

Annex 11 Uncertainty, quality assurance and verification

A11.1 Estimating uncertainties

For the PRTR dataset of 2015 uncertainties are calculated with the propagation of error method based on literature and expert judgements. Since calculation methods of activity data and emission factors do not change often, this dataset of uncertainties can be used for multiple years. When a calculation method is changed also the uncertainty of the considered activity data or emission factor is adjusted based on literature and expert judgements, to keep the data set of uncertainties up to date.

List of experts consulted
Eric Arets
André Bannink
Cor van Bruggen
Arthur Denneman
Jan Dijkstra
Karin Groenestein
Marga Hoogeveen
Jan Huijsmans
Harry Luesink
Frank de Ruijter
Gerard Velthof
Jan Vonk

A11.2 Quality assurance and quality control (QA/QC)

The PRTR task force leader on Agriculture is responsible for:

1. well documented and adopted data;
2. calculations having been implemented correctly;
3. assumptions are consistent, specific parameters (e.g. activity data) are used consistently;
4. complete and consistent data sets have been supplied.

A yearly check on the above mentioned responsibilities is performed. Any actions that result from these checks are noted on an ‘action list’ by the ER secretary. The task force leader is responsible for improvements and communicates by e-mail regarding these QC checks, actions and results with the ER secretary.

While adding a new emission year the task force leader performs a trend analysis, in which data from the new year are compared with data from the previous years. The task force leader provides an explanation if the increase or decrease of emissions exceeds the minimum level of 5% at target group level or 0.5% at national level. These explanations are also sent by e-mail to the ER secretary by the task force leader.

The ER secretary keeps a logbook of all these QC checks and trend explanations and archives all concerned e-mails on the ER network. This shows explicitly that the required checks and corrections have been carried out. Based on the results of the trend analysis and the feedback on the control and correction process (‘action list’) the Working Group on Emissions Monitoring (WEM) gives advice to the institute representatives (Deltares on behalf of Rijkswaterstaat, Statistics Netherlands (CBS) and Netherlands Environmental Assessment Agency (PBL)) to approve the dataset. The ER project leader at RIVM defines the dataset, on receipt of an e-mail by the institute representatives, in which they give their approval.

Furthermore, all changes of emissions in the whole time series as a result of recalculations are documented in CRF table 8(b).

A11.3 Verification

To check the quality of the calculated emissions for the sources named in this report, general QA/QC-procedures have been followed that are in line with the IPCC Guidelines. These are described further in the QA/QC-programme used by the National System, and the annual working plans published by the PRTR.

Sector-specific QC

No additional specific verification procedures are implemented for the sources defined in this sector.

Annex 12 List of abbreviations

B_o	Maximum methane production potential
CBS	Statistics Netherlands
CDM	Dutch Scientific Committee of the Manure Act
CH_4	Methane
CLRTAP	Convention on Long Range Transboundary Air Pollution
CO_2	Carbon dioxide
CRF	Common Reporting Format
DMI	Dry matter intake
EEA	European Environment Agency
EMEP	European Monitoring and Evaluation Programme
EU	European Union
EZK	Ministry of Economic Affairs and Climate Policy
GE	Gross energy intake
IenW	Ministry of Infrastructure and Water Management
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land Use Change and Forestry
MCF	Methane conversion factor (for the calculation of CH_4 from manure management)
N	Nitrogen
N_2	Dinitrogen
N_2O	Nitrous oxide
NEC	National Emission Ceilings
NEMA	National Emission Model for Agriculture
NFR	Nomenclature For Reporting
NH_3	Ammonia
NIE	National Inventory Entity
NO_x	Nitrogen oxides
PBL	PBL Netherlands Environmental Assessment Agency
PM_{10}	Particulate matter up to 10 μm in size
$PM_{2.5}$	Particulate matter up to 2.5 μm in size
PRTR	Pollutant Release and Transfer Register
RIVM	National Institute for Public Health and the Environment
RVO	Netherlands Enterprise Agency
TAN	Total Ammoniacal Nitrogen
UN	United Nations
VS	Volatile Solids
WUR	Wageningen University & Research centre
Y_m	Methane conversion factor (for the calculation of CH_4 from enteric fermentation)

Published documents in the Technical reports series of the Statutory Research Tasks Unit for Nature & the Environment from 2017 onwards.

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P.O. Box 47
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E info.wnm@wur.nl

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