CARBON LIMITS

Calculation of atmospheric nitrogen emissions from manure in Norwegian agriculture

Technical description of the revised model

Project for the Norwegian Environment Agency

M-1848|2020

Contents:

Abstract

Manure management in Norway is a source of emissions to air of ammonia (NH_3), nitrous oxide (N_2O), nitric oxide (NO) and nitrogen (in the form of N_2). The dominating pollutant emitted from manure management is NH_3, with cattle being by far the most important source in Norway, followed by pigs and then sheep. Emissions of NH_3 from manure depend on several factors, e.g. type of animal, nitrogen content in fodder, manure management system, climate, time of spreading of manure and cultivation practices. These parameters need to be taken into consideration when building a model to calculate emissions of ammonia and other nitrogen species.

The Norwegian model for calculating the agricultural nitrogen emissions to atmosphere is used for reporting for the Norwegian emission inventory. The model closely follows the stepwise approach proposed in the EMEP/EEA 2019 guidebook, with all the 15 steps proposed in the former being followed in the Norwegian model. Although based on this tier 2 technology-specific approach, the updated Norwegian model includes certain aspects which are more in line with the EMEP/EEA tier 3 approach. The effect of abatement measures and improved manure management and manure use practices are described in the revised model. The main manure management and use phases considered in the model are (i) animal housing, (ii) manure storage, (iii) manure spreading on agricultural land, and (iv) deposition as a result of animal grazing, plus (v) use of manure for biogas production. The latter was introduced in the model during 2020 revision and includes nitrogen emissions from pre-storage of manure before anaerobic digestion, separation of digestate into solid and liquid fractions and storage of digestate. In line with the EMEP/EEA guidebook, the emissions from spreading to land of digestate produced from manure are reported together with the emissions from spreading of untreated manure.

In line with EMEP/EEA 2019 guidebook and IPCC 2006 guidelines, the Norwegian model calculates direct emissions of N_2O, NO and N_2 in order to more accurately estimate the TAN available at each stage of manure management, in addition to calculating emissions of NH_3. The model integrates the mineralisation of N and the immobilisation of TAN during storage of manure, and also estimates indirect emissions of N_2O from leaching/run-off during storage, application to land and grazing and through volatilisation of N from manure management, application to land and deposition during grazing. In 2020 revision, the emission factors for NH_3 and NO_X have been updated in accordance to the EMEP/EEA 2019 guidebook.

All methodological changes introduced during 2020 revision are indicated in the report below (chapters, tables and figures affected by the revision are marked with “updated”). In addition, the Annex summarizes the key changes introduced, including updated emission factors.

Terms and abbreviations

AD	Anaerobic digestion
EEA	European Environment Agency
EF	Emission factor
EMEP	Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe
FYM	Farmyard manure
IPCC	Intergovernmental Panel on Climate Change
N_2	Di-nitrogen
NO	Nitric oxide
NH_3	Ammonia
N_2O	Nitrous oxide
NOx	Nitrogen oxides
NO	NO Nitric oxide
Tot-N Total nitrogen	Total nitrogen
TAN	Total ammonical nitrogen

1. Introduction

1.1 Sources and gases

Manure management in Norway is a source of emissions to air of ammonia (NH_3), nitrous oxide (N_2O), nitric oxide (NO) and nitrogen (in the form of N_2). The dominating pollutant emitted from manure management is NH_3 (NFR 3B), with cattle being by far the most important source in Norway, followed by pigs and then sheep. Emissions of NH_3 from manure depend on several factors, e.g. type of animal, nitrogen content in fodder, manure management system, climate, time of spreading of manure and cultivation practices. All of these parameters need to be taken into consideration when building a model to calculate emissions of ammonia and other nitrogen species.

1.2 Aim of the project

The main aim of the project was to revise and expand the models which have been used by Norway for calculating the agricultural nitrogen emissions to atmosphere as input to the Norwegian emission inventory. Specifically, the key objectives of the project were the following:

- To update the model to meet the most recent requirements of the emission inventory guidebook of UNECE (henceforth referred to as EMEP/EEA 2019);
- To update the emission factors used in order to reflect current national and international knowledge and best practice;
- To expand the model to better reflect current manure management practices;
- To better understand the mass flow and associated emissions of the different nitrogen species through the different stages of manure management, and therefore identify the most effective options for emission reductions;
- To "future-proof" the model and allow potential future manure management practices in Norway to be readily integrated into upcoming annual emission reports.

The most significant aspect of the new model was development of a spreadsheet tool in excel which was designed based on the EMEP/EEA 2019 Tier 2 technology-specific approach, which uses a mass-flow approach based on the of flow of both total ammoniacal nitrogen (TAN) and total nitrogen through the manure management system (including anaerobic digestion (AD) of the manure) until application to land (or deposition during grazing).

In line with EMEP/EEA 2019 guidebook and IPCC 2006 guidelines (henceforth referred to as IPCC 2006), the Norwegian model calculates direct emissions of N_2O, NO and N_2 in order to more accurately estimate the TAN available at each stage of manure management, in addition to calculating emissions of NH_3. The model integrates the mineralisation of N and the immobilisation of TAN during storage of manure, and also estimates indirect emissions of N_2O from leaching/run-off during storage, application to land and grazing and through volatilisation of N from manure management, application to land and deposition during grazing.

2. Calculation of nitrogen emissions

2.1 General system description (updated)

The model closely follows the stepwise approach proposed in the EMEP/EEA 2019guidebook[1], with all the 15 steps proposed in the former being followed in the Norwegian model. Although based on this tier 2 technology-specific approach, the updated Norwegian model includes certain aspects which are closer to the EMEP/EEA 2019 tier 3 approach, specifically with respect to using country-specific emission factors (EFs) where available and the inclusion of measures and practices which result in lower emissions of NH_3 compared to the tier 2 defaults (e.g. covering of slurry tanks, low incorporation times after spreading of manure on land, spreading through injection). The estimates resulting from this approach are expected to be more accurate than those relying solely on the tier 2 approach.

As recommended in EMEP/EEA 2019, the effect of the abatement measures and improved practices are described using a reduction factor, i.e. a proportional reduction in the emission estimate for the unabated situation. Also, as highlighted in EMEP/EEA 2019, the introduction of abatement measures and improved practices which reduce emissions of NH_3 may alter emissions of other nitrogen species (i.e. NO, N_2 and N_2O). The Norwegian model also includes a slightly greater number of livestock categories and manure types than listed under EMEP/EEA 2019 tier 2. Where possible, priority has been given to using EFs that stem from studies that were undertaken in Norway. However, where suitable country-specific EFs were not available, EFs from other comparable countries or from the EMEP/EEA 2019 guidebook were used, following the application of temperature correction factors which reflect the difference in climatic conditions between Norway and central European countries. For NO, N_2 and N_2O, default emission factors as specified in EMEP/EEA 2019 and IPCC 2006 were applied. The Norwegian model includes three different manure management systems (slurry, deep litter and farmyard manure), which is more detailed than those defined in the EMEP/EEA 2019 guidebook tier 2 approach. Emission factors specific to each of these three manure types have been sought and used where possible, but where separate emission factors were not available, deep litter and farmyard manure were considered to fall under the category of solid manure and applicable EMEP/EEA 2019 EFs were used.

An important difference between the previous Norwegian nitrogen model and the updated model is the inclusion of added N in animal bedding (applicable to solid manure only) and the consequent immobilization of TAN in that bedding, as prescribed in step 7 of the EMEP/EEA 2019 guidebook. In order to reflect common practice in Norway, three different types of bedding materials are used, namely straw, sawdust/wood chips and peat.

The updated model, being based on the nitrogen mass balance approach specified by EMEP/EEA, allows estimates to be made of all the main nitrogen species, namely NH_3, N_2O, NO and N_2. It should be noted that ultimately all NO emissions in the model are reported as NO_2, in accordance with Annex I of the NFR Reporting Guidelines.

The updated excel spreadsheet model allows for separate accounting of the flow of total nitrogen (tot-N) and the flow of ammoniacal nitrogen (TAN) between each of the 15 steps, and of any possible transition between these two fractions of N. As for the previous Norwegian nitrogen model and as

[1] The EMEP/EEA 2019 guidebook focuses primarily on emissions of NH_3 and NO, whereas emissions of nitrous oxide (N_2O) are only accounted for, when necessary, for the accurate estimation of emissions of the former two nitrogen species. Emissions of N_2O are, however, fully accounted for in the Norwegian model, based on the methodology and emission factors proposed in IPCC 2006

specified by the EMEP/EEA 2019 guidelines, the main stages of manure management and use considered in the calculation model are (i) animal housing, (ii) manure storage, and (iii) manure spreading on agricultural land, and (iv) deposition as a result of animal grazing, plus (v) use of manure for biogas production. The latter was introduced in the model during 2020 revision and includes nitrogen emissions from pre-storage of manure before anaerobic digestion, separation of digestate into solid and liquid fractions and storage of digestate. In line with the EMEP/EEA 2019 guidebook, the emissions from spreading of digestate to land produced from manure are reported together with the emissions from spreading of untreated manure.

2.2 Animal categories

In total, 25 separate animal categories are identified in the revised model, as summarized in Table 1. This detailed list of animal categories allows greater accuracy with respect to the total annual excretion of N. However, as the emission factors to be used are generally applicable to a less detailed group of related animals, certain animal categories are further grouped prior to calculating the amounts of TAN and tot-N deposited in buildings (step 5), as summarized in Table 1. The final list of animal categories is also defined so that it meets the requirements of the reporting to the UNFCCC and UNECE.

Table 1: Animal categories included in the Norwegian emission calculation model

Detailed categorization of animals	Final list of animal categories
Dairy cattle	Dairy cattle
Suckling cows	Suckling cows
Heifers	Young beef cattle
Heifers for slaughter	
Bull for slaughter	
Sows	Swine
Boars	
Piglets	
Fattening pigs	
Young pigs for breeding	
Laying hens	Laying hens
Chickens reared for laying	Broilers
Broilers	
Turkeys for slaughter	Turkeys
Ducks and geese for slaughter	Other poultry
Turkeys, ducks and geese reared for laying	
Horses	Horses
Dairy goats	Goats
Other goats	
Sheep over 1 year old	Sheep
Sheep under 1 year old	
Mink	Fur animals

Foxes	
Deer	Deer
Reindeer	Reindeer

2.3 Activity data (updated)

The main sources of the livestock statistics are the register of production subsidies (sheep for breeding, goats, breeding pigs, poultry for egg production and beef cows), statistics of approved carcasses (animals for slaughter) and the Cow Recording System at TINE BA[2] (heifers for breeding and dairy cows). These sources cover 80-100 per cent of the animal populations. The estimated shortage of coverage is compensated in the estimations.

Surveys for assessing use of manure management systems have been carried out in 2000 (Gundersen & Rognstad 2001), 2003 (Statistics Norway 2004), 2013 (Gundersen & Heldal 2015), and 2018 (Kolle & Oguz-Alper 2020) henceforth called the "manure surveys". The distribution of manure systems in 2019 is given in Table 2.

Table 2: Fraction of total excretion per animal category for each management system and for pasture (MS) used in the estimations[3] (updated)

	In-house slurry pit	Tank without cover	Tank with cover	In-house deep litter	Dry lot	Heaps	Pasture range and paddock
Dairy cattle	0.57	0.01	0.26	0.00	0.00	0.00	0.16
Other cattle	0.42	0.01	0.15	0.05	0.02	0.05	0.30
Swine	0.54	0.31	0.12	0.01	0.01	0.02	0.00
Poultry	0.22	0.00	0.00	0.00	0.00	0.78	0.00
Sheep	0.25	0.01	0.00	0.05	0.01	0.02	0.67
Goat	0.58	0.00	0.00	0.10	0.01	0.01	0.30
Horse	0.26	0.01	0.00	0.05	0.04	0.38	0.26
Fur bearing animals	0.29	0.00	0.00	0.00	0.00	0.71	0.00

Source: Data for storage systems from Statistics Norway (Kolle & Oguz-Alper 2020), data for pasture times from (TINE BA Annually) (Dairy cattle, goat), Statistics Norway's Sample Survey 2001 (Statistics Norway 2002)

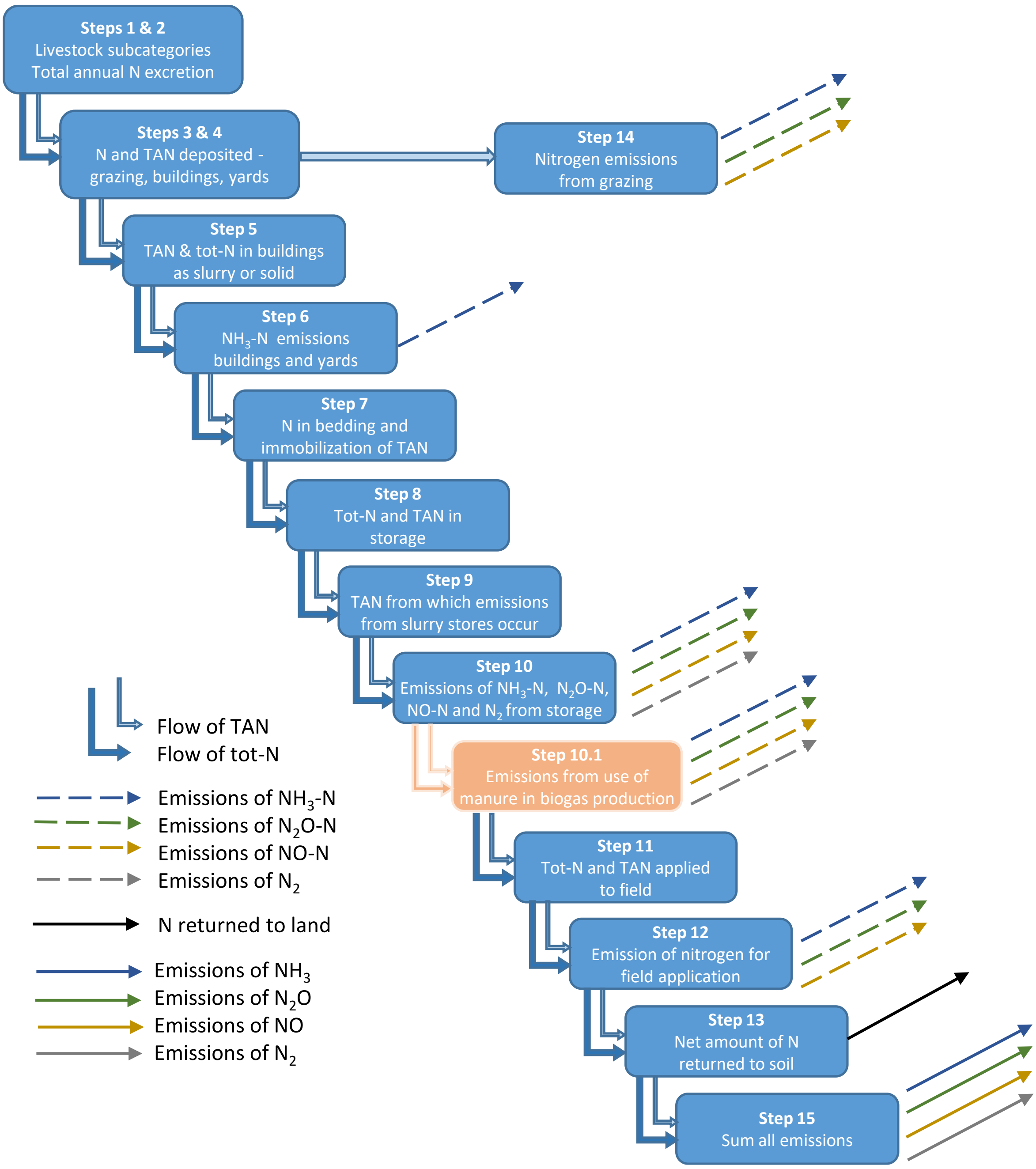
Data on storage systems for years other than 2000, 2003, 2013 and 2018 are not available. Separate estimations of the effects on emissions of the assumed changes in storage systems since 1990 show that these assumed changes do not have a significant impact. For the intermediate years 2004-2012 and 2014-2017 between the surveys of 2003, 2013 and 2018, the distribution of management system has been estimated using a linear interpolation. The 2018 data on storage systems will be used in approaching years until newer data becomes available. The surveys on management systems usually do not include pasture, but for 2018 manure survey this was included and gave updated pasture data for other cattle and sheep

[2] TINE BA is the sales and marketing organization for Norway's dairy cooperative and covers most of the milk production and the meat production induced by milk production.
[3] For generalized animal categories the table presents simple mean values, not weighted average. For more detailed values, please, see National inventory report 2020 (in preparation).

2.4 Detailed model description (updated)

As mentioned above, the model closely follows the stepwise approach proposed in the EMEP/EEA 2019 guidebook, with all the 15 steps proposed in the former being followed in the Norwegian model. The following section provides a step by step outline of each of the 15 steps, as summarized in Figure 1. The input data for some of the steps is treated in the same sheets, and for this reason some steps are grouped in the description below. The description given for each step is the same as given in EMEP/EEA 2019.

Figure 1: Summary of the 15-step approach



Steps 1 and 2

Objective for step 1: define the livestock subcategories that are homogeneous with respect to feeding, excretion and age/weight range.

Objective for step 2: calculate the total annual excretion of N by the animals.

The detailed list of animal categories which are considered to be homogeneous with respect to feeding, excretion and age/weight range has been presented in Table 1.

The rationale for the Norwegian values for N in excreta is given in Karlengen et al. (2012). For beef cow, the nitrogen excretion factor was estimated by the Norwegian University of Life Sciences (NMBU) in 2018 based on national feeding data for beef cow. The method will be described more in detail in Aspeholen Åby et al. (2019) (NIR 2019, Annex IX). The N-excretion factors for cattle, poultry and pigs have been scientifically investigated, while the remaining categories have been given by expert judgements (Karlengen et al. 2012). Based on typical Norwegian feedstock ratios, the excretion of nitrogen (N) was calculated by subtracting N in growth and products from assimilated N and P. Comparisons have also been made with emission factors used in other Nordic countries and IPCC default factors.

The factors for cattle are based on equations using animal weight, production (milking cows), life time (young cattle) and protein content in the fodder as activity data.

The Nordic feed evaluation system (NorFor) was used to develop the nitrogen factors for dairy cows and young cattle. Excretions of N in the manure were calculated as the difference between their intake, and the sum of what is excreted in milk, fetus and deposited in the animal itself. The procedure used for calculating the excretion of faeces and N consisted of two steps:

1. Simulations in “NorFor” were conducted to gain values for the faeces/manure characteristics covering a wide variation of feed characteristics (N content) and production intensities (milk yield/meat production).
2. The results from the simulations were used to develop regression equations between faeces/manure characteristics and parameters related to the diet (N content) and animal characteristics (milk yield, weight, age etc.).

Calculations of N-factors based on these equations have been made back to 1990 for cattle. For beef cattle national feeding data from only one year is available. There have been some changes in the composition of the breed of beef cow population in Norway since 1990. But we lack data for a good variable that we could use to get a trend for beef cow. It is expected that this is a minor source of error, since the population of beef cow was of less significance earlier. Since the change in the composition of the population has been an increase of heavier breed, does this mean that there is a minor overestimation of the emissions for the earlier years. For poultry and pigs, N-factors have been estimated for 2011 in Karlengen et al. (2012). The factors used until this update were estimated in 1988 (Sundstøl & Mroz 1988), and are regarded as still valid for 1990. A linear interpolation has been used for the years between 1990 and 2011. For the remaining animal categories, the N in excreta are considered constant throughout the time series. The N-factors are shown in Table 3.

Table 3: N in excreta from different animals for 2019, kg/animal/year unless otherwise specified in the footnote

	Total N	Ammonium N
Dairy cow	132.9	75.4
Beef cow	93.0	52.6
Replacement heifer[2]	89.0	49.2
Bull for slaughter[2]	71.4	43.3
Finishing heifer[2]	64.5	39.1
Young cattle[3]	43.7	26.3
Horses	50.0	25.0
Sheep < 1 year	7.7	4.3
Sheep > 1 year	11.6	6.38
Goats	13.3	7.9
Pigs for breeding	23.5	15.7
Pigs for slaughtering[4]	3.2	2.13
Hens	0.670	0.29
Chicks bred for laying hens[4]	0.046	0.017
Chicks for slaughtering[4]	0.030	0.011
Ducks, turkeys/ goose for breeding	2.0	0.8
Ducks, turkeys/ goose for slaughtering[4]	0.4	0.18
Mink	4.3	1.7
Foxes	9.0	3.6
Reindeer	6.0	2.7
Deer	12.0	5.4

[1] Includes pasture.
[2] Factors for excreted nitrogen apply for the whole life time of animals, and nitrogen is calculated when animals are slaughtered/replaced.
[3] Average factor for all heifers for slaughter and replacement and bulls for slaughter, per animal and year.
[4] Per animal. For these categories, life time is less than a year. This means that the number of animals bred in a year is higher than the number of stalls (pens).
Source: Karlengen et al. (2012), Aspeholen Åby et al. (2019) to be published, and estimations by Statistics Norway 2018

The output from these two stages is the total N excreted per year (Nex) and TAN excreted per year (TANex) for each of the 25 detailed animal categories.

Steps 3 and 4

Objective for step 3: calculate the amount of the annual N excreted that is deposited within buildings in which livestock are housed, on uncovered yards and during grazing.

Objective for step 4: calculate the amount of TAN deposited during grazing, on yards or in buildings

The output from these two steps is the tot-N and TAN excreted per year which is either deposited within buildings in which the livestock are housed or on pasture land during grazing. Unlike the EMEP/EEA 2019 guidebook the amount of total N and TAN deposited on uncovered yards is not calculated as this option is not considered common practice in Norway.

The amounts of tot-N and TAN deposited within buildings or on pasture land is calculated based on the output of step 2 (total annual excretion of N by the animals) and the proportion of time spent on pasture land by each animal type (it is assumed that the amount of manure deposited during grazing is proportionate to the amount of time spent grazing).

Step 5

Objective for step 5: calculate the amounts of TAN and total N deposited in buildings handled as liquid slurry or as solid.

Step 5 consists of inputting data on the proportion of manure which is deposited in buildings in the form of slurry, deep litter and solid manure. This data is input for each of the 14 listed animal categories. It should be noted that the grouping of certain categories of animals in order to proceed from the “detailed categorization of animals” to the “final list of animal categories” is done during steps 3 and 4.

The proportion of manure in the form of slurry, deep litter and solid manure is determined based on data collected by Statistics Norway through the regular “manure surveys”.

The output of step 5 is amounts of tot-N and TAN which are deposited in buildings per type of manure for each year and for each of the 14 animal categories.

Step 6

Objective for step 6: calculate the emissions of NH_3-N from the livestock building and from the yards.

The amount of TAN deposited in buildings for each of the 14 animal categories is multiplied by emission factors for NH_3-N in order to determine emissions of NH_3-N from animal housing, which equates to NH_3-N losses from this stage of the manure management system.

All emission factors used at this stage are sourced from EMEP/EEA 2019 (these have been updated during 2020 revision of the nitrogen model from previously used EF based on the EMEP/EEA 2016 Guidebook). These are summarized in Table 4.

Table 4: Emission factors used for NH_3-N from buildings (updated)

	NFR code	Slurry	Solid manure
Dairy cattle	3B1a Dairy cattle	24%	8%
Suckling cows	3B1b Non-dairy cattle (young cattle, beef cattle and suckling cows)	24%	8%
Young beef cattle	3B1b Non-dairy cattle (young cattle, beef cattle and suckling cows)	24%	8%
Swine	3B33 ‘Swine’ (fattening pigs, 8–110 kg)	27%	23%
Laying hens	3B4gi Laying hens	41 %	20%
Broilers	3B4gii Broilers	21%	21%
Turkeys	3B4giii Turkeys	35 %	35 %
Other poultry	3B4giv Other poultry (geese)	57 %	57 %
Horses	3B4e Horses	22 %	22 %
Goats	3B4d Goats	22 %	22 %
Sheep	3B2 Sheep	22 %	22 %
Fur animals	3B4h Other animals (fur animals)	27 %	27 %
Deer	3B4h Other animals	24%	24%

Reindeer	3B4h Other animals	24%	24%

The 14 animal categories defined in the Norwegian model do not always correspond to the categories used in EMEP/EEA 2019. In addition, the EMEP/EEA Guidebook does not provide EFs for all manure types, in particular with respect to solid manure for certain animal categories. With respect to these issues the following assumptions have been made:

- As all swine types in the Norwegian model are grouped into a single category, the EFs for "'Swine' (fattening pigs, 8–110 kg)" have been used as this is considered to be a conservative approach;
- The EFs for "Dairy cattle" have been used for deer and reindeer as both of the latter are ruminants (although manure management emissions from deer and reindeer are reported under NFR code "3B4h Other animals", the EFs for this category are not considered relevant to larger ruminants);
- Where EFs are not available for solid manure from certain animal categories, the EF given for slurry has been used, and vice versa.

The Norwegian model integrates the impact of slatted floors in animal buildings, which results in a lower residence time of the manure in buildings, and therefore lower emissions of NH_3-N at this stage of the manure management system. For the proportion of animals kept in buildings with slatted floor, the EF given in Table 4 is halved, which correlates with the approach used by Rösemann et al. (2017), based on studies by Döhler et al. (2002), Dämmgen et al. (2010a) and UNECE (1999).

A temperature correction factor is applied to the EMEP/EEA 2019 EFs, which reflects the fact that the latter are based on studies representing climatic conditions different from those in Norway. The same approach as that proposed by Grönroos et al. (2017) has been adopted, which is based on studies by Cowell and ApSimon (1996) that assumed that a rise of 3°C in temperature increases volatilisation of ammonia by 10%. On average, annual outdoor temperatures in Norway are almost 4.5°C lower than in Central Europe, with slightly lower difference in the summer period (see Table 5). Following the approach applied by Grönroos et al. (2017), it is assumed that although there are no significant differences in the indoor temperatures of animal buildings, the higher outdoor temperatures in Central Europe result in increased need for ventilation of facilities, which is likely to increase emissions. In addition, for non-isolated animal shelters, the indoor temperature is assumed to closely follow the outdoor temperature. These assumptions result in a temperature correction factor of 0.93 for animal houses in Norway.

Table 5: Average outdoor temperature (°C) in Norway (mean of Oslo, Fagernes, Sola, Sandane, Valljord and Slettnes) (eklima.met.no) and in Central Europe (based on Grönroos et al. (2017)).

Region	Whole year	April-May	June-July	Aug-Nov
Norway	4.8	5.7	12.7	7.3
Central Europe	9.2	10	15.8	11.5
Diff NOR-Europe	-4.4	-4.3	-3.1	-4.2

The output from this stage is annual NH_3-N emissions (losses) from buildings (total and for each of 14 animal categories), and the tot-N and TAN remaining in the manure after housing.

Step 7

Objective for step 7: allow for the addition of N in animal bedding and account for the consequent immobilisation of TAN in that bedding (solid manure only).

In order to reflect common practice in Norway, three different types of bedding materials are prescribed in the model, namely straw, sawdust/wood chips and peat. The volumes of each of these three bedding types used per animal place per year is based on Luostarinen et al. (2017). These volumes are converted into weights and thence tot-N added due to bedding as quoted in Grönroos et al. (2017).

This step also calculates the fraction of TAN that is immobilized in organic matter when manure is managed as a litter-based solid, as this immobilization reduces the potential NH_3-N emissions during storage and after spreading. For solid manure the same approach as is described by Rösemann et al. (2017), and also by Grönroos et al. (2017), is adopted, whereby 40% of TAN entering storage is considered to be immobilized. This is based on the expert judgement of the EAGER working group.

The output of this step is an estimate of the total N added through the use of bedding for each of the 14 animal categories, and the TAN in the manure following immobilization due to the addition of bedding.

Step 8

Objective for step 8: to calculate the amounts of total-N and TAN stored before application to land per type of manure use

Prior to estimating nitrogen per storage category in this step, the amount of manure that is sent for anaerobic digestion is separated. A separate calculation module for emissions from manure sent for anaerobic digestion has been developed under 2020 revision of the model and will be described in more detail under Step 10.1 below.

Real activity data on use of manure for anaerobic digestion (AD) was used to estimate the share of nitrogen that the manure used for biogas production contains. The total amount of manure used for biogas production is split between that used by farmers directly at farm-scale facilities and at centralized facilities (where manure is co-digested with other organic feedstocks). The amount of manure used for biogas production in 2019 still remains very modest, representing about 1 – 1.5% of the total nitrogen in all manure deposited in housing (only cattle and swine manure is currently used for AD in Norway). The analysis is based on the data from the Norwegian Agriculture Agency (https://www.landbruksdirektoratet.no/no/statistikk/miljostatistikk/utslipp-til-luft):

Tonnes manure used for biogas production

Year	Centralized biogas plants	Farm-scale biogas	**TOTAL**
2013	0	3 178	3 178
2014	0	2 926	2 926
2015	15 003	7 512	22 515
2016	56 040	5 583	61 623
2017	63 643	6 989	70 632
2018	62 068	6 819	68 887
2019	73 297	10 890	84 187

The amount of nitrogen coming into storage was split between three categories of manure use: (i) “regular”, or spreading of untreated manure to land, (ii) anaerobic digestion on site (farm-scale biogas), and (iii) anaerobic digestion export (biogas at centralized facilities). For each of the manure use type, the amount of tot-N and TAN which is stored under different storage options is calculated for each of the 14 animal categories. The different options for storage considered in the Norwegian model are:

- Manure cellar, under slatted floor
- Manure cellar, under solid floor
- Open manure tank for slurry (unabated)
- Manure tank with tight roof
- Manure tank with artificial floating cover (plastic sheeting, LECA balls)
- Manure tank with floating cover (natural crust or cover with straw)
- Indoor built up/deep litter
- Outdoors built up/deep litter
- Solid manure, outdoor storage

The proportion of manure which is stored under each of the above options is determined based on data collected through the regular "manure surveys". For manure pre-stored before AD, there is currently no sufficient empirical information available about the different practices of manure storage (manure is often stored first at the farm before being collected and either delivered to a centralized or a farm-scale facility; at centralized plants, manure can also be pre-stored before it is delivered to the digester). Due to unavailability of these data, information about typical storage practices of untreated manure are applied for manure pre-stored before AD. It is, however, assumed that this manure will be stored over shorter period of time (around 1 month, according to Østfoldforskning (2019)), which will reduce nitrogen emissions (see step 10 for more details).

Step 9

Objective for step 9: to calculate the amount of TAN from which emissions will occur from slurry stores.

For slurries, a fraction of the organic N is mineralized to TAN before the gaseous emissions are calculated. For untreated slurry, it was assumed that 10% of the organic nitrogen entering manure storage is converted to TAN during storing, as recommended in EMEP/EEA 2019 based on studies by Dämmgen et al. (2007).

The output of this step is an estimate of TAN from which emissions will occur for 14 animal categories and under the different options for storage determined in step 8.

Step 10

Objective for step 10: to calculate the emissions of NH_3, N_2O, NO and N_2 from storage (and pre-storage of manure used for AD).

Emissions of NH_3-N from storage of "regular" manure that is spread untreated to land are calculated based on the unabated emission factors sourced from EMEP/EEA 2019, as presented in Table 6.

Table 6: Emission factors used for NH_3-N from storage (updated)

	NFR code	% NH_3-N losses from storage	
		Slurry	Solid
Dairy cattle	3B1a Dairy cattle	25 %	32 %

Suckling cows	3B1b Non-dairy cattle (young cattle, beef cattle and suckling cows)	25 %	32 %
Young beef cattle	3B1b Non-dairy cattle (young cattle, beef cattle and suckling cows)	25 %	32 %
Swine	3B33 ‘Swine’ (fattening pigs, 8–110 kg)	11 %	29 %
Laying hens	3B4gi Laying hens	14 %	8 %
Broilers	3B4gii Broilers	30 %	30 %
Turkeys	3B4giii Turkeys	24 %	24 %
Other poultry	3B4giv Other poultry (geese)	24 %	24 %
Horses	3B4e Horses	35 %	35 %
Goats	3B4d Goats	28 %	28 %
Sheep	3B2 Sheep	32 %	32 %
Fur animals	3B4h Other animals (fur animals)	9 %	9 %
Deer	3B4h Other animals	25 %	25 %
Reindeer	3B4h Other animals	25 %	25 %

Note: where EMEP/EEA 2019 only provides an EF for one type of manure (slurry or solid) that EF is used for both manure types in the Norwegian model where required

The 14 animal categories defined in the Norwegian model do not always correspond exactly to the categories used in EMEP/EEA 2019, and the following assumptions have therefore been made:

- As all swine types in the Norwegian model are grouped into a single category, the EF for "‘Swine’ (fattening pigs, 8–110 kg)" have been used as this is considered to be a conservative approach;
- The EFs for “Dairy cattle” have been used for deer and reindeer as both of the latter are ruminants (although manure management emissions from deer and reindeer are reported under NFR code "3B4h Other animals", the EFs for this category are not considered applicable to larger ruminants).

The Norwegian model takes into consideration the “abatement” effect of the different storage options which were identified in step 8. The NH_3-N emissions reduction potential for each of the storage options for cattle and pig slurry is based on Bittman et al. (2014) and has been reviewed by Rivedal et al (2019), as outlined in Table 7. The comparison of previously used and values updated during 2020 revision are presented in Annex I.

Table 7: Ammonia reduction potential for abatement measures for cattle and pig slurry storage (updated)

	NH_3-N emissions reduction	**Comments**

Manure cellar for slurry, under slatted floor	30 %	Some crust is assumed to be formed under the slatted floors, however, supply of urine that will accumulate on top of the crust will lead to some NH3 emissions
Manure cellar for slurry, under solid floor	60 %	Covers a broad category from tight lids with water locks to covered but with open access for manure. Emission reduction associated applied to “Manure tank with floating cover” considered conservative
Open manure tank for slurry (unabated)	0 %	From EMEP/EEA Guidebook 2016
Manure tank with tight roof	80 %	From Bittman et al. (2014)
Manure tank with floating cover (plastic sheeting, lecca)	60 %	From Bittman et al. (2014)
Manure tank with floating cover (natural crust)	40 %	From Bittman et al. (2014)
Indoor built up/deep litter	0 %	No abatement assumed
Outdoors built up/deep litter	0 %	No abatement assumed
Solid manure, outdoor storage	0 %	No abatement assumed

The researchers at the Norwegian Institute of Bioeconomy Research (NIBIO) (Rivedal et al (2019)) have reviewed the emission factors and emission reduction efficiencies of different manure management practices and recommended some changes based on their academic and practical experience with Norwegian agriculture. The changes identified by NIBIO and implemented in the 2020 model update are presented below:

- The emission reduction efficiency for manure cellar with slatted floors has been updated in accordance to Rivedal et al (2019). According to NIBIO, a number of observations of slurry stored using this method indicate that manure tends to develop a rather solid porous crust (porous due to lack of precipitation). Although these observations are not yet documented by measurements, the researchers base their observations on many years of field experience, including communication with farmers. However, even if solid crust is formed under slatted floors, there will be supply of new urine that will for some time stay on the surface leading to some NH3 emissions, which will depend, among other things, on porosity of the crust. As the emissions from such storage type have not been directly measures, it is recommended that a conservative estimate of 30% emission reduction is used for manure cellar with slatted floors.

A temperature correction factor is applied to the EMEP/EEA 2019 EFs, which reflects the fact that the latter are based on studies representing climatic conditions different from those in Norway. The same approach as used in step 6 has been adopted, and the difference of 4.5˚C in the annual average outdoor temperature between Norway and Central Europe (Table 5) results in a reduction of 15% in ammonia volatilisation which implies a temperature correction factor of 0.85 for storage in Norway.

For losses of NO and N_2, the default values for the EFs given in EMEP/EEA 2019 (Table 3.10) are used, and applied to the TAN in slurry and solid manure during storage. For losses of N_2O, the default values for the EFs as given in the IPCC 2006 guidelines are used and applied to total N excreted. In addition, as part of the Rivedal et al (2019) review of the model, some changes are implemented to N2O emission factors for 2 storage types: (1) manure cellar with slatted floors, and (2) manure tank with floating cover (natural crust):

1. As described above for NH3 emission factor from storage, manure stored in cellar under slatted floors will likely form porous crust, but not as solid as the uncovered manure storage. This is reflected in adjusted N2O emission factor – 0.25% (1/2 of the EF for manure with solid natural crust cover of 0.5% from IPCC 2006).
2. NIBIO suggest to use a lower N2O EF for manure stored in a tank with natural crust cover (0.25% instead of 0.5%) due to the fact that this type of storage is typically placed outside, where it is exposed to rain- and snowfall. Precipitation will make the natural crust wet or even break it, which will lead to lower N2O emissions in these periods.

Table 8 and Table 9 summarize the emission factors for NO, N2 and direct N2O emissions from the sources described above.

Table 8: Default values for NO and N_2 losses needed in the mass-flow calculation

	Proportion of TAN
EFstorage_slurryNO	0.0001
EFstorage_slurryN2	0.0030
EFstorage_solidNO	0.0100
EFstorage_solidN2	0.3000

Notes: Due to differences in the description of the storage systems in the “manure survey” compared to those given in IPCC 2006, the following EFs are used:

1. For horses, goats and sheep, EF for “Pit storage below animal confinements” used. For all other animal categories except poultry EF for “Liquid/Slurry, without natural crust” used, as it is assumed that the continuous addition of manure to the surface of the pit storage precludes the formation of a natural crust. This is a conservative assumption with respect to NH_3 emissions;
2. For horses, goats and sheep, EF for “Pit storage below animal confinements” used. For all other animal categories except poultry, it is expected that as manure is not continuously fed from the top, formation of natural crust is possible, and EF for “Liquid/Slurry, with natural crust” is used. This is a conservative assumption with respect to NH_3 emissions;
3. For all poultry categories, EF corresponds to “Poultry manure with / without litter” as defined in IPCC 2006;
4. For swine, it is assumed that 10% of manure systems form a natural crust (based on the share of swine manure that is using straw as bedding material, as opposed to saw dust and peat).

Step 10 also calculates losses through indirect N_2O-N emissions from leaching/run-off during storage of solid manure, and indirect N_2O emissions through volatilisation of N in the form of NH_3 and NO_x losses from housing and storage of manure (Table 10). For both of these estimates the default values for the EFs as given in the IPCC 2006 guidelines are used and applied to total N. For leaching/run-off during storage, expert estimate has been used to determine the fraction of (i) indoor built up/deep litter, (ii) outdoors built up/deep litter, (iii) outdoor solid manure and (iv) poultry litter which can be assumed to be prone to leaching (see Table 11).

Table 9: Default emission factors for direct N_2O emissions from manure management (updated)

	Manure cellar for slurry, under slatted floor	**Manure cellar for slurry, under solid floor**	**Open manure tank for slurry**	**Manure tank with tight roof**	**Manure tank, floating cover (plastic, lecca)**	**Manure tank, floating cover (natural crust)**	**Indoor built up/deep litter**	**Outdoors built up/deep litter**	**Solid manure, outdoor storage**
System as described in IPCC 2006 (all categories other than poultry)	See note 1	See note 2	Liquid/slurry, without natural crust	Liquid/slurry, with natural crust	Liquid/slurry, with natural crust	Liquid/slurry, with natural crust	Cattle and swine deep bedding	Dry lot	Solid storage
					kg N_2O-N/kg Nex				
Dairy cattle	0,0025	0.005	0	0.005	0.005	0.0025	0.01	0.02	0.005
Suckling cows	0,0025	0.005	0	0.005	0.005	0.0025	0.01	0.02	0.005
Young beef cattle	0,0025	0.005	0	0.005	0.005	0.0025	0.01	0.02	0.005
Swine (note 3)	0,00025	0.0005	0	0.0005	0.0005	0.00025	0.01	0.02	0.005
Laying hens (note 4)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Broilers	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Turkeys	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Other poultry	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Horses	0.002	0.002	0	0.005	0.005	0.0025	0.01	0.02	0.005
Goats	0.002	0.002	0	0.005	0.005	0.0025	0.01	0.02	0.005
Sheep	0.002	0.002	0	0.005	0.005	0.0025	0.01	0.02	0.005
Fur animals	0,0025	0.5	0	0.005	0.005	0.0025	0.01	0.02	0.005
Deer	0,0025	0.5	0	0.005	0.005	0.0025	0.01	0.02	0.005
Reindeer	0,0025	0.5	0	0.005	0.005	0.0025	1.0	2.0	0.005

Table 10: Losses through N_2O-N emissions from leaching/run-off during storage, and indirect N_2O emissions through volatilization of N in the form of NH_3 and NOx

	Value	Units
EF for indirect N2O-N emissions from storage (leaching/runoff)	0.0075	kg N_2O-N/kg N leached/runoff
EF for N2O-N for deposition of N from NH3 and NOx emissions from housing and storage	0.01	kgN_2O-N/kg NH_3-N + NOx-N volatilised

Table 11: Fraction for storage systems that are assumed to have leaching

Type of manure	% of storage systems
Indoor built up/deep litter	15%
Outdoors built up/deep litter	25%
Outdoor solid manure	25%
Poultry manure	25%

The emission factors for pre-storage of manure used for AD are based on the factors presented in Tables 6 through 11 above. However, as the duration of storage of untreated manure is typically much longer than pre-storage of manure used for AD, this had to be taken into account in calculation of emissions. According to research (Østfoldforskning (2019), the current average pre-storage time for manure used for anaerobic digestion is about 1 month, whereas the average retention time for untreated manure is a little over 5 months (based on expert opinion of John Morken (NMBU), about 1/6 of manure is stored for less than a month, whereas the remining manure is stored over prolonged periods before being spread). Based on the approach for manure pre-stored before AD described in Haenel et al (2018), emissions of NH3 and N2O from pre-storage in the absence of measurement data can be approximated using a linear relationship to the time manure is stored for (as a rule, during the short time of pre-storage of slurry along with effective mixing little natural crust can develop or if developed, there is limited time for it to dry[4]). Thus, for manure pre-stored before AD, a "correction factor" of 0.2 is applied to unabated N2O and NH3 emission factors presented in Table 6 and Table 9. The calculation of emissions of NO and N2 are performed by analogy. Same share of storage systems is assumed to be leaching when estimating emissions from pre-storage of manure used for AD as for storage of untreated manure. Thus, indirect emissions of N2O are estimated for pre-storage the same way and using the same factors as for regular manure.

[4] According to approach in Haenel et al (2018), emissions of N2O, NO and N2 from pre-storage of slurry can be neglected all together, as only a dry crust allows for nitrification of NH4 to NO3 as pre-stage for N2O. However, pre-storage of manure before AD in the German inventory report is said to take only 7 days (instead of around 1 month for Norway), so to maintain a conservative approach, emissions of these species from pre-storage are not considered negligible in the nitrogen model, and estimated as specified above for all manure types (slurry, farmyard manure and deep litter).

The output of step 10 is an estimate of direct emissions NH_3-N, N_2O-N, NO-N and N_2, plus an estimate of indirect emissions of N_2O-N from leaching/run-off during storage of “regular” manure and pre-storage of manure used for AD and through volatilisation of N from manure management.

Step 10.1

Objective for step 10.1: to calculate emissions from use of manure in biogas production (digestion, separation of digestate and storage of digestate)

This is a new step in the nitrogen model added during 2020 revision, During the step, emissions related to anaerobic digestion of manure (farm-scale and centralized) are estimated from the moment manure enters the digester until digestate from manure is ready to be spread to land (spreading of digestate is accounted for together with spreading of manure under Step 12), including:

- Emissions from digester
- Emissions from separation of digestate into liquid and solid fractions (if applicable)
- Emissions from storage of digestate

Please, note, that emissions of different nitrogen species from pre-storage of manure used for AD are estimated during Step 8, together with emissions from storage of untreated manure (but using adjusted emission factors). The amount of nitrogen remaining in the manure used for AD after pre-storage is used as input in Step 10.1. Similar to the logic of the entire model the steps within “biogas module” follow the TAN and N balance, i.e. emissions from previous steps are deducted before estimating emissions in the following steps. For example, prior to estimating emissions from storage of digestate, emissions from digestated are deducted from the total amount of nitrogen coming out of the digester.

The emission factors for AD process are based on EMEP/EEA 2016 guidebook (for NH3 emissions) and 2019 IPCC Refinement (for N2O emissions). Emissions of NOx and N2 are not estimated.

Table 12: Emission factors used in estimation of emissions related to use of manure in biogas production

	Digestate type	Value	Unit
EF for losses of NH3-N from digester	N/A	0	kg NH_3-N/kg N in feedstock
EF for losses of N2O-N from digester	N/A	0	kg N_2O-N/kg N in feedstock
EF for losses of NH3-N from digestate separation	N/A	0.0012	kg NH_3-N/kg N in feedstock
EF for losses of N2O-N from storage of digestate	Unseparated	0.0006	kg N_2O-N/kg N in feedstock
	Liquid phase	0.0006	
	Solid phase	0.0006	
EF for losses of NH3-N from storage of digestate	Unseparated	0.0266	kg NH_3-N/kg N in feedstock
	Liquid phase	0.0116	
	Solid phase	0.015	

Step 11

Objective for step 11: to calculate the total-N and TAN that is applied to field.

The total-N and TAN that is applied to agricultural land is calculated by subtracting emissions of NH_3, N_2O (including indirect emissions from leaching/run-off), NO and N_2 during storage of untreated manure, pre-storage of manure used for AD, as well as digestion and storage of digestate from manure from total-N and TAN entering storage. According to EMEP/EEA 2019 guidebook, nitrogen in digestate produced from manure should be accounted for under “manure” and not “waste” reporting category. Thus, all nitrogen remaining in digestate that will then be spread to land (which is the current practice in Norway), is accounted for together with the nitrogen in the untreated manure.

Any total-N and TAN in manure spread directly to land is also added at this stage.

Step 12

Objective for step 12: to calculate the emissions of NH_3, NO, N_2O (direct and indirect) during and immediately after field application.

Emissions from spreading of stored manure vary with land use (meadow/pasture or arable), time of year for spreading, spreading method, water content and time and type of incorporation.

There are several sources of activity data on spreading of manure. The main sources are manure surveys performed in 2000, 2003, 2013 and 2018 by Statistics Norway (Gundersen & Rognstad 2001), (Gundersen & Heldal 2015) and (Kolle & Oguz-Alper 2020), various sample surveys of agriculture and forestry 1990-2007 and the annual animal population.

The manner of spreading the manure affects the NH_3 emissions estimates, while the N_2O and NO_x emission estimations are assumed insensitive to methods of spreading.

Table 13 shows the parameters included in the estimation of NH_3 emissions from manure, and the source of the activity data for each of these parameters. This activity data is reported as proportions of the tot-N and TAN that is applied to agricultural land.

Table 13: Parameters included in the estimation of NH_3 emissions from manure (updated)

	Sources
Area where manure is spread, split between cultivated field, meadow and cultivated pastures (innmarksbeite)	Statistics Norway (Sample Surveys of Agriculture, various years), Gundersen & Rognstad (2001), Gundersen & Heldal (2015), Kolle & Oguz-Alper (2020)
Area and amount where manure is spread, split between spring and autumn	Gundersen and Rognstad (2001) and Gundersen and Heldal (2015), Kolle & Oguz-Alper (2020)
Addition of water to manure	Gundersen & Rognstad (2001), Gundersen and Heldal (2015), expert judgements, Statistics Norway’s Sample Survey 2006 (2007), Kolle & Oguz-Alper (2020)
Spreading techniques	Gundersen & Rognstad (2001), Gundersen and Heldal (2015), Kolle & Oguz-Alper (2020) expert judgements
Usage and time of incorporation after application of manure	Gundersen & Rognstad (2001), Gundersen and Heldal (2015), Kolle & Oguz-Alper (2020),

	expert judgements, Statistics Norway's Sample Surveys of Agriculture

During step 12, the share of manure applied to pasture land and applied to arable land in spring, summer and autumn is determined. The proportion of manure to which more than 100% water is added is also determined, as is the spreading technique. Step 12 also determines the time for incorporation after application and the type of incorporation. Emission factors for spreading of manure will vary according to the different parameters highlighted above, as shown in Table 14 for meadow and Table 15 for arable land.

Table 14: Emission factors for spreading to meadow/cultivated pastures (updated)

Meadow / Cultivated pastures				
		Spring	**Summer**	**Autumn**
			kg NH_3-N/kg TAN	
Spreading method	**Added water**			
Broadcast spreading	< 100%	0.4	0.7	0.7
	> 100%	0.24	0.35	0.35
Trailing hose	< 100%	0.3	0.5	0.4
	> 100%	0.18	0.25	0.2
Injection		0.15	0.30	0.05
Dry manure		0.7	0.9	0.7

Table 15: Emission factors for spreading to arable land

Arable land						
			Incorporation time	**Spring**	**Summer**	**Autumn**
					kg NH3-N/kg TAN	
Spreading method		**Added water**	Hours			
Ploughing	Broadcast spreading	< 100%	0-1	0.08	0.08	0.12
			1-4	0.20	0.20	0.30
			4-12	0.33	0.33	0.45
			12+	0.50	0.50	0.45
		> 100%	0-1	0.04	0.04	0.06
			1-4	0.10	0.10	0.15
			4-12	0.17	0.17	0.28
			12+	0.25	0.25	0.28
	Trailing hose	< 100%	0-1	0.03	0.03	0.05
			1-4	0.12	0.12	0.17
			4-12	0.23	0.23	0.35
			12+	0.50	0.50	0.45
		> 100%	0-1	0.02	0.02	0.02
			1-4	0.06	0.06	0.09
			4-12	0.12	0.12	0.22
			12+	0.25	0.25	0.28
Dry manure				0.70	0.70	0.70

The emission factors for spreading of manure to meadow are taken from Karlsson S. and Rodhe L. (2002). These EFs are used as they allow a differentiation to be made between spreading methods (i.e. by broadcast spreading or by trailing hose) and better reflects the level of data collected in the Norwegian manure surveys. They also include different EFs for spring, summer and autumn and are considered relevant to climatic conditions in Norway as they have been prepared for the case of Sweden.

The emission factors for spreading of manure to cultivated land are based on Norwegian specific emission factors (R. Linjordet et al. 2005) but have been amended proportionally based on EFs proposed by Rösemann et al. (2017). This also allows a greater level of differentiation to be made with respect to spreading methods (i.e. by broadcast spreading or by trailing hose) and incorporation times, and better reflects the level of data collected (or to be collected) in the Norwegian “manure surveys”. As the EFs are based on Norwegian specific emission factors, a temperature correction is not considered to be required.

Step 12 also calculates direct losses of N_2O-N and NO-N from application to land, and indirect emissions of N_2O-N from leaching/run-off from application to land and from atmospheric deposition of N from NH_3 and NOx emissions from application to land. For all of these estimates the default values for the EFs as given in the IPCC 2006 guidelines and EMEP/EEA 2019 guidebook are used and applied to total N (Table 16).

Table 16: Direct and indirect emissions of N_2O-N and NO-N from application to land and grazing

	Value	Units	References
EF for direct N_2O-N emissions from application to land	0.01	kg N_2O-N/kg N applied to land	2006 IPCC GL
EF for NO-N emissions from application to land and grazing	0.04	kg NO_2-N/kg N applied to land or deposited during grazing	EMEP/EEA 2019 GB
EF for indirect N_2O-N emissions from application to land (leaching/runoff)	0.0075	kg N_2O-N/kg N leached/runoff	2006 IPCC GL
Fraction of N applied to land or deposited during grazing that is assumed to be leaching/runoff	0.22		(Bechmann et al. 2012)
N_2O-N EF for deposition of N from NH3 and NOx emissions from application to land	0.01	kg N_2O-N/kg NH_3-N + NOx-N volatilised	2006 IPCC GL

For leaching/run-off during application to land, expert estimate has been used to determine the fraction of manure applied to land which can be assumed to be prone to leaching.

The output of step 12 is an estimate of direct emissions NH_3-N, N_2O-N, and NO-N, plus an estimate of indirect emissions of N_2O-N from leaching/run-off during storage and through volatilisation of N from field application of manure.

Step 13

Objective for step 13: to calculate the net amount of N returned to soil from manure after losses of NH_3-N.

In this step, the net amount of N returned to soil from manure after losses of NH_3-N is calculated by subtracting emissions of all nitrogen species from total-N applied to land, as calculated in step 11.

Step 14

Objective for step 14: to calculate the NH_3, NO, N_2O (direct and indirect) emissions from grazing.

The amounts of TAN deposited on pasture land for each of the 14 animal categories is determined in step 4, and this figure is multiplied by the EFs for grazing provided in EMEP/EEA 2019 (for NH_3 emissions) and IPCC 2006 (for NO-N and N_2O-N and emissions, see Table 16 and Table 17 respectively).

A temperature correction factor is applied to the EMEP/EEA 2019 EFs, which reflects the fact that the latter are based on studies representing climatic conditions different from those in Norway. The same approach as used in step 6 has been adopted, which results in a temperature correction factor of 0.9 for emissions of NH_3 from grazing in Norway.

Table 17: Emission factors of NH_3-N and N_2O-N from grazing (updated)

	EF for losses of NH_3-N from grazing	EF for direct losses of N2O-N from grazing
	kg NH_3-N/kg TAN	kg N2O–N/kg N
Dairy cattle	0.14	0.02
Suckling cows	0.14	0.02
Young beef cattle	0.14	0.02
Swine	0.31	0.02
Laying hens	0	0.02
Broilers	0	0.02
Turkeys	0	0.02
Other poultry	0	0.02
Horses	0.35	0.01
Goats	0.09	0.01
Sheep	0.09	0.01
Fur animals	0.09	0.01
Deer	0.14	0.01
Reindeer	0.14	0.01

Step 14 also calculates losses through N_2O-N emissions from leaching/run-off during grazing, and indirect N_2O emissions through volatilisation of N in forms of NH_3 and NO_x from grazing. For both of these estimates the default values for the EFs as given in the IPCC 2006 guidelines are used and applied to total N (same values as for manure applied to land). For leaching/run-off during grazing, the same expert estimate of the fraction of manure prone to leaching has been used as for manure applied to land.

The output of step 14 is an estimate of direct emissions of NH_3-N, N_2O-N, and NO-N, plus an estimate of indirect emissions of N_2O-N from leaching/run-off during grazing and through volatilisation of N from grazing.

Step 15

Objective for step 15: sum all the emissions from the manure management system that are to be reported under Chapter 3B and convert to the mass of the relevant compound.

Under this step all emissions of NH_3-N from manure management systems, application to land and from manure deposited during grazing are summed and converted to NH_3. Similarly, all direct emissions of N_2O-N and NO-N from these sources are summed and converted to N_2O and NO_x respectively, and are reported along with total N_2 emissions.

Indirect emissions of N_2O-N from leaching/run-off during storage, application to land and grazing and indirect N_2O emissions through volatilisation of N are also summed in this stage and converted to, and reported as, N_2O.

The output of step 15 is an estimate of direct emissions NH_3, N_2O and NO_2 from all stages of the manure management and use system (housing, storage, grazing and application to land) plus an estimate of indirect emissions of N_2O from leaching/run-off during storage, application to land and grazing and through volatilisation of N.

2.5 Uncertainty

Emission factor uncertainties

All emission factors for NH_3 which have been used for both housing and storage are sourced from EMEP/EEA 2019. As stated in EMEP/EEA 2019, uncertainties with regard to NH_3 EFs vary considerably. EMEP/EEA 2019 concludes that the overall uncertainty for the United Kingdom NH_3 emissions inventory, as calculated using a Tier 3 approach, was ±21 % (Webb and Misselbrook, 2004), while that for the Netherlands, also calculated using a Tier 3 approach, was ±25 % (Wever et al., 2018, cited in Bruggen et al., 2018).

For NO, as stated in EMEP/EEA, it is difficult to quantify nitrification and denitrification rates in livestock manures. Consequently, there are large uncertainties associated with current estimates of emissions for this source category (–50 % to +100 %).

The emission factors for N_2O are sourced from IPCC 2006. As for NO, the IPCC 2006 guidelines state that there are large uncertainties associated with the default emission factors for this source category (–50% to +100%).

Activity data uncertainties

The data for number of animals is considered to be known within ±5 per cent. There is also uncertainty connected to the fact that some categories of animals are only alive part of the year and the estimation of how long this part is.

For the amount of nitrogen in manure, the figures are generated for each animal type, by multiplying the number of animals with a nitrogen excretion factor. The nitrogen excretion factors are uncertain. The range is considered to be within ±15 per cent (Rypdal 1999). The uncertainty is connected to differences in excreted N between farms in different parts of the country, that the survey farms may not have been representative, general measurement uncertainty and the fact that fodder and feeding practices have changed since the factors were determined. This uncertainty was substantially reduced in 2013 when the nitrogen factors were assessed in a research project (Karlengen et al. 2012).

There is also an uncertainty connected to the division between different storage systems for manure, which is considered to be within ±10 per cent, and the division between storage and pasture, which is considered to be within ±15 per cent.

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Annex I. Updates introduced to the model in 2020

A revision of the tool has been performed in 2020, in order to identify any potential areas of improvement, in light with updated international EMEP/EEA 2019 guidebook and newly available national data. In addition, a revision of the model was performed by researchers at the Norwegian Institute of Bioeconomy Research (NIBIO), which provided an opportunity to update some of the factors based on national knowledge and practices (Rivedal et al (2019).

The following sections compare the updated factors introduced in the 2020 revision of the model with the original factors used in the nitrogen model:

Housing

Emission factors used for NH_3-N from buildings:

		Original model		2020 revision	
	NFR code	**Slurry**	**Solid manure**	**Slurry**	**Solid manure**
Dairy cattle	3B1a Dairy cattle	20 %	19 %	24%	8%
Suckling cows	3B1b Non-dairy cattle (young cattle, beef cattle and suckling cows)	20 %	19 %	24%	8%
Young beef cattle	3B1b Non-dairy cattle (young cattle, beef cattle and suckling cows)	20 %	19 %	24%	8%
Swine	3B33 'Swine' (fattening pigs, 8–110 kg)	28 %	27 %	27%	23%
Laying hens	3B4gi Laying hens	41 %	41 %	41 %	20%
Broilers	3B4gii Broilers	28 %	28 %	21%	21%
Turkeys	3B4giii Turkeys	35 %	35 %	35 %	35 %
Other poultry	3B4giv Other poultry (geese)	57 %	57 %	57 %	57 %
Horses	3B4e Horses	22 %	22 %	22 %	22 %
Goats	3B4d Goats	22 %	22 %	22 %	22 %
Sheep	3B2 Sheep	22 %	22 %	22 %	22 %
Fur animals	3B4h Other animals (fur animals)	27 %	27 %	27 %	27 %
Deer	3B4h Other animals	20 %	20 %	24%	24%
Reindeer	3B4h Other animals	20 %	20 %	24%	24%

Storage

Emission factors used for NH_3-N from storage

NFR code	% NH_3-N losses from storage	
	Original model	2020 revision

		Slurry	Solid	Slurry	Solid
Dairy cattle	3B1a Dairy cattle	20 %	27%	25 %	32 %
Suckling cows	3B1b Non-dairy cattle (young cattle, beef cattle and suckling cows)	20 %	27%	25 %	32 %
Young beef cattle	3B1b Non-dairy cattle (young cattle, beef cattle and suckling cows)	20 %	27%	25 %	32 %
Swine	3B33 'Swine' (fattening pigs, 8–110 kg)	14 %	45%	11 %	29 %
Laying hens	3B4gi Laying hens	14 %	14 %	14 %	8 %
Broilers	3B4gii Broilers	17 %	17 %	30 %	30 %
Turkeys	3B4giii Turkeys	24 %	24 %	24 %	24 %
Other poultry	3B4giv Other poultry (geese)	24 %	24 %	24 %	24 %
Horses	3B4e Horses	35 %	35 %	35 %	35 %
Goats	3B4d Goats	28 %	28 %	28 %	28 %
Sheep	3B2 Sheep	28 %	28 %	32 %	32 %
Fur animals	3B4h Other animals (fur animals)	9 %	9 %	9 %	9 %
Deer	3B4h Other animals	20 %	27%	25 %	25 %
Reindeer	3B4h Other animals	20 %	27%	25 %	25 %

Ammonia reduction potential for abatement measures for cattle and pig slurry storage

	NH_3-N emissions reduction	
	Original model	2020 revision
Manure cellar for slurry, under slatted floor	0 %	30 %
Manure cellar for slurry, under solid floor	60 %	60 %

Open manure tank for slurry (unabated)	0 %	0 %
Manure tank with tight roof	80 %	80 %
Manure tank with floating cover (plastic sheeting, lecca)	60 %	60 %
Manure tank with floating cover (natural crust)	40 %	40 %
Indoor built up/deep litter	0 %	0 %
Outdoors built up/deep litter	0 %	0 %
Solid manure, outdoor storage	0 %	0 %

Default emission factors for direct N_2O emissions from manure management

	kg N_2O-N/kg Nex			
	Original model		2020 revision	
	Manure cellar for slurry, under slatted floor	Manure tank, floating cover (natural crust)	Manure cellar for slurry, under slatted floor	Manure tank, floating cover (natural crust)
Dairy cattle	0	0.005	0,0025	0.0025
Suckling cows	0	0.005	0,0025	0.0025
Young beef cattle	0	0.005	0,0025	0.0025
Swine (note 3)	0	0.0005	0,00025	0.00025
Laying hens (note 4)	0.001	0.001	0.001	0.001
Broilers	0.001	0.001	0.001	0.001
Turkeys	0.001	0.001	0.001	0.001
Other poultry	0.001	0.001	0.001	0.001
Horses	0.002	0.005	0.002	0.0025
Goats	0.002	0.005	0.002	0.0025
Sheep	0.002	0.005	0.002	0.0025
Fur animals	0	0.005	0,0025	0.0025
Deer	0	0.005	0,0025	0.0025
Reindeer	0	0.005	0,0025	0.0025

Spreading

No changes to the emission factors.

Grazing

Emission factors of NH_3-N from grazing

	kg NH_3-N/kg TAN	
	EF for losses of NH_3-N from grazing	
	Original model	2020 revision
Dairy cattle	0.1	0.14
Suckling cows	0.1	0.14
Young beef cattle	0.06	0.14
Swine	0.25	0.31
Laying hens	0	0
Broilers	0	0
Turkeys	0	0
Other poultry	0	0
Horses	0.35	0.35
Goats	0.09	0.09
Sheep	0.09	0.09
Fur animals	0.09	0.09
Deer	0.1	0.14
Reindeer	0.1	0.14

In addition, the following changes to the activity data on manure management systems, pasture and manure spreading areas were introduced based on final figures from the manure survey 2018 (Kolle & Oguz-Alper 2020)[5]:

- The main differences were that data on MMS for horse and goat now became split between two animal categories. These two categories were earlier treated with the same manure distribution. The share of manure per storage type was changed for these categories, and led together with other updated information, to changes in methane emissions. The manure distribution for fur-bearing animals was also changed as a result of this update, since the same values for manure storage distribution as for horse-goat was used earlier. In updated model manure distribution for horse was used for fur-bearing animals.

- The updated MMS data from 2018 manure survey also gave changes in values for housing and storage practices for cattle and sheep

[5] The updated activity data can be found in 2020 National Inventory Report (in preparation)

- Updated time on pasture data for sheep, horse and all cattle except dairy cow. As a result, the amount of manure entering housing and storage also changed but had small impact on the total changes in methane from manure emissions.
- Updated data on spreading techniques, incorporation time and the introduction of three instead of two types of spreading areas; cultivated field, meadow and cultivated pastures (innmarksbeite). Earlier it was split between cultivated field and meadow.

Percent of total excretion deposited on pasture per animal type

	% manure to pasture original	**Updated % manure to pasture**
Beef cows	31 %	37 %
Young cattle	31 %	24 %
Goats	37 %	30 %
Sheep	62 %	77 %