Category		Title
NFR	**3.B**	Manure Management
	3.B.1.a, 3.B.1.b, 3.B.2, 3.B.3, 3.B.4.a, 3.B.4.d, 3.B.4.e, 3.B.4.f, 3.B.4.g.i, 3.B.4.g.ii, 3.B.4.g.iii, 3.B.4.g.iv, 3.B.4.h	
SNAP	100901	Dairy cattle
	100902	Non-dairy cattle
	100905	Sheep
	100903, 100904	Swine (Fattening pigs and Sows)
	100914	Buffalo
	100910	Goats
	100906	Horses
	100912	Mules and asses
	100907	Laying hens
	100908	Broilers
	100909	Turkey
	100909	Other poultry
	100911, 100913, 100915	Fur animals, Camels, Other Animals
ISIC		
Version	Guidebook 2016	

*Under NFR reporting, 'Fur animals' and 'Camels' should be reported under 3.B.4.h 'Other animals'.

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Contents

1 Overview

Inventories of emissions are required for three purposes:

- to provide annual updates of total emissions in order to assess compliance with agreed commitments;
- to identify the main sources of emissions in order to formulate approaches to make the most effective reductions in emissions;
- to provide data for models of dispersion and the impacts of the emissions.

The guidance in this guidebook primarily aims to enable countries to prepare annual national inventories for regulatory purposes. The results obtained using the methods outlined here may also be suitable for some modelling purposes, e.g. the production of abatement cost curves. However, because of the lack of disaggregation at both the temporal and geographical scales, and also because the methods proposed take only limited account of the impacts of weather on emissions, the output may not be suitable for use in other models. This limited account of the impacts of weather is a result mainly of the difficulty in obtaining sufficiently detailed activity data to enable accurate estimates to be made of the impacts of temperature and rainfall, for example, on emissions. If possible, users should develop methods to take account of the influence of more detailed activity data. This guidebook provides methodologies that use inputs that can be reliably obtained by emission inventory compilers.

Ammonia (NH_3) emissions lead to the acidification and eutrophication of natural ecosystems. NH_3 may also form secondary particulate matter (PM). Nitric oxide (NO) and non-methane volatile organic compounds (NMVOCs) are involved in the formation of ozone (O_3), which, near the surface of the Earth, can have an adverse effect on human health and plant growth. Particulate emissions also have an adverse impact on human health.

Emissions of NH_3, NO and NMVOCs arise from the excreta of agricultural livestock that are deposited in and around buildings and collected as liquid slurry, solid manure or litter-based farmyard manure (FYM). In this chapter, solid manure and FYM are treated together as 'solid'. These emissions occur from buildings housing livestock and outdoor yard areas, from manure stores, after land spreading of manures and during grazing. Emissions of PM arise mainly from feed, and also from bedding, animal skin or feathers, and occur from buildings housing livestock. Emissions of nitrous oxide (N_2O) also occur, and are accounted for here, when necessary, for the accurate estimation of NH_3 and NO emissions; however, they are not reported here as N_2O is a greenhouse gas.

Livestock excreta and manure account for more than 80 % of NH_3 emissions from European agriculture. There is, however, wide variation among countries in emissions from the main livestock sectors: cattle, pigs, poultry and sheep. This variation from country to country is explained by the different proportions of each livestock category and their corresponding nitrogen (N) excretion and emissions, by differences in agricultural practices, such as housing and manure management, and by differences in climate.

NO emissions from livestock buildings, open yard areas and manure stores are currently estimated to account for only c. 0.1 % of total NO emissions (Table 1.1). There is considerable uncertainty concerning the NMVOC emissions from this source. Hobbs et al. (2004) estimated emissions from livestock production could be c. 7 % of total United Kingdom emissions and a similar proportion is currently reported by the European Monitoring and Evaluation Programme (EMEP) (Table 1.1).

Emissions from buildings housing pigs and poultry represent around 30 and 55 %, respectively, of agricultural PM_{10} emissions; the remainder is mainly produced by arable farming. Emissions from livestock housing are estimated to produce c. 9 % of total PM_{10} emissions.

This chapter provides guidance on the calculation of emissions from all stages of manure management, including emissions from livestock buildings, open yard areas and manure stores, together with the emissions that occur after the application of manures to land and from excreta deposited in fields by grazing animals. Some of these sources are reported in Nomenclature for Reporting (NFR) 3D, Crop production and agricultural soils, but all methodologies are presented together in this chapter because the Tier 2 methodology developed to calculate NH_3 emissions from livestock production treats these emissions as part of a chain of sources, enabling the impact of NH_3 and other N emissions at one stage of manure management on the NH_3 emissions from subsequent sources to be estimated (see Annex 1, section A1.2). For a full description of reporting requirements see section 3.2.

In the remainder of this chapter, the comment 'see Annex 1' indicates that further information is provided in the annex.

Table 1.1 Contributions from only livestock production and fertiliser application to emissions of gases

	NH_3 ([a])	NO_x	NMVOC	$PM_{2.5}$	PM_{10}	TSP
Total, Gg a^{-1}	3 810	8 166	6 933	1 220	1 808	3 440
Livestock, Gg a^{-1}	2 327	7	495	34	164	354
Livestock, %	61.1	0.1	7.1	2.8	9.1	10.3

Notes: The figures are 2013 estimates for EU-27.
(a) The estimates of NH_3 emissions includes those from only buildings, uncovered yard areas and manure stores. Emissions after manure application and during grazing are reported under NFR 3D, Crop production and agricultural soils. Gg a^{-1}: Gigagrammes per year, NO_x, nitrogen oxides; TSP, total suspended particles.

Source: http://ceip.at

This chapter is divided into two separate sections. The first section, the main part of the chapter, provides guidance on the methodologies available for calculating emissions at the Tier 1 and 2 levels. The second part, the annex, provides the scientific documentation underlying the Tier 1 and 2 methodologies and guidance for the development of Tier 3 methodologies.

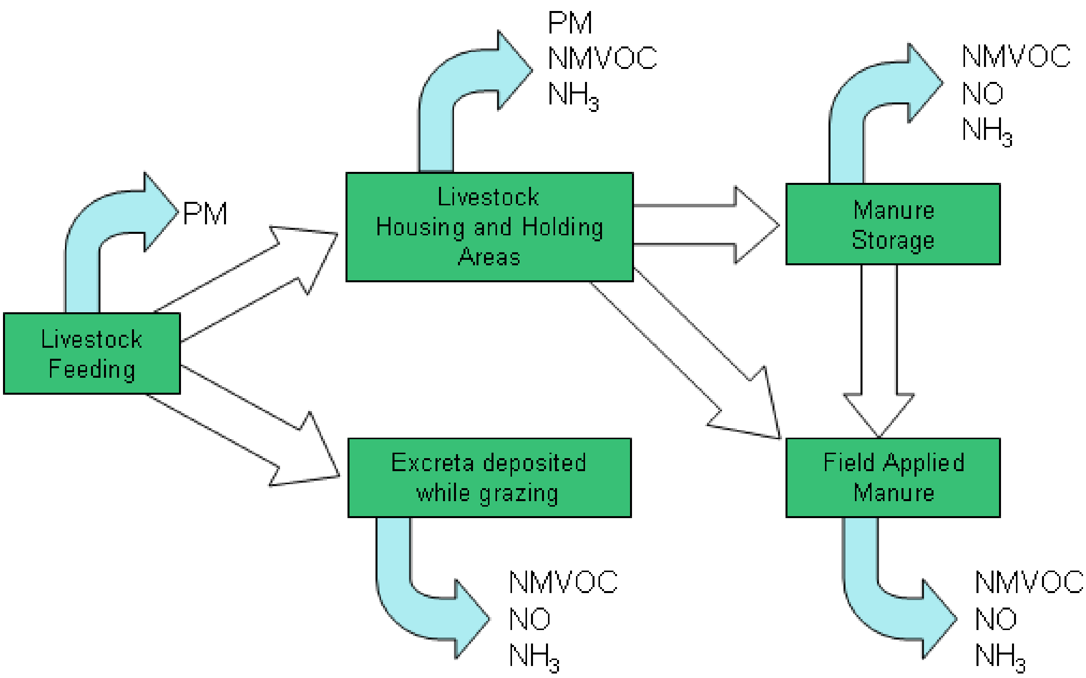
2 Description of sources

There are five main sources of emissions related to livestock husbandry and manure management:

- livestock feeding (PM);
- manure generated in livestock housing and on open yard areas (NH_3, PM, NMVOCs);
- manure storage (NH_3, NO, NMVOCs);
- field-applied manure (NH_3, NO, NMVOCs);
- excreta deposited during grazing (NH_3, NO, NMVOCs).

2.1 Process description

Figure 2.1 Process scheme for emissions resulting from livestock feeding, livestock excreta and manure management



Ammonia

NH_3 volatilisation occurs when NH_3 in solution is exposed to the atmosphere. The extent to which NH_3 is emitted depends on the chemical composition of the solution (including the concentration of NH_3), the temperature of the solution, the surface area exposed to the atmosphere and the resistance to NH_3 transport in the atmosphere.

The source of NH_3 emissions from manure management is the N excreted by livestock.

NH_3 is emitted if excreta or manure are exposed to the atmosphere, namely in livestock housing, from manure stores, after manure application to fields and from excreta deposited by grazing animals (note that although the NH_3 emissions after manure application and from pastures grazed by livestock are calculated here, they should be reported under NFR 3D, Crop production and agricultural soils). Differences in agricultural practices, such as housing and manure management, and differences in climate have significant impacts on emissions.

Further information on the processes leading to emissions of NH_3 is given in Annex 1, section A1.2.1.

Nitric oxide

NO is formed through nitrification in the surface layers of stored manure or in manure aerated to reduce odour or to promote composting. At present, few data are available on NO emissions from manure management. NO emissions from soils are generally considered to be products of nitrification. Increased nitrification is likely to occur after the application of manures and the deposition of excreta during grazing. NO emissions arising from livestock buildings and manure stores should be reported under NFR 3B, while those arising after the application of manures to land or from grazed pastures should be reported under NFR 3D.

Non-methane volatile organic compounds

Significant emissions of NMVOCs have been measured from livestock production. In addition to manure management, silage stores are a major source and emissions occur during feeding with silage.

Sites of emission include livestock buildings, yards, manure stores, fields on which manure is spread and fields grazed by livestock. Emissions occur from manure managed in solid form or as slurry. Only a limited number of studies have been undertaken on NMVOC emissions from livestock husbandry, the results of which are highly variable thus leading to large uncertainties in the emission estimates. Most of the NMVOC studies have focused on emissions from housing and on odour-related issues.

Particulate matter

The main sources of PM emission are buildings housing livestock, although outdoor yard areas may also be significant sources. These emissions originate mainly from feed, which accounts for 80 to 90 % of total PM emissions from the agriculture sector. Bedding materials, such as straw or wood shavings, can also give rise to airborne particulates. Poultry and pig farms are the main agricultural sources of PM. Emissions from poultry buildings also arise from feathers and manure, while emissions from pig houses arise from skin particles, faeces and bedding. Animal activity may also lead to the re-suspension of previously settled dust into the atmosphere of the livestock building (re-entrainment). Winkel et al. (2015) demonstrated that PM concentrations within a building housing pigs were considerably greater during daytime and particular periods of animal activity. It is therefore important to ensure that any emission measurements are taken over a long enough period to ensure that they are suitably representative before being scaled up to determine an annual emissions estimate.

2.2 Reported emissions

Ammonia

Estimates of NH_3 emissions from agriculture indicate that in Europe 80–90 % originate from livestock production (http://webdab.emep.int). The amount of NH_3 emitted by each livestock category will vary among countries according to the size of that category. In most countries, dairy cows and other cattle are the largest sources of NH_3 emissions. For example, in France, dairy cows account for 31 % of the total from agriculture, while other cattle account for 24 % of the agriculture total (CITEPA, 2015). Cattle are also the largest source of NH_3 emissions in many other countries. In some countries, emissions from pig production may also be large, e.g. in Denmark where pig production accounts for about 40 % of emissions (Hutchings et al., 2001). Emissions from livestock categories other than cattle, pigs and poultry tend to be from minor sources, although sheep can be a significant source for some countries.

It is important to consider the relative amounts of emissions from different stages of manure management. For most countries, the greatest proportions of NH_3 emissions from livestock production arise from buildings housing livestock and after the application of manures to land, each of which typically account for 30–40 % of NH_3 emissions resulting from livestock production. Emissions from storage and outdoor livestock each typically account for 10–20 % of the total. Emissions during grazing tend to be fairly small as the total ammoniacal nitrogen (TAN) in urine deposited directly on pastures is quickly absorbed by the soil. The proportion of emission from buildings and after manure spreading will decrease as the proportion of the year spent at pasture increases.

The wide-scale introduction of abatement techniques, although reducing total NH_3 emissions, is likely to increase the proportions arising from buildings and during grazing, since these sources are the most difficult to control. Abatement measures for the land spreading of manures have been introduced to the greatest extent, since these are among the most cost effective. In contrast, abatement techniques for buildings are often expensive and tend to be less effective.

In order to calculate NH_3 emissions, it is necessary to have quantitative data on all the factors noted at the beginning of this section. In practice, results may be summarised to provide 'average' emission factors (EFs) per animal housing place for each emission stage for the main livestock categories and management types, or to provide total annual EFs. Total NH_3 emissions are then scaled by the numbers of each class of livestock in each country.

Nitric oxide

Very few data are available on emissions of NO from manures during housing and storage that can be used to compile an inventory. Emissions of NO are estimated to quantify the N mass balance for the Tier 2 methodology used to calculate NH_3 emissions, and by doing so are used to estimate NO emissions during housing and storage.

Non-methane volatile organic compounds

A list of the principal NMVOCs, from the main emission sources, and a classification of the volatile organic compounds (VOCs) according to their importance, was included in the Convention on Long-range Transboundary Air Pollution (CLRTAP) protocol in order to address reductions in VOC emissions and their transnational flows (UNECE, 1991). The CLRTAP protocol classifies NMVOCs into three groups, according to their importance in the formation of O_3 episodes, considering both the global quantity emitted and the VOCs' reactivity with hydroxyl radicals.

Some of the major NMVOCs released from livestock buildings are listed in Annex 1, section A1.2.2.

Particulate matter

In order to calculate PM emissions in detail, it would be necessary to have quantitative data on all the factors noted in Annex 1, section A1.2.2. In practice, the data available allow the use of only average EFs for each livestock sub-category.

Further information on emissions is given in Annex 1, section A1.2.2.

2.3 Controls

Ammonia

Descriptions of measures to reduce NH_3 emissions from manure management can be found online (http://www.unece.org/fileadmin/DAM/env/documents/2012/EB/N_6_21_Ammonia_Guidance_Document_Version_20_August_2011.pdf).

Chapter 3 explains how the implementation of abatement measures can be accounted for in national inventories using a Tier 3 methodology. Annex 1, section A1.4, summarises the activity data that are needed to take account of the adoption of abatement measures.

Nitric oxide

The use of nitrification inhibitors has been proposed to reduce emissions of N_2O, and their use may have an additional benefit in curtailing emissions of NO.

NMVOCs

Techniques which reduce NH_3 and odour emissions may also be considered effective in reducing the emission of NMVOCs from livestock manure (Annex 1, section A1.2.3). Possibilities ways of achieving such reductions include the immediate covering of silage stores (pits) and minimising the area of silage available to feeding animals.

Particulate matter

Techniques to reduce concentrations of airborne dust in livestock buildings have been investigated. These are summarised in Annex 1, section A1.2.3.

2.4 Factors to be taken into account during inventory preparation

Ammonia

When applying or developing techniques to estimate and report emissions, users need to consider that NH_3 emissions from livestock production depend on many factors including:

- the proportion of time spent by animals indoors and outside, e.g. at pasture or in yards or buildings, and animal behaviour;
- whether livestock excreta are handled as slurry or solid;
- the housing system of the animal (especially the floor area per animal) and whether or not manure is stored inside the building.

In addition, account will need to be taken of the amounts of livestock manures used as feedstocks for anaerobic digestion (AD), as emissions from the storage of AD feedstocks are accounted for in Chapter 5B2.

The excretion of N, and the subsequent emission of NH_3, varies among livestock species (e.g. cattle and pigs). Within a livestock species, there are large differences among animals kept for different purposes (e.g. dairy cattle versus beef cattle). It is therefore necessary, whenever possible, to disaggregate livestock according to species and production type.

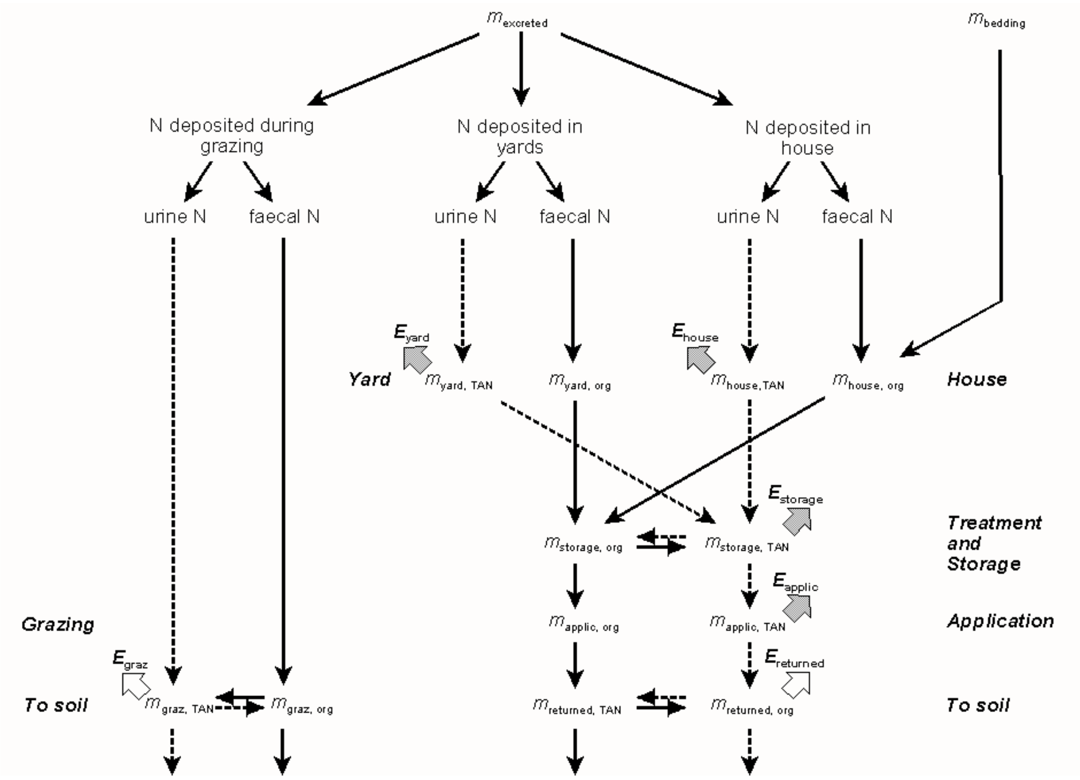
NH_3 emissions from livestock manures that occur during housing and storage, and as a result of field application, depend on:

- livestock category
- bedding material
- the TAN content of the excreta.

Other factors, which can be taken into account using Tier 3 methodologies, are listed in Annex 1, section A1.4.

The pathways for the emission of N species are shown in Figure 2.2.

Figure 2.2 N flows in the manure management system (Source: Dämmgen and Hutchings, 2008)

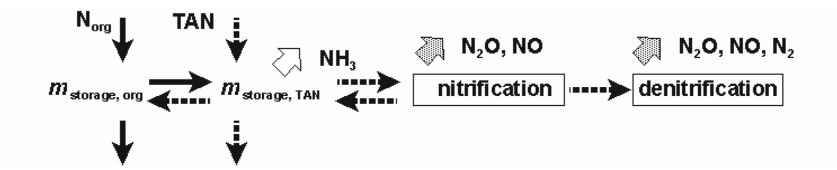


Notes:

Narrow broken arrows refer to TAN; narrow continuous arrows refer to organic N; *m* refers to mass from which emissions may occur. The horizontal arrows denote the process of immobilisation in systems with bedding occurring in the house, and the process of mineralisation during storage. Broad hatched arrows denote emissions assigned to manure management (E_{applic}, NH_3 emissions during and after spreading; E_{house}, NH_3 emissions from house; $E_{storage}$, NH_3, N_2O, NO and di-nitrogen (N_2) emissions from storage; E_{yard}, NH_3 emissions from yards). Broad open arrows indicate emissions from soils (E_{graz}, NH_3, N_2O, NO and N_2 emissions during and after grazing; $E_{returned}$, N_2O, NO and N_2 emissions from soil resulting from manure input). See subsection 3.4 of the present chapter for key to variable names.

Transition between the two forms is possible, as shown in Figure 2.3. The gaseous losses occur solely from the TAN fraction. This means that in order to estimate emissions of NH3 accurately it is necessary to follow the fate of the two fractions of N separately.

Figure 2.3 Processes leading to the emission of gaseous N species from manure



Nitric oxide

NO may be produced during nitrification and denitrification as indicated in Figure 2.2.

Non-methane volatile organic compounds

Over 500 volatile compounds originating from cattle, pigs and poultry have been identified, although only c. 20 compounds were considered significant by Hobbs et al. (2004) and the United States Environmental Protection Agency (US EPA, 2012), accounting for 80–90 % of the total emissions. These compounds have very different physical and chemical properties. Variations in chemical activity, water solubility and the extent to which the compounds bind to surfaces presents significant challenges for the measuring methodology which, again, may yield large uncertainties and difficulties related to the interpretation of measured data.

Emissions of NMVOCs occur from silage, manure in livestock buildings, outside manure stores, field application of manure and from grazing animals. There is a lack of emission estimates related to feeding with silage, outdoor manure stores, manure application and grazing animals. The great majority of research has focused on emissions from housed animals. The emission estimates provided here are thus based on assumed proportions of the emissions that in livestock buildings (for a detailed explanation, please refer to Annex 1, section A1.2.2).

Particulate matter

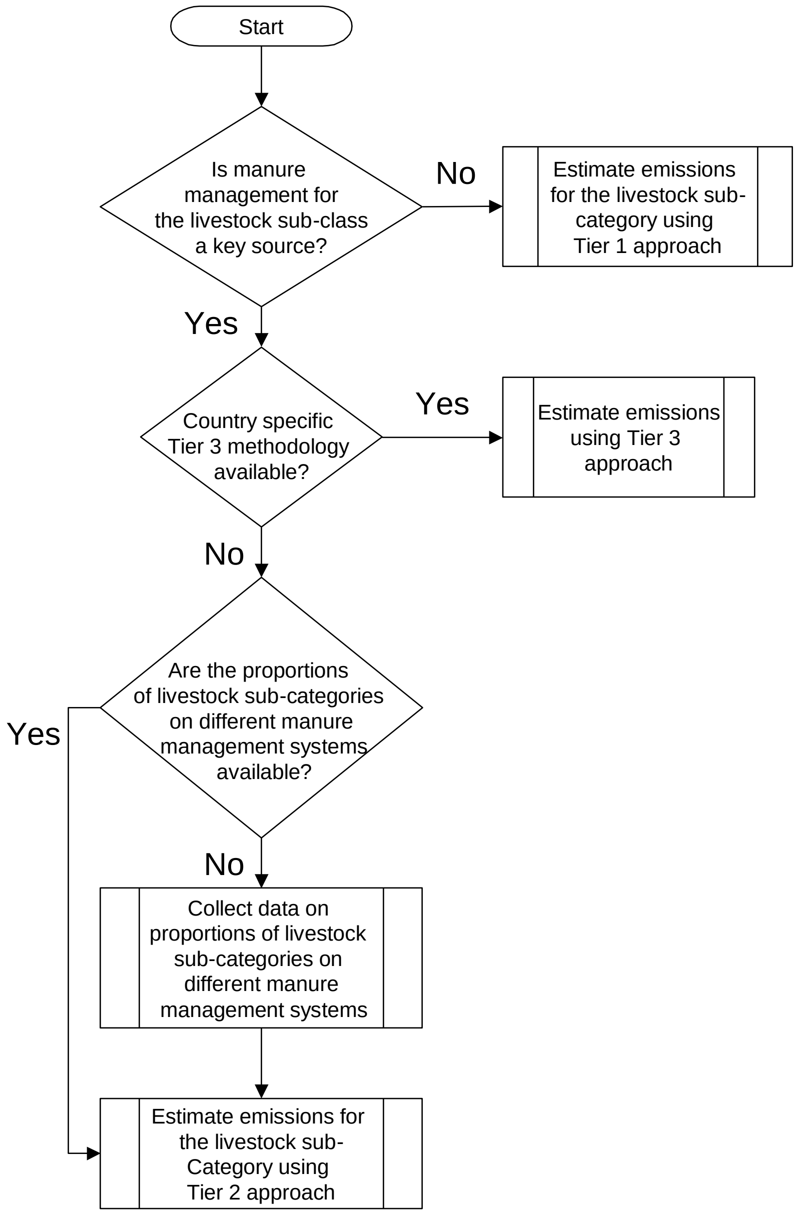
Emissions of PM occur from both housed and free-range livestock. However, the lack of available emissions measurements for free-range livestock means that the development of EFs has focused on housed livestock. Factors determining the size of PM emissions are listed in Annex 1, section A1.3.1. More data are needed on emission rates of particulates in order to better determine both mean emission rates and the variability of emission rates due to various environmental and management factors. This source is therefore also a target for prospective verification studies.

3 Methods

3.1 Choice of method

The decision tree in Figure 3.1provides a guide to the choice of method for estimating emissions. Starting from the top left, it guides the user towards the most applicable approach.

Figure 3.1 Decision tree for source category 3B Manure management



General guidance on the identification of key sources can be found in Part A (the general guidance chapters) of this guidebook, namely Chapter 2, 'Key category analysis and methodological choice' (EMEP/EEA, 2016). In most, if not all, countries, the main livestock categories will be key sources of NH_3 and it is good practice to calculate emissions using at least a Tier 2 approach for these key categories. For livestock categories that make a minor contribution to emissions, the use of a Tier 1 approach would comply with good practice requirements.

The approach is outlined below.

- If detailed information of sufficient quality is available, then it should be used.
- If the source category is a key source, it is good practice to use a Tier 2 or better method. The decision tree directs the user to the Tier 2 method, and the necessary input data with respect to N excretion and manure management systems, if the country-specific EFs needed for a Tier 3 estimate are not available.
- The use of a Tier 3 method is recommended for countries with enough data to enable the enumeration of country-specific EFs. Countries that have developed a mass-flow approach to calculating national NH_3-N emissions should use this approach in compliance with subsection 4.6, 'Inventory quality assurance/quality control (QA/QC)'.

3.2 Reporting emissions

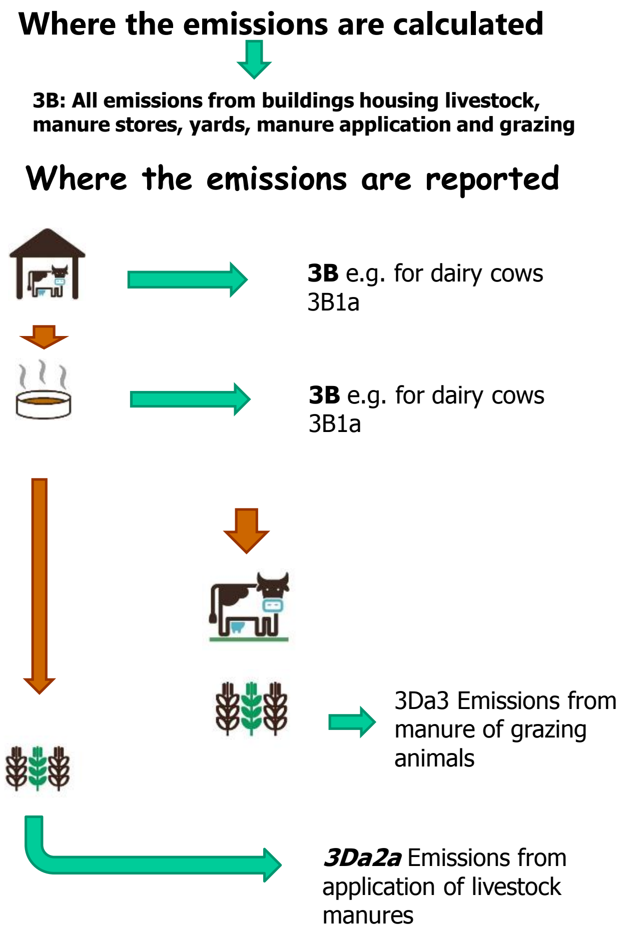
Emissions of NH_3 at one stage of manure management, e.g. during housing, can influence NH_3 emissions at later stages of manure management, e.g. during manure storage and application to land. The more NH_3 emitted at early stages of manure management the less is available for emission later (Reidy et al., 2007, 2009). Manure management also effects NH_3 emissions from grazed pastures. The more time grazing livestock are housed, the smaller the proportion of their excreta deposited on grazed pastures will be, and hence the smaller the emissions from those pastures. For this reason, emissions at the Tier 2 level are calculated sequentially using a mass-flow approach (Reidy et al., 2007, 2009). The Tier 1 default EFs are derived from the Tier 2 mass-flow method.

Emissions from field-applied manure and from excreta deposited by grazing animals are reported separately from those of livestock buildings, outdoor yards and manure storage. This allows emissions to be reported to the current NFR reporting structure (under the United Nations Economic Commission for Europe (UNECE)), which is specifically maintained to be consistent with the common reporting format (CRF) reporting structure (under the United Nations Framework Convention on Climate Change (UNFCCC)) for greenhouse gases. Figure 3.2 illustrates which emissions are to be calculated and where they are to be reported. The full reporting requirements are given in Table 3.1.

Table 3-1 NFR codes under which emissions from manure management are calculated and reported

Livestock category	Calculation	Reporting NH_3 emissions from		
		Housing, storage and yards	Manure application	Grazed pastures
Dairy cattle	3B1a	3B1a	3Da2a	3Da3
Non-dairy cattle (including young cattle, beef cattle and suckling cows)	3B1b	3B1b	3Da2a	3Da3
Sheep	3B2	3B2	3Da2a	3Da3
'Swine' — Fattening pigs	3B3	3B3	3Da2a	3Da3
'Swine' — Sows	3B3	3B3	3Da2a	3Da3
Buffalo	3B4a	3B4a	3Da2a	3Da3
Goats	3B4d	3B4d	3Da2a	3Da3
Horses	3B4e	3B4e	3Da2a	3Da3
Mules and asses	3B4f	3B4f	3Da2a	3Da3
Laying hens	3B4gi	3B4gi	3Da2a	3Da3
Broilers	3B4gii	3B4gii	3Da2a	3Da3
Turkeys	3B4giii	3B4giii	3Da2a	3Da3
Other poultry	3B4giv	3B4giv	3Da2a	3Da3
Other animals	3B4h	3B4h	3Da2a	3Da3

Figure 3.2 Reporting procedure for source category 3B Manure management



This explanation of the separation of calculating and reporting emissions is also relevant to NH_3, as this is the only emission calculated using a mass-flow approach.

3.3 Tier 1 default approach

Algorithm

The objective of **Step 1** is to define appropriate livestock categories and obtain the annual average number of animals in each category (see subsection 3.3.3, 'Activity data'). The aim of this categorisation is to group types of livestock that are managed similarly (typical examples are shown in Table 3.1).

The objective of **Step 2** is to decide for each cattle or pig livestock category whether manure is typically handled as slurry or solid.

The objective of **Step 3** is to find the default EF for each livestock category from subsection 3.3.2 of the present chapter.

The objective of **Step 4** is to calculate the pollutant emissions ($E_{pollutant\_animal}$) for each livestock category, using the corresponding annual average population for each category (AAP_{animal}) and the relevant EF ($EF_{pollutant\_animal}$):

$$E_{pollutant\_animal} = AAP_{animal} \times EF_{pollutant\_animal} \quad (1)$$

where AAP_{animal} is the number of animals of a particular category that are present, on average, within the year (for a fuller explanation, see IPCC, 2006, section 10.2).

Ammonia

The Tier 1 method entails multiplying the AAP in each livestock category by default EFs, expressed as kg AAP^{-1} a^{-1} NH_3. There is one EF for emissions from buildings together with emissions from open yards and manure stores, one for emissions during grazing for ruminant livestock and one for emissions after spreading of manures for each livestock category. This means that when using the Tier 1 methodology for a livestock category, NH_3 emissions can be reported under NFR 3B for emissions from buildings, open yards and manure stores, while emissions from grazing and manure application can be reported for the livestock category under NFR 3D.a.3.

Nitric oxide

Emissions of NO need to be estimated using the Tier 2 mass-flow approach to calculate NH_3 emissions, in order to accurately calculate the flow of TAN. The output from these calculations, as cited below, provides EFs for NO. The default Tier 1 EFs for NO have been calculated using the Tier 2 default NO-N EFs for manure storage, based on default activity data on N excretion, the proportions of TAN in excreta and, if appropriate, the length of the grazing period. If appropriate, separate EFs are provided for slurry- and litter-based manure management systems. The user may choose the EF for the predominant manure management system for that livestock category in the relevant country. These EFs have been calculated on the basis that all manure is stored before surface application without rapid incorporation. For these reasons, countries are encouraged to calculate emissions using at least a Tier 2 approach if possible.

NMVOCs

The Tier 1 method entails multiplying the AAP in each livestock category by a single default EF, expressed as kg NMVOC AAP^{-1} a^{-1}. This EF represents emissions from housing. This means that when using the Tier 1 methodology for a livestock category, emissions should be reported under NFR 3B alone, and no emissions from grazing should be reported for the livestock category under NFR 3D.a.3.

Emissions from livestock on grass are assumed to be small and are only estimated as part of the Tier 2 approach.

Particulate matter

The Tier 1 method entails multiplying the AAP in each livestock category by a single default EF, expressed as kg PM AAP^{-1} a^{-1}. This EF and the available methodology represent emissions from housing only, because of a lack of available information on emissions from other sources.

Default Tier 1 emission factors

The default EFs are listed in Table 3.2 and are categorised according to pollutant and then source. Users wishing to see the same EFs categorised according to source and then pollutant are directed to Annex A1.3.1.

Ammonia

The default Tier 1 EFs for NH_3 have been calculated using the Tier 2 default NH_3-N EFs for each stage of manure management (see section 3.4) and default activity data on N excretion, the proportions of TAN in excreta and, if appropriate, the length of the grazing period. If appropriate, separate EFs are provided for slurry- and litter-based manure management systems. The user may choose the EF for the predominant manure management system for that livestock category in the relevant country. These EFs have been calculated on the basis that all manure is stored before surface application without rapid incorporation. For these reasons, countries are encouraged to calculate emissions using at least a Tier 2 approach if possible.

Table 3.2 Default Tier 1 EF (EF_{NH3}) for calculation of NH_3 emissions from manure management. Figures are annually averaged emissions in kg AAP^{-1} a^{-1} NH_3, as defined in subsection 3.3.1

Revised NFR	Livestock	Manure type	Total EF_{NH3} (kg a^{-1} AAP^{-1} NH_3)	EF_{NH3} (kg a^{-1} AAP^{-1} NH_3) for emissions from housing, storage and yards	EF_{NH3} (kg a^{-1} AAP^{-1} NH_3) for emissions following manure application	EF_{NH3} (kg a^{-1} AAP^{-1} NH_3) for emissions from grazed pastures
				Reported under		
				'Manure management'	'Manure applied to soils' (3Da1)	'Excreta deposited by grazing livestock' (3.D.a.3)
3B1a	Dairy cows	Slurry	39.3	19.2	17.2	2.9
3B1a	Dairy cows	Solid	28.7	16.9	8.8	2.9
3B1b	Other cattle (including young cattle, beef cattle and suckling cows)	Slurry	13.4	6.9	5.7	0.8
3B1b	Other cattle	Solid	9.2	6.2	2.2	0.8
3B2	Sheep	Solid	1.4	0.4	0.2	0.8
3B3	'Swine' — Fattening pigs	Slurry	6.7	4.0	2.7	0.0
3B3	'Swine' — Fattening pigs	Solid	6.5	5.4	1.1	0.0
3B3	'Swine' – Sows	Slurry	15.8	9.0	6.0	0.0
3B3	'Swine' – Sows	Solid	18.2	15.0	3.2	0.0
3B3	'Swine' – Sows	Outdoor	7.3	0.0	0.0	7.3
3B4a	Buffalo	Solid	9.0	4.3	0.7	4.0
3B4d	Goats	Solid	1.4	0.4	0.2	0.8
3B4e	Horses	Solid	14.8	7.0	1.7	6.1
3B4f	Mules and asses	Solid	14.8	7.0	1.7	6.1
3B4gi	Laying hens (laying hens and parents)	Solid	0.48	0.32	0.15	0.0
3B4gi	Laying hens (laying hens and parents)	Slurry	0.48	0.32	0.15	0.0
3B4gii	Broilers (broilers and parents)	Litter	0.22	0.15	0.07	0.0
3B4giii	Turkeys	Litter	0.95	0.56	0.39	0.0
3B4giv	Other poultry (ducks)	Litter	0.68	0.45	0.23	0.0
3B4giv	Other poultry (geese)	Litter	0.35	0.30	0.05	0.0
3B4h	Other livestock (fur animals)		0.02	0.02	0.00	0.0
3B4h	Other livestock (camels)	Solid	10.5			

Source: IPCC, 2006; default grazing periods for cattle were taken from Table 10A 4–8, Chapter 10, 'Emissions from livestock and manure management', and default N excretion data for western Europe were taken from Table 10.19, Chapter 10 (these data are also given in Table 3.9, together with the housing period on which these EFs are based).

'Sheep' are defined here as 'mature ewes with lambs until weaning'. To calculate emissions for lambs from weaning until slaughter, or other sheep, the EFs quoted in Table 3.2 can be adjusted according to the ratio of annual N excretion by other sheep to that of the mature ewes. Note that estimates of the number of sheep will vary according to the time of the agricultural census. If taken in summer, the count will be of ewes, rams, other sheep and fattening lambs. If taken in winter, few, if any, fattening lambs will be recorded. Details of how the activity data should be calculated are given in subsection 3.3.3. The default EFs presented in Table 3.2 were calculated using the Tier 2 approach outlined in subsection 3.3.3 using default EFs for each emission derived from those used in the mass-flow models evaluated by the European Agricultural Gaseous Emissions Inventory Researchers Network (EAGER) group (http://www.eager.ch/) (Reidy et al., 2007, and references cited therein).

Nitric oxide

Table 3.3 Default Tier 1 EFs for NO from stored manure. According to Annex I of the NFR Reporting Guidelines, NO emissions have to be reported as NO_2

NFR	Livestock	Manure type	EF_{NO} (kg a^{-1} AAP^{-1} NO_2)
3B1a	Dairy cattle	Slurry	0.011
3B1a	Dairy cattle	Solid	0.236
3B1b	Non-dairy cattle (including young cattle, beef cattle and suckling cows)	Slurry	0.003
3B1b	Non-dairy cattle	Solid	0.144
3B2	Sheep	Solid	0.008
3B3	'Swine' — Fattening pigs	Slurry	0.002
3B3	'Swine' — Fattening pigs	Solid	0.069
3B3	'Swine' – Sows	Slurry	0.006
3B3	'Swine' – Sows	Solid	0. 204
3B3	'Swine' – Sows	Outdoor	0
3B4a	Buffalo	Solid	0.066
3B4d	Goats	Solid	0.008
3B4e	Horses	Solid	0.201
3B4f	Mules and asses	Solid	0.201
3B4gi	Laying hens (laying hens and parents)	Solid	0.005
3B4gi	Laying hens (laying hens and parents)	Slurry	0.0002
3B4gii	Broilers (broilers and parents)	Litter	0.002
3B4giii	Turkeys	Litter	0.008
3B4giv	Other poultry (ducks)	Litter	0.004
3B4giv	Other poultry (geese)	Litter	0.002
3B4h	Other animals	Litter	0.0003

Source: IPCC, 2006; default grazing periods for cattle were taken from Table 10A 4–8, Chapter 10, 'Emissions from livestock and manure management', and default N excretion data for western Europe were taken from Table 10.19, Chapter 10 (these data are also given in Table 3.9, together with the housing period on which these EFs are based).

Non-methane volatile organic compounds

The default Tier 1 NMVOC EFs are based on results from a study (the National Air Emissions Monitoring (NAEM) study) in the USA (US EPA, 2012). This NAEM study included NMVOC measurements from 16 different livestock production facilities covering dairy cattle, sows, fatteners, egg layers and broilers. The average measured emissions were converted to agricultural conditions for western Europe by using Intergovernmental Panel on Climate Change (IPCC) default values for livestock feed intake and excretion of Volatile Substances (VS) (US EPA, 2012; IPCC 2006; Shaw et al., 2007). The EFs for other cattle, sheep, goats, horses, mules and asses, rabbits, reindeer, camels and buffaloes are based on the values for the relative VS excretion rates from the IPCC 2006 guidelines. Please refer to Annex 1, section A1.2.3, for a detailed explanation.

Silage is a major source of emissions; therefore, there is a need to distinguish between feed intake with and without silage. No distinction has been made between liquid and solid manure as the limited data do not allow such a differentiation. The assumed lengths of the housing periods are shown in Table 3.9.

Countries are encouraged to calculate emissions using a Tier 2 approach if possible.

Table 3.4 Default Tier 1 EFs for NMVOCs

Code	Livestock	EF, with silage feeding	EF, without silage feeding
		NMVOC, kg AAP^{-1} a^{-1}	
3B1a	Dairy cattle	17.937	8.047
3B1b	Non-dairy cattle ([a])	8.902	3.602
3B2	Sheep	0.279	0.169
3B3	'Swine' (Fattening pigs ([b]))	–	0.551
3B3	'Swine (Sows)	–	1.704
3B4a	Buffalo	9.247	4.253
3B4d	Goats	0.624	0.542
3B4e	Horses	7.781	4.275
3B4f	Mules and asses	3.018	1.470
3B4gi	Laying hens (laying hens and parents)	–	0.165
3B4gii	Broilers (broilers and parents)	–	0.108
3B4giii	Turkeys[3]	–	0.489
3B4giv	Other poultry (ducks, geese) ([c])	–	0.489
3B4h	Other animals (fur animals)	–	1.941
3B4h	Other animals (rabbits)	–	0.059
3B4h	Other animals (reindeer ([4]))	–	0.045
3B4h	Other animals (camels)	–	0.271

([a]) Includes young cattle, beef cattle and suckling cows.

([b]) Includes piglets from 8 kg to slaughtering.

([c]) Based on data for turkeys.

([d]) Assumes 100 % grazing.

Particulate matter

Emissions of PM occur from both housed and free-range or grazing livestock. However, emission measurements have focused on housed livestock, and a general lack of available information in the scientific literature means that EFs that are specific to free-range or grazing livestock are not available. The processes that give rise to emissions from housed poultry are similar to those for free-range poultry. So, when calculating PM emissions using the Tier 1 default EFs, it is good practice to use the housed livestock EFs for estimating emissions from both housed and free-range poultry. For other livestock types, grazing animals are not considered to be subject to the same processes for PM emissions as those within livestock buildings. So it is good practice to apply the Tier 1 EFs to housed livestock only. Knowledge of a variety of different parameters is important in order to determine emissions of PM, of which the most decisive parameters are feeding conditions, animal activity and bedding material. The PM_{10} and $PM_{2.5}$ EFs are based on the most up-to-date literature. Takai et al. (1998) and Winkel et al. (2015) and the overviews of publications presented therein are the main sources for the EFs. Recently undertaken studies present smaller EFs than those derived from Takai et al. (1998); therefore, around 50 % of the EFs have been updated. This decrease could be explained by changes in livestock management practices. The footnote of Table 3.5 provides a complete list of the studies considered and Annex 1 provides a detailed description.

Table 3.5 Default Tier 1 estimates of EF for particle emissions from livestock husbandry (housing)

Code	Livestock	EF for TSP (kg AAP^{-1} a^{-1})	EF for PM_{10} (kg AAP^{-1} a^{-1})	EF for $PM_{2.5}$ (kg AAP^{-1} a^{-1})
3B1a	Dairy cattle	1.38 (a)	0.63 (a)	0.41 (a)
3B1b	Non-dairy cattle (including young cattle, beef cattle and suckling cows)	0.59 (a)	0.27 (a)	0.18 (a)
3B1b	Non-dairy cattle (calves)	0.34 (a)	0.16 (a)	0.10 (a)
3B2	Sheep	0.14 (b)	0.06 (b)	0.02 (b)
3B3	'Swine' (Fattening pigs)	1.05(c)	0.14 (d)	0.006 (e)
3B3	'Swine' (Weaners)	0.27 (c)	0.05 (f)	0.002 (c)
3B3	'Swine' (Sows)	0.62 (c)	0.17 (f)	0.01 (c)
3B4a	Buffalo	1.45 (a)	0.67 (a)	0.44 (a)
3B4d	Goats	0.14 (b)	0.06 (b)	0.02 (b)
3B4e	Horses	0.48 (g)	0.22 (g)	0.14 (g)
3B4f	Mules and asses	0.34 (a)	0.16 (a)	0.10 (a)
3B4gi	Laying hens (laying hens and parents)	0.19 (c)	0.04 (h)	0.003 (i)
3B4gii	Broilers (broilers and parents)	0.04 (c)	0.02 (j)	0.002 (k)
3B4giii	Turkeys	0.11 (l)	0.11 (m)	0.02 (c)
3B4giv	Other poultry (Ducks)	0.14 (a)	0.14 (a)	0.02 (a)
3B4giv	Other poultry (Geese)	0.24 (a)	0.24 (a)	0.03 (a)
3B4h	Other animals (Fur animals)	0.018 (b)	0.008 (b)	0.004 (b)

Notes: The $PM_{2.5}$ EFs for pigs ('Swine') presented here represent the information available from the scientific literature. However, caution should be used with these EFs as the ratio between PM_{10} and $PM_{2.5}$ is considerably different from that for larger livestock categories, suggesting a particularly high degree of uncertainty with these data.

Sources:

(a) Takai et al. (1998).
(b) Mosquera and Hol (2011); Mosquera et al. (2011).
(c) Winkel et al. (2015).
(d) Chardon and van der Hoek (2002); Schmidt et al. (2002) cited in Winkel et al. (2015); Jacobson et al. (2004); Koziel et al. (2004) cited in Winkel et al. (2015); Haeussermannn et al. (2006, 2008); Costa et al. (2009); Van Ransbeeck et al. (2013; Winkel et al. (2015).
(e) Van Ransbeeck et al. (2013); Winkel et al. (2015).
(f) Haeussermann et al. (2008); Costa et al. (2009); Winkel et al. (2015).
(g) Seedorf and Hartung et al. (2001).
(h) Lim et al. (2003); Demmers et al. (2010); Costa et al. (2012) cited in Winkel et al. (2015); Valli et al. (2012); Hayes et al. (2013); Shepherd et al. (2015); Winkel et al. (2015); Haeussermann et al. (2008); Costa et al. (2009); Winkel et al. (2015).
(i) Lim et al. (2003); Demmers et al. (2010); Hayes et al. (2013); Shepherd et al. (2015); Fabbri et al. (2007); Dunlop et al. (2013); Winkel et al. (2015).
(j) Redwine et al. (2002); Lacey et al. (2003); Roumeliotis and Van Heyst (2007); Calvet et al. (2009); Demmers et al. (2010); Modini et al. (2010); Roumeliotis et al. (2010); Lin et al. (2012) cited in Winkel et al. (2015); Winkel et al. (2015).
(k) Roumeliotis and Van Heyst (2007); Demmers et al. (2010); Modini et al. (2010); Roumeliotis et al. (2010); Lin et al. (2012) cited in Winkel et al. (2015); Winkel et al. (2015).
(l) Assume same ratio for TSP to PM10 as 'Other poultry'.
(m) Schmidt et al. (2002) cited in Winkel et al. (2015); Li et al. (2008) cited in Winkel et al. (2015); Winkel et al. (2015).
(n) Lim et al. (2003); Fabbri et al. (2007); Demmers et al. (2010); Costa et al. (2012) cited in Winkel et al. (2015); Valli et al. (2012); Hayes et al. (2013); Shepherd et al. (2015); Dunlop et al. (2013); Winkel et al. (2015).
TSP, total suspended particles.

Activity data

For Tier 1, data are required on livestock numbers for each of the categories listed in Table 3.1. An annual national agricultural census can supply these data. Otherwise, statistical information from Eurostat (http://ec.europa.eu/eurostat) or the Food and Agriculture Organization of the United Nations (FAO) Statistical Yearbooks (e.g. FAO, 2014) can be used.

As mentioned above, the AAP is the average number of animals of a particular category that are present, on average, within the year. This number can be obtained by a number of methods. If the number of animals present on a particular day does not change over the year, a census of the animals present on a particular day will give the AAP. However, if the number of animals present varies over the year, e.g. because of seasonal production cycles, it may be more accurate to base the AAP on a census of the number of animal places. If this is done, allowance has to be made for the time that the animal place is empty. There can be a number of reasons why the animal place may be empty for part of the year, but the most common are that the production is seasonal or because the building is being cleaned in preparation for the next batch of animals.

Table 3.6 Definitions of the terms used in the explanation of how to calculate annual emissions

Terms	Units	Definition
Annual average population (AAP)	–	Number of animals of a particular category that are present, on average, within the year
Animal places (nplaces)	–	Average capacity for a livestock category in the animal housing that is usually occupied
Milk yield	L a–1	The mean amount (L) of milk produced by the dairy animal during the year for which annual emissions are to be calculated
Empty period (tempty)	d	The average duration during the year when the animal place is empty (in d)
Cleaning period (tcleanse)	d	The time between production cycle or rounds when the animal place is empty, e.g. for cleaning (in d)
Production cycle (nround)	–	The average number of production cycles per year
Number of animals produced (nprod)	a–1	The number of animals produced during the year
Proportion dying (xns)	–	Proportion of animals that die and are not sold

If the AAP is estimated from the number of places (n_{places}), the calculation is:

$$AAP = n_{places} \times (1 - t_{empty}/365) \qquad (2)$$

If the duration of an animal life or the time that animals remain within a category is less than 1 year, it will be common to have more than one production cycle per year. In this situation, t_{empty} will be the product of the number of production cycles or rounds (n_{round}) per year and the duration per round of the period during which the animal place is empty ($t_{cleanse}$):

$$t_{empty} = n_{round} \times t_{cleanse} \qquad (3)$$

A third method of estimating AAP is to use statistics recording the number of animals produced per year:

$$AAP = n_{prod}/(n_{round} \times (1 - x_{ns})) \qquad (4)$$

where x_{ns} is the proportion of animals that die and are not sold.

3.4 Tier 2 technology-specific approach

Algorithm for ammonia and nitric oxide

Tier 2 uses a mass-flow approach based on the concept of a flow of TAN through the manure management system, as shown in the schematic diagram in Figure 2.2. It should be noted that the calculations of a mass-flow approach must be carried out on the basis of kg of N. The resultant estimates of NH_3-N emissions are then converted to NH_3. If calculating emissions of NH_3 using a mass-flow approach, a system based on TAN is preferred to one based on total N, as is used by IPCC to estimate emissions of N_2O. This is because emissions of NH_3 and other forms of gaseous N arise from TAN. Accounting for the TAN in manure as it passes through the manure management system therefore allows for more accurate estimates of gaseous N emissions. It also allows for the methodology to reflect the consequences of changes in livestock diets on gaseous N emissions, since the excretion of total N and TAN respond differently to such changes. Such estimates of the percentage of TAN in manures may be used to verify the accuracy of the mass-flow calculations (e.g. Webb and Misselbrook, 2004).

Despite the apparent complexity of this approach, the methodology is not inherently difficult to use; it does, however, necessarily require much more input data than the Tier 1 methodology. Different systems are represented at each stage to account for real differences in management systems and resulting emissions. In particular, distinctions are made between slurry and solid systems at each stage.

The adoption of a consistent N-flow model, based on proportional transfers of TAN, allows different options or pathways to be incorporated, in order to account for differences among real-world systems. This approach has several advantages over the Tier 1 methodology, as outlined below.

- The method ensures that there is consistency between the N species reported using this guidebook (e.g. under the LRTAP Convention) and those reported using the IPCC Guidelines.
- A mass balance can be used to check for errors (the N excreted plus the N added in bedding minus the N emitted, and the N entering the soil should be zero).
- The impacts of making changes at one stage of manure management (upstream) on emissions at later stages of manure management (downstream) can be taken into account, e.g. differences in emissions during housing will, by leading to different amounts of TAN entering storage and field application, give rise to differences in the potential size of NH_3 emissions during storage or after field application.

The greatest potential benefit arises when the mass-flow approach is further developed to a Tier 3 methodology that can make proper allowances for the introduction of abatement techniques.

- Possible abatement measures can be also included as alternative systems. This approach ensures that the changes in the N-flow through the different sources that occur as a result of the use of abatement measures are correct. This makes it easier to document the effect of abatement (reduction) measures that have already been introduced or are considered for the future. Hence, this Tier 2 approach may be considered a step towards developing a Tier 3 methodology (see section 3.5 below).

Default values are provided for N excretion, the proportion of TAN and the emissions at each stage of manure management (Table 3.9). It is good practice for every country to use country-specific activity data. Table A1.8 explains how the default NH_3-N EF was derived, which may be helpful for calculating country-specific EFs for Tier 3. Country-specific EFs may give rise to more accurate estimates of emissions because they encompass a unique combination of activities within that country or because they have different estimates of emissions from a particular activity within the country, or both. The amount of N flowing through the different pathways may be determined by country-specific information on livestock husbandry and manure management systems, while the proportion volatilised as NH_3-N at each stage in the system is treated as a percentage, based primarily on measured values and, if necessary, expert judgement.

Tier 2 methodologies estimate the mineralisation of N and the immobilisation of TAN during manure management, and also estimate other losses of N, e.g. as NO, in order to more accurately estimate the TAN available at each stage of manure management.

In the stepwise procedure outlined below, manure is assumed to be managed as either slurry or solid. Slurry consists of excreta, spilt livestock feed and drinking water, some bedding material and water added during cleaning or to assist in handling. It is equivalent to the liquid/slurry category described in IPCC (2006). For more information, see Table 3.13 (section 3.4.5), which relates storage categories commonly referred to in NH_3 inventories to the classification used by the IPCC. Solid manure consists of excreta, spilt livestock feed and drinking water, and may also include bedding material. It is equivalent to the solid manure category described in IPCC, 2006. For situations in which manure is separated into liquid and solid fractions, the liquid should be treated as slurry.

The objective of **Step 1** is to define the livestock subcategories that are homogeneous with respect to feeding, excretion and age/weight range. Typical livestock categories are shown in Table 3.1. The corresponding number of animals has to be obtained, as described in subsection 3.4.1. Steps 2 to 14 inclusive should then be applied to each of these subcategories and the emissions summed.

In **Step 2**, the total annual excretion of N by the animals (N_{ex}; kg AAP^{-1} a^{-1}) is calculated. Many countries have detailed procedures to derive N excretion rates for different livestock categories. If these are not available, the method described in Chapter 10 of IPCC, 2006 (equations 10.31, 10.32 and 10.33) should be used as guidance, where N_{ex} is equivalent to $Nex_{(T)}$. For convenience, default values are given in Table 3.9; these are derived from the estimates of N excretion used to calculate national NH_3 emissions by the European Agricultural Gaseous Emissions Inventory Researchers (EAGER) network.

The purpose of **Step 3** is to calculate the amount of the annual N excreted that is deposited within buildings in which livestock are housed, on uncovered yards and during grazing. This is based on the total annual N excretion (N_{ex}) and the proportions of excreta deposited at these locations (x_{build}, x_{yards} and x_{graz}, respectively). These proportions depend on the fraction of the year that animals spend in buildings, on yards and grazing, and on animal behaviour. Unless better information is available, x_{build}, x_{yards} and x_{graz} should equate to the proportion of the year spent at the relevant location, and must always add up to 1.0.

$$m_{graz\_N} = x_{graz} \times N_{ex} \quad (5)$$

$$m_{yard\_N} = x_{yards} \times N_{ex} \quad (6)$$

$$m_{build\_N} = x_{build} \times N_{ex} \quad (7)$$

In **Step 4** the proportion of the N excreted as TAN (x_{TAN}) is used to calculate the amount of TAN deposited during grazing, on yards or in buildings (m_{graz_TAN}, m_{yard_TAN} and m_{build_TAN}).

$$m_{graz\_TAN} = x_{TAN} \times m_{graz\_N} \quad (8)$$

$$m_{yard\_TAN} = x_{TAN} \times m_{yard\_N} \quad (9)$$

$$m_{build\_TAN} = x_{TAN} \times m_{build\_N} \quad (10)$$

If detailed national procedures for deriving N excretion rates that provide the proportion of N excreted as TAN are available, these should be used. If these are not available, the default values shown in Table 3.9 should be used.

The objective of **Step 5** is to calculate the amounts of TAN and total N deposited in buildings handled as liquid slurry ($m_{build\_slurry\_TAN}$) or as solid ($m_{build\_solid\_TAN}$).

$$m_{build\_slurry\_TAN} = x_{slurry} \times m_{build\_TAN} \quad (11)$$

$$m_{build\_slurry\_N} = x_{slurry} \times m_{build\_N} \quad (12)$$

$$m_{build\_solid\_TAN} = (1 - x_{slurry}) \times m_{build\_TAN} \quad (13)$$

$m_{build\_solid\_N} = (1 - x_{slurry}) \times m_{build\_N}$ (14)

where x_{slurry} is the proportion of livestock manure handled as slurry (the remainder is the proportion of livestock manure handled as solid).

In **Step 6**, the NH_3-N losses and E_{build}, from the livestock building and from the yards, is calculated by multiplying the amount of TAN (m_{build_TAN}) by the EF EF_{build} (NH_3-N), for both slurry and FYM:

$E_{build\_slurry} = m_{build\_slurry\_TAN} \times EF_{build\_slurry}$ (15)

$E_{build\_solid} = m_{build\_FYM\_TAN} \times EF_{build\_solid}$ (16)

And by multiplying the amount of TAN ($m_{yard,TAN}$) by the EF EF_{yard}:

$E_{yard} = m_{yard,TAN} \times EF_{yard}$ (17)

This will give emissions as kg NH_3-N.

Step 7 applies to only solid manure. Its function is to allow for the addition of N in animal bedding ($m_{bedding}$) in these litter-based housing systems and to account for the consequent immobilisation of TAN in that bedding. The amounts of total-N and TAN in solid manure that are removed from buildings and yards ($m_{ex\text{-}build\_solid\_N}$ and $m_{ex\text{-}build\_solid\_TAN}$), and either passed to storage or spread directly to the fields, are then calculated, remembering to subtract the NH_3-N emissions from the livestock buildings.

A Microsoft Excel spreadsheet with automatic calculation and error-checking functions will be available as a separate file at the same location as the online version of this guidebook. (currently on development)

If detailed information is lacking, the amounts of straw used and the N inputs ($m_{bedding}$) can be obtained from the example calculation spreadsheet available from the same location as the online version of this guidebook (see Table 3.7).

Table 3.7 Default values for length of housing period, annual straw use in litter-based manure management systems and the N content of straw

Livestock category	Housing period, day	Straw, kg AAP^{-1} a^{-1}	([a]) N added in straw, kg AAP^{-1} a^{-1}
Dairy cattle (3B1a)	180	1,500	6.00
Non-dairy cattle (3B1b)	180	500	2.00
Finishing pigs (3B3)	365	200	0.80
Sows (3B3)	365	600	2.40
Sheep and goats (3B2 and 3B4d)	30	20	0.08
Horses, etc. (3B4e and 3B4f)	180	500	2.00
Buffalos (3B4a)	225	1,500	6.00

([a]) Based on a straw N content of 4 g kg^{-1}.

The amounts of straw given are for the stated housing period. For longer or shorter housing periods, the straw used may be adjusted in proportion to the length of the housing period.

Account must also be taken of the fraction of TAN that is immobilised in organic matter (f_{imm}) when manure is managed as a litter-based solid, as this immobilisation will greatly reduce the potential NH_3-N emission during storage and after spreading (including from manures spread directly from buildings).

$m_{ex\text{-}build\_solid\_TAN} = (m_{build\_solid\_TAN} - E_{build\_solid}) \times (1 - f_{imm})$ (18)

$m_{ex\text{-}build\_solid\_N} = (m_{build\_solid\_N} + m_{bedding\_N} + f_{imm}) - E_{build\_solid}$ (19)

If data for f_{imm} are not available, it is recommended that a f_{imm} value of 0.0067 kg N kg^{-1} straw is used (Webb and Misselbrook, 2004, based on data reported by Kirchmann and Witter, 1989).

The objective of **Step 8** is to calculate the amounts of total-N and TAN stored before application to land. Not all manures are stored before spreading; some will be applied to fields directly from buildings. Some manures (mainly slurries) will be used as feedstocks for AD in biogas facilities (x_{feed_slurry} and x_{feed_FYM}). Emissions from biogas facilities are calculated and reported in Chapter 5B2. Hence, any manures used as biogas feedstocks need to be subtracted before calculating emissions from storage and spreading. Therefore, the proportions of slurry and FYM stored on farms (x_{store_slurry} and x_{store_FYM}), together with x_{feed_slurry} and x_{feed_FYM}, must be known.

For slurry:

$$m_{storage\_slurry\_TAN} = [(m_{build\_slurry\_TAN} - E_{build\_slurry}) + (m_{yard\_TAN} - E_{yard})] \times x_{store\_slurry} \quad (20)$$

$$m_{storage\_slurry\_N} = [(m_{build\_slurry\_N} - E_{build\_slurry}) + (m_{yard\_N} - E_{yard})] \times x_{store\_slurry} \quad (21)$$

$$m_{spread\_direct\_slurry\_TAN} = [(m_{build\_slurry\_TAN} - E_{build\_slurry}) + (m_{yard\_TAN} - E_{yard})] \times (1 - (x_{store\_slurry} + x_{feed\_slurry})) \quad (22)$$

$$m_{spread\_direct\_slurry\_N} = [(m_{build\_slurry\_N} - E_{build\_slurry}) + (m_{yard\_N} - E_{yard})] \times (1 - (x_{store\_slurry} + x_{feed\_slurry})) \quad (23)$$

To ensure that all of the slurry is accounted for, and that there is no duplication, the sum of the proportions of x_{store} and x_{feed} and the proportion for direct spreading must amount to 1.0.

For solid:

$$m_{storage\_solid\_TAN} = m_{ex\text{-}build\_solid\_TAN} \times x_{store\_FYM} \quad (24)$$

$$m_{storage\_solid\_N} = m_{ex\text{-}build\_solid\_N} \times x_{store\_FYM} \quad (25)$$

$$m_{spread\_direct\_solid\_TAN} = m_{ex\text{-}build\_solid\_TAN} \times (1 - (x_{store\_solid} + x_{feed\_FYM})) \quad (26)$$

$$m_{spread\_direct\_solid\_N} = m_{ex\text{-}build\_solid\_N} \times (1 - (x_{store\_solid} + x_{feed\_FYM})) \quad (27)$$

As for slurry, and if there is no duplication, the sum of the proportions x_{store} and x_{feed} and the proportion for direct spreading must amount to 1.0.

The equations provided for Step 8 assume that the N and TAN remaining on yards after NH_3 emission are collected and either put into the slurry store, spread directly on to land or used as AD feedstock (Equations 20–23). In some countries where the weather is typically warm and dry, the excreta deposited on yards may dry before the yards are cleaned and the scrapings are applied to a solid manure store. In such cases, Equations 20–27 should be adjusted to place the N and TAN remaining on yards after NH_3 emission into the solid store.

Step 9 applies to only slurries and its function is to calculate the amount of TAN from which emissions will occur from slurry stores. For slurries, a fraction of the organic N is mineralised (f_{min}) to TAN before the gaseous emissions are calculated.

The modified mass $mm_{storage,slurry,TAN}$, from which emissions are calculated, is calculated as in Equation 28:

$$mm_{storage\_slurry\_TAN} = m_{storage\_slurry\_TAN} + ((m_{storage\_slurry\_N} - m_{storage\_slurry\_TAN}) \times f_{min}) \quad (28)$$

If data for f_{min} are not available, it is recommended that an f_{min} value of 0.1 is used (Dämmgen et al., 2007).

In **Step 10**, the emissions of NH_3, N_2O, NO and N_2 are calculated (using the corresponding EFs $EF_{storage}$ and $mm_{storage\_TAN}$).

For slurry:

$$E_{storage\_slurry} = E_{storage\_slurry\_NH3} + E_{storage\_slurry\_N2O} + E_{storage\_slurry\_NO} + E_{storage\_slurry\_N2}$$

$$= mm_{storage\_slurry\_TAN} \times (EF_{storage\_slurry\_NH3} + EF_{storage\_slurry\_N2O} + EF_{storage\_slurry\_NO} + EF_{storage\_slurry\_N2}) \quad (29)$$

For solid manure emissions, not only gaseous emissions should be included, as for slurry, but soluble N lost from the store in effluent should also be included:

$$E_{storage\_solid} = E_{storage\_solid\_NH3} + E_{storage\_solid\_N2O} + E_{storage\_solid\_NO} + E_{storage\_solid\_N2} + E_{storage\_solid\_effluent\_N}$$
$$= m_{storage\_solid\_TAN} \times (EF_{storage\_solid\_NH3} + EF_{storage\_solid\_N2O} + EF_{storage\_solid\_NO} + EF_{storage\_solid\_N2} + EF_{storage\_effluent\_N}) \quad (30)$$

For both slurry and litter-based manures, default values for the EFs are given in Table 3.8 (N_2O), Table 3.9 (NH_3) and Table 3.10 (NO and N_2). Equations 28 and 29 provide the Tier 2 EF for NO.

Table 3.8 Default Tier 2 EFs for direct N_2O emissions from manure management. Table 3.13 explains how the manure storage types referred to here relate to those used by the IPCC

Storage system	EF kg N2O-N (kg TAN entering store)–1
Cattle slurry without natural crust	0
Cattle slurry with natural crust	0.01
Pig slurry without natural crust	0
Cattle manure heaps, solid	0.02
Pig manure heaps, solid	0.01
Sheep and goat manure heaps, solid	0.02
Horse (mules and asses) manure heaps, solid	0.02
Layer manure heaps, solid	0.002
Broiler manure heaps, solid	0.002
Turkey and duck manure heaps, solid	0.002
Goose manure heaps, solid	0.002
Buffalo manure heaps, solid	0.02

The derivation of these EFs as a proportion of TAN is given in Annex 1, Table A1.8.

In **Step 11**, the total-N and TAN (m_{applic_N} and m_{applic_TAN}) that is applied to the field is calculated, remembering to subtract the emissions of NH_3, N_2O, NO and N_2 from storage.

For slurry:

$$m_{applic\_slurry\_TAN} = m_{spread\_direct\_slurry\_TAN} + mm_{storage\_slurry\_TAN} - E_{storage\_slurry} \quad (31)$$

$$m_{applic\_slurry\_N} = m_{spread\_direct\_slurry\_N} + mm_{storage\_slurry\_N} - E_{storage\_slurry} \quad (32)$$

For solid:

$$m_{applic\_solid\_TAN} = m_{spread\_direct\_solid\_TAN} + mm_{storage\_solid\_TAN} - E_{storage\_solid} \quad (33)$$

$$m_{applic\_solid\_N} = m_{spread\_direct\_solid\_N} + mm_{storage\_solid\_N} - E_{storage\_slurry\_solid} \quad (34)$$

In **Step 12**, the emission of NH_3-N during and immediately after field application is calculated using an EF EF_{applic} (Table 3.9) combined with m_{applic_TAN}.

For slurry:

$$E_{applic\_slurry} = m_{applic\_slurry\_TAN} \times EF_{applic\_slurry} \quad (35)$$

For solid:

$$E_{applic\_solid} = m_{applic\_solid\_TAN} \times EF_{applic\_solid} \quad (36)$$

In **Step 13**, the net amount of N returned to soil from manure ($m_{returned\_N}$ and $m_{returned\_TAN}$) after losses of NH_3-N is calculated (to be used in calculations of NO emissions in Chapter 3.D, Crop production and agricultural soils').

For slurry:

$$m_{returned\_slurry\_TAN} = m_{applic\_slurry\_TAN} - E_{applic\_slurry} \quad (37)$$

$$m_{returned\_slurry\_N} = m_{applic\_slurry\_N} - E_{applic\_slurry} \quad (38)$$

For solid:

$$m_{returned\_solid\_TAN} = m_{applic\_solid\_TAN} - E_{applic\_solid} \quad (39)$$

$$m_{returned\_solid\_N} = m_{applic\_solid\_N} - E_{applic\_solid} \quad (40)$$

Note that the gross amount of N returned to soil during grazing (m_{graz_N}), before the loss of NH_3-N (to be used in the calculation of subsequent emissions of NO in Chapter 3.D, 'Crop production and agricultural soils'), was calculated in Step 3.

In **Step 14**, the NH_3-N emissions from grazing are calculated:

$$E_{graz} = m_{graz\_TAN} \times EF_{grazing} \quad (41)$$

No distinction is made between emissions from cattle and sheep excreta. In the example spreadsheet, fixed EFs, as a percentage of TAN deposited during grazing, are used.

In **Step 15**, all the emissions from the manure management system that are to be reported under Chapter 3B are summed and converted to the mass of the relevant compound:

$$E_{MMS\_NH3} = (E_{yard} + E_{build\_slurry} + E_{build\_solid} + E_{storage\_NH3\_slurry} + E_{storage\_NH3\_solid}) \times 17/14 \quad (42)$$

According to Annex I of the NFR Reporting Guidelines, NO emissions have to be reported as NO_2.

$$E_{MMS\_NO2} = (E_{storage\_NO\_slurry} + E_{storage\_NO\_solid}) \times 46/14 \quad (43)$$

where E_{MMS_NH3} and E_{MMS_NO2} are the emissions from the manure management system of NH_3 and NO_2, respectively (in kg).

As a quality control, a N balance should be calculated, i.e. the total input of N (total amount of N in animal excretion plus the total amount in bedding) should match the output of N (total of all emissions, N inputs to the soil and N in manures used as AD feedstocks). However, in order to check the mass balance calculations, the net return of N during grazing needs to be calculated as well, using the equivalent equation to that used to calculate net returns after manure application.

Algorithm for non-methane volatile organic compounds

NMVOC emissions arise from six different sources:

1. silage stores
2. the feeding table if silage is used for feeding
3. livestock housing
4. outdoor manure stores
5. manure application

6. grazing animals.

The emissions from housing include emissions from feeds other than silage. As feeding with silage can be a large source of NMVOCs, especially with regard to dairy cows, two different methodologies are given: one for 'dairy cows plus other cattle' and another for the 'remaining' livestock categories. The methodology for dairy cattle and other cattle is based on feed intake. The methodology for other livestock categories is based on excreted volatile substances.

At present, few studies are described in the scientific literature that provide NMVOC emission estimates for housed livestock, manure storage and manure application together. Hence, EFs are not available to directly, and independently, estimate emissions of NMVOCs resulting from manure storage and manure application. However, a correlation between NH_3 emissions and many of the different NMVOCs emitted from livestock buildings has been found ($r^2 \approx 0.5$) (Feilberg et al., 2010). Therefore, NMVOC emissions from manure stores and manure application are estimated as a fraction of those from livestock housing. This fraction is assumed to be the same ratio as for NH_3 emissions. This methodology could be biased, especially for manure application, because the NMVOCs are formed in the manure during storage and released after manure application. This is a different process from that of NH_3 because there is relatively little mineralisation of organic N to NH_4^+ during manure storage. Bias may also arise as NMVOCs calculated using this approach will not account for NMVOCs emitted at biogas plants during the storage of feedstocks and digestates.

Dairy cattle and other cattle:

$E_{NMVOC\_i} = AAP_{animal\_i} \times (E_{NMVOC,silage\_store\_i} + E_{NMVOC,silage\_feeding\_i} + E_{NMVOC,building\_i} + E_{NMVOC,store\_i} + E_{NMVOC,appl.\_i} + E_{NMVOC,graz\_i})$(44)

where i is the *i*th livestock category and:

$E_{NMVOC,silage\_store\_i} = MJ_{\_i} \times x_{house\_i} \times (EF_{NMVOC,silage\_feeding\_i} \times Frac_{silage}) \times Frac_{silage\_store\_i}$ (45)

$E_{NMVOC,silage\_feeding\_i} = MJ_{\_i} \times x_{building\_i} \times (EF_{NMVOC,silage\_feeding\_i} \times Frac_{silage})$ (46)

$E_{NMVOC,house\_i} = MJ_{\_i} \times x_{building\_i} \times (EF_{NMVOC,house\_i})$ (47)

$E_{NMVOC,manure\_store\_i} = E_{NMVOC,building\_i} \times (E_{NH3,storage\_i\_}/E_{NH3,building\_i})$ (48)

$E_{NMVOC,appl.\_i} = E_{NMVOC, building\_i} \times (E_{NH3appl.\_i}/E_{NH3building\_i})$ (49)

$E_{NMVOC,graz\_i} = MJ_{\_i} \times (1 - x_{building\_i}) \times EF_{NMVOC,graz\_i}$ (50)

where $MJ_{\_i}$ is the gross feed intake in megajoules (MJ) per year.

Values of feed intake in MJ should, if possible, be country specific (refer to the format for annual reporting of greenhouse gases to the UNFCCC, Table 4.A). If the data from the UNFCCC are used they should be multiplied by 365 to obtain intake in MJ per year. If no country-specific data on feed intake in MJ are available, the default data given in the IPPC 2006 Guidelines should be used. The conversion between dry matter intake and MJ can be made by multiplying the amount of dry matter by 18.45 (IPCC, 2006, equation 10.24). The EFs are listed in Table 3.11.

The value for x_{house} is the proportion of time the animals spend in the livestock building in a year. If no national data are available, refer to Table 3.9 for default values for the length of the housing period in days from which the proportions of time spent within buildings can be derived.

The $Frac_{silage_}$is the fraction of feed in dry matter during housing that is silage, out of the maximum proportion of silage possible in the feed composition. In practice, the maximum proportion of silage in dry matter is approximately 50 % of the total dry matter intake. If silage feeding is dominant, $Frac_{silage}$ should be 1.0.

The $Frac_{silage\_store}$ is the proportion of the emissions from the silage store compared with the emissions from the feeding table in the building. In practice, there is a relationship between the size of the silage store and the number of animals. In equation 51, it is assumed that these emissions are a fraction of the emissions from the feeding table, which again depends on its size and its emissions. A tentative default value of 0.25 is proposed for European conditions. This value of 0.25 is an average based on Alanis et al. (2008), Chung et al. (2010) and a temperature correction to account for typical European climatic conditions (Alanis et al., 2010).

$E_{NH3,storage\_i}$, $E_{NH3,building\_i}$ and $E_{NH3appl.\_i}$: NH_3 emissions.

All livestock categories other than cattle:

$E_{NMVOC,silage\_store\_i} = VS_{\_i} \times x_{building\_i} \times (EF_{NMVOC,\ silage\ feed\_i} \times Frac_{silage}) \times Frac_{silage\_store}$ (51)

$E_{NMVOC,silage\_feeding\_i} = VS_{\_i} \times x_{building\_i} \times (EF_{NMVOC,silage\_feeding\_i} \times Frac_{silage})$ (52)

$E_{NMVOC,house\_i} = VS_{\_i} \times x_{building\_i} \times (EF_{NMVOC,\ building\_i})$ (53)

$E_{NMVOC,manure\_store\_i} = E_{NMVOC,\ building\_i} \times (E_{NH3,storage\_i\_}/E_{NH3,\ building\_i})$ (54)

$E_{NMVOC,appl.\_i} = E_{NMVOC,\ building\_i} \times (E_{NH3appl.\_i}/E_{NH3building\_i})$ (55)

$E_{NMVOC,graz\_i} = kg\ VS_{\_i} \times (1 - x_{building\_i}) \times EF_{NMVOC,graz\_i}$ (56)

where kg $VS_{\_i}$ is the excreted VS in kg per year for livestock category i, in kg per year.

The proportion of silage in the feed will vary by animal species, among countries and between years. It is therefore good practice to provide an estimate for the proportion of silage used of the maximum feasible amount of silage in the feed.

Values for excreted VS in kg should preferably be country specific and refer to the annual reporting of greenhouse gases under the UNFCCC in Table 3.B(a)s1. If the data from the UNFCCC are used, they must be multiplied by 365 to obtain a value for VS excretion per year, since VS emissions are reported under UNFCCC as daily VS excretion values. If no country-specific data on VS excretion are available, it is recommended that the default data given in the IPPC 2006 Guidelines are used. The EFs are listed in Table 3.11.

Algorithm for particulate matter

A number of recent studies have demonstrated that there is still considerable variability in EFs among measurement programmes. In particular, studies carried out between 2006 and 2016, suggest that results from Takai (1998), which were used to give Tier 2 EFs in the *EMEP/EEA air pollutant emissions inventory guidebook 2013* (EMEP/EEA, 2013), are large by comparison with other results and may not represent typical current levels of PM emissions.

Countries are encouraged to develop country-specific EFs, taking into account information on the parameters presented in section 2.2.4. Information from the literature suggests that, for example, housing systems used to reduce NH_3 emissions may substantially increase emissions of PM. The reduction in PM emissions as a result of using air scrubbing in livestock buildings can be taken into account by reducing the EF by the proportion by which PM emissions are reduced by the scrubbers. For the reasons given in section 2.1.4, PM emissions should not be affected by diverting a proportion of the manures for AD.

Annex 1, section A1.3.1, presents the EFs used to estimate Tier 1 EFs for all animals but pigs and poultry differentiated by type of manure management system (solid or liquid). However, a review of the scientific literature as a whole does not support the inclusion of a Tier 2 methodology.

Tier 2 emission factors

Ammonia

Table 3 shows the default NH_3-N EFs and the proportions of TAN in the manure excreted.

Table 3.9 Default Tier 2 NH_3-N EFs and associated parameters for the Tier 2 methodology for the calculation of the NH_3-N emissions from manure management

Code	Livestock	Housing period, d a^{-1}	N_{ex} ([a])	Proportion of TAN	Manure type	$EF_{housing}$	EF_{yard}	$EF_{storage}$	$EF_{spreading}$	$EF_{grazing/outdoor}$
3B1a	Dairy cattle	180	105	0.6	Slurry	0.20	0.30 ([b])	0.20	0.55	0.10
					Solid	0.19	0.30 ([b])	0.27	0.79	0.10
3B1a	Dairy cattle, tied housing	180	105	0.6	Slurry	0.066	0.30 ([b])	0.20	0.55	0.10
					Solid	0.066	0.30 ([b])	0.27	0.79	0.10
3B1b	Non-dairy cattle (young cattle, beef cattle and suckling cows)	180	41	0.6	Slurry	0.20	0.53 ([b])	0.20	0.55	0.06
					Solid	0.19	0.53 ([b])	0.27	0.79	0.06
3B2	Sheep	30	15.5	0.5	Solid	0.22	0.75 ([b])	0.28	0.90	0.09
3B33	'Swine' (fattening pigs, 8–110 kg)	365	12.1	0.7	Slurry	0.28	0.53 ([b])	0.14	0.40	
					Solid	0.27	0.53 ([b])	0.45	0.81	
3B3	'Swine' (sows and piglets to 8 kg)	365	34.5	0.7	Slurry	0.22	NA	0.14	0.29	
					Solid	0.25	NA	0.45	0.81	
		0			Outdoor	NA	NA	NA	NA	0.25 ([c])
3B4a	Buffalo[c]	140	82.0 ([d])	0.5	Solid	0.20	NA	0.17	0.55	0.13
3B4d	Goats)	30	15.5	0.5	Solid	0.22	0.75 ([b])	0.28	0.90	0.09
3B4e+ 3B4f	Horses (and mules, asses)	180	47.5	0.6	Solid	0.22	NA	0.35	0.90 ([d])	0.35
3B4gi	Laying hens (laying hens and parents)	365	0.77	0.7	Solid, can be stacked	0.41	NA	0.14	0.69	
3B4gi	Laying hens (laying hens and parents)	365	0.77	0.7	Slurry, can be pumped	0.41	NA	0.14	0.69	
3B4gii	Broilers (broilers and parents)	365	0.36	0.7	Solid	0.28	NA	0.17	0.66	
3B4giii	Turkeys	365	1.64	0.7	Solid	0.35	NA	0.24	0.54	
3B4giv	Other poultry (ducks)	365	1.26	0.7	Solid	0.24	NA	0.24	0.54	
3B4giv	Other poultry (geese)	365	0.55 ([b])	0.7	Solid	0.57	NA	0.16	0.45	
3B4h	Other animals (fur animals)	365	4.60 ([c])	0.6	Solid	0.27	NA	0.09	NA	

Notes: EFs are given as a proportion of TAN.

Sources: Default EFs are from the European Agricultural Gaseous Emissions Inventory Researchers (EAGER) network (http://www.eager.ch/)

(a) Default N excretion data were taken from Table 10.19, Chapter 10, of IPCC, 2006.

(b) Taken from Table 10–19 of IPCC (2006).

(c) Taken from NARSES.

(d) From Rösemann et al. (2015).

The values for the proportion of TAN were the average from EAGER comparisons (Reidy et al., 2007, and expert judgement). The national EFs from which the values were derived are given in Annex 1, Table A1.8.

Table 3.10. Default values for other losses needed in the mass-flow calculation (from Misselbrook et al., 2015)

	Proportion of TAN
EFstorage_slurryNO	0.0001
EFstorage_slurryN2	0.0030
EFstorage_solidNO	0.0100
EFstorage_solidN2	0.3000

Non-methane volatile organic compounds

NMVOC Tier 2 EFs are based on measurements from the NAEM study (US EPA, 2012). These findings have been adjusted to reflect agricultural conditions in western Europe (See Annex 1, sections A1.2.1 and A1.2.2, for details). It is good practice for all countries to use country-specific activity data if available.

The results from the NAEM study allow the estimation of NMVOC emissions during only housing. The calculation of emissions from the other sources, i.e. silage storage, silage feeding, storage of manure and application of manure, is based on fractions of emission from housing (Alanis et al., 2008, 2010; Chung et al., 2010). The emissions from grazing animals are based on measurements made by Shaw et al. (2007).

The emissions during housing are estimated as an average of NMVOC emissions and non-methane hydrocarbon (NMHC) emissions. The NMHC measurements are converted to NMVOC emissions. For broilers and fatteners, the emission estimates are converted to 'per 500 kg animal' values, as the measurements cover a wide range of animal weights. These average data were then converted to western European production levels based on the IPCC 2006 guidelines (IPCC, 2006) and other default values in this guidebook.

The NAEM study included emissions from feeding tables, enteric fermentation and manure stored inside buildings. These measurements have been split into emissions from feeding with silage and feeding without silage based on data from Alanis et al. (2008) and Chung et al. (2010).

The NAEM study covered a wide range of climatic conditions. The measured data are highly variable and it has not been feasible to include temperature correction functions for the different climatic conditions found in the EMEP area. The proposed EFs are therefore averages without corrections for climatic conditions, except for emissions from silage stores for which a temperature correction factor from 20 °C to 10 °C has been made (Alanis et al., 2010).

Table 3.11 Default NMVOC Tier 2 EFs for dairy cattle and other cattle ([a])

		$EF_{NMVOC,silage\_feeding}$	$EF_{NMVOC,building}$	$EF_{NMVOC,graz}$
Code	**Livestock**	**kg NMVOC kg/MJ feed intake**		
3B1a	Dairy cattle	0.0002002	0.0000353	0.0000069
3B1b	Non-dairy cattle ([b])	0.0002002	0.0000353	0.0000069

(a) Data from the NAEM study (US EPA, 2012) converted to European conditions.
(b) Includes young cattle, beef cattle and suckling cows.

Table 3.12 Default NMVOC Tier 2 EFs for livestock categories other than cattle ([a])

Code	Livestock	$EF_{NMVOC,silage\ feed.}$	$EF_{NMVOC,building}$	$EF_{NMVOC,graz}$
		kg NMVOC/kg VS excreted		
3B2	Sheep	0.010760	0.001614	0.00002349
3B3	'Swine' (fattening pigs ([b]))		0.001703	
3B3	'Swine' (sows)		0.007042	
3B4a	Buffalo ([c])	0.010760	0.001614	0.00002349
3B4d	Goats ([c])	0.010760	0.001614	0.00002349
3B4e	Horses ([c])	0.010760	0.001614	0.00002349
3B4f	Mules and Asses ([c])	0.010760	0.001614	0.00002349
3B4gi	Laying hens (laying hens and parents)		0.005684	
3B4gii	Broilers (broilers and parents)		0.009147	
3B4giii	Turkeys[4]		0.005684	
3B4giv	Other poultry (ducks, geese) ([d])		0.005684	
3B4h	Other animals (fur animals)		0.005684	
3B4h	Other animals (rabbits) ([c])		0.001614	
3B4h	Other animals (reindeer) ([c])		0.001614	0.00002349

(a) Data from the NAEM study (US EPA, 2012) converted to account for European conditions.

(b) Includes piglets from 8 kg to slaughtering.

(c) Based on data for sheep.

(d) Based on data for layers.

Particulate matter

PM emissions depend on, among other things, the factors discussed in Annex 1, section A1.2.2. The available literature does not allow the estimation of EFs that take account of the impact of the above-mentioned variables.

Activity data

Time spent in yard areas

The inclusion of emissions resulting from livestock in yard areas does complicate the calculation since, in most cases, livestock will spend only a few hours per day in yards and spend the rest of the day in buildings, grazing or both. Hence, the length of the housing period, expressed in days, will need to be reduced to account for the total time estimated to be spent in yards, so that the proportions of x_{build}, x_{yards} and x_{graz} add up to 1.0. For example, if dairy cows are estimated to spend 25 % of their time in collecting yards before and after milking, both the housing and grazing periods need to be reduced by 25 % to accurately estimate x_{build} and x_{graz}. Data on the proportions of the day that livestock spend in open yard areas may not be available. In the absence of country-specific data, the value of 25 % of daily TAN deposited to yards by dairy cows, cited by Webb and Misselbrook (2004; see Figure 1 of Webb and Misselbrook, 2004), may be used.

Housing, manure storage and grazing, manure treatment and manure application

Activity data should be gathered from national farming statistics and farm practice surveys. Of particular importance are estimates of N excretion, the length of the grazing period for ruminants and the type of store.

Table 3.13 describes the manure storage systems referred to in this chapter and makes comparisons with the definitions of manure management systems used by the IPCC.

Table 3.13 Comparison of manure storage type definitions used here and those used by the IPCC

Term	Definition	IPCC equivalent
Lagoons	Storage with a large surface area to depth ratio; normally shallow excavations in the soil	Liquid/slurry Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the livestock building, usually for periods of less than 1 year
Tanks	Storage with a low surface area to depth ratio; normally steel or concrete cylinders	
Heaps	Piles of solid manure	Solid storage The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked because of the presence of a sufficient amount of bedding material or loss of moisture by evaporation
In-house slurry pit	Mixture of excreta and washing water, stored within the livestock building, usually below the confined animals	Pit storage below animal confinements Collection and storage of manure usually with little or no added water, typically below a slatted floor in an enclosed livestock confinement facility, usually for periods of less than 1 year
In-house deep litter	Mixture of excreta and bedding, accumulated on the floor of the livestock building	Cattle and pig deep bedding As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system is also known as a bedded pack manure management system
Crust	Natural or artificial layer on the surface of slurry which reduces the diffusion of gasses to the atmosphere	No definition given
Cover	Rigid or flexible structure that covers the manure and is impermeable to water and gasses	No definition given
Composting, passive windrow	Aerobic decomposition of manure without forced ventilation	Composting, static pile Composting in piles with forced aeration but no mixing
Forced-aeration composting	Aerobic decomposition of manure with forced ventilation	Composting, in-vessel Composting in piles with forced aeration but no mixing
Biogas treatment	Anaerobic fermentation of slurry and/or solid	Anaerobic digester Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel or covered lagoon. Digesters are designed and operated for waste stabilisation by the microbial reduction of complex organic compounds to CO_2 and CH4, which is captured and flared or used as a fuel
Slurry separation	The separation of the solid and liquid components of slurry	No definition given
Acidification	The addition of strong acid to reduce manure pH	No definition given

Note: CH_4, methane; CO_2, carbon dioxide.

3.5 Tier 3 emission modelling and the use of facility data

There is no restriction on the form of Tier 3, provided it can supply estimates that can be demonstrated to be more accurate than Tier 2. If data are available, emission calculations may be made for a greater number of livestock categories than listed under Tier 2 (but see subsection 4.2). Mass-balance models developed by the reporting country may be used in preference to the structure proposed here. A Tier 3 method might also utilise the calculation procedure outlined under Tier 2, but with the use of country-specific EFs or the inclusion of abatement measures. The effect of some abatement measures can be adequately described using a reduction factor, i.e. a proportional reduction in the emission estimate for the unabated situation. For example, if NH_3 emissions from animal housing were reduced by using partially slatted flooring instead of fully slatted flooring, equation 15 (see subsection 3.4.1) could be modified as follows:

$$E_{build\_slurry} = m_{build\_slurry\_TAN} \times reduction\_factor \times EF_{build\_slurry} \quad (57)$$

However, users need to be aware that the introduction of abatement measures may require the modification of EFs for compounds other than the target pollutant. For example, covering a slurry store may also alter N_2 and N_2O emissions, and therefore amendments to their relevant EFs would also be required. The Tier 2 equations will require further amendment if abatement techniques that remove N from the manure management system are employed, e.g. biofilters that clean the exhaust air from livestock buildings which denitrify captured N. If N is removed by air scrubbing by dissolving the NH_3, and if this N solution is added to the slurry store or spread directly, it must be accounted for as an additional amount of N at another stage.

Tier 3 methods must be well documented in order to clearly describe estimation procedures and must be accompanied by supporting literature.

3.6 Technical support

A worked example of the use of these steps will be provided in the accompanying spreadsheet file to this chapter, that will be available from the EMEP/EEA guidebook 2016 website (http://eea.europa.eu/emep-eea-guidebook); the spreadsheet is currently under development.

4 Data quality

4.1 Completeness

A complete inventory should estimate NH_3, NO, PM and NMVOC emissions from all systems of manure management for all livestock categories. To make Tier 2 estimates of NH_3 emissions losses of all N species from livestock buildings, emissions from open yard areas and manure stores need to be calculated. Population data should be cross-checked among the main reporting mechanisms (such as national agricultural statistics databases and Eurostat) to ensure that the information used in the inventory is complete and consistent. Because of the widespread availability of the FAO database of livestock information, most countries should be able to prepare, at a minimum, Tier 1 estimates for the major livestock categories. For more information regarding the completeness of livestock characterisation, see IPCC, 2006 (section 10.2).

4.2 Avoiding double counting with other sectors

In cases in which it is possible to split these emissions among manure management sub-categories within the livestock categories, it is good practice to do so. However, care must be taken that the emissions are not double counted. This may occur if emissions are reported from outdoor yard areas without making appropriate reductions in emissions from buildings or grazed pastures.

4.3 Verification

Documentation, detailing when and where the agricultural inventory was checked and by whom, should be included.

Dry and wet deposition or ambient atmospheric concentration time series which support or contradict the inventory should be discussed.

4.4 Developing a consistent time series and recalculation

General guidance on developing a consistent time series is given in Chapter 4 of the *EMEP/EEA air pollutant emission inventory guidebook 2016*, 'Time series consistency' (EMEP/EEA, 2016).

Developing a consistent time series of emission estimates for this source category requires, at a minimum, the collection of an internally consistent time series of livestock population statistics. General guidance on the development of a consistent time series is addressed in Part A (the general guidance chapters), Chapter 4 'Time series consistency', of the Guidebook (EMEP/EEA, 2016). Under current IPCC guidance (IPCC, 2006), the other two activity data sets required for this source category (i.e. N excretion rates and manure management system usage data), as well as the manure management EF, will be kept constant for the entire time series. However, if using a Tier 2 or Tier 3 approach to calculating NH_3 emissions, in which emissions are estimated as a proportion of TAN excreted, it will be necessary to make reliable estimates of N excretion for each year of the time series, since these N excretions, and/or the proportions of TAN, may change over time. For example, milk yield and live weight gain may increase with time, and farmers may alter livestock feeding practices which could affect N excretion rates. Furthermore, the livestock categories in a census may change. A particular system of manure management may change because of operational practices or new technologies such that a revised EF is warranted. These changes in practices may be due to the implementation of explicit emission reduction measures, or may be due to changing agricultural practices without regard to emissions. Regardless of the driver of change, the parameters and EF used to estimate emissions must reflect the change. The inventory text should thoroughly explain how the change in farm practices or the implementation of mitigation measures has affected the time series of activity data or EFs. Projections need to take account of likely changes in agricultural activities, not just changes in livestock numbers, but also changes in spreading times and methods due, for example, to the need to introduce manure management measures to comply with the Nitrates Directive, the IPPC and the Water Framework Directive.

4.5 Uncertainty assessment

General guidance on quantifying uncertainties in emission estimates is given in Chapter 5, 'Uncertainties', of the Guidebook (EPA, 2013c). In the following sections, the results of some previous studies of uncertainties in emission estimates from agricultural sources are reported.

Emission factor uncertainties

Ammonia

Uncertainties with regard to NH_3 EFs vary considerably. A study in the United Kingdom (Webb and Misselbrook, 2004), in which a distribution was attached to each of the model inputs (activity or EF data), based on the distribution of raw data (or if no or only single estimates existed, on expert assumptions) indicated an uncertainty range from ±14 %, for the EF for slurry spreading, to ±136 %, for beef cattle grazing. In general, EFs for the larger sources tended to be based on a greater number of measurements than those for smaller sources and, as a consequence, tended to be more certain. The exceptions were the EFs for buildings in which livestock were housed on straw and grazing EFs for beef cattle and sheep. The uncertainties related to the partial EFs have yet to be discussed. 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 ±17 % (van Gijlswijk et al., 2004).

Nitric oxide

Although the principles of the bacterial processes leading to NO emissions (nitrification and denitrification) are reasonably well understood, it is still difficult to quantify nitrification and denitrification rates in livestock manures. In addition, the observed fluxes of NO show large temporal and spatial variations. Consequently, there are large uncertainties associated with current estimates of emissions for this source category (–50 % to +100 %). Accurate and well-designed emission measurements from well characterised types of manure and manure management systems can help reduce these uncertainties. These measurements must account for temperature, moisture conditions, aeration, manure N content, metabolisable carbon, duration of storage and other aspects of treatment.

Non-methane volatile organic compounds

The EFs included are initial estimates and, as such, provide only broad indications of the likely range. The uncertainties associated with these EFs are very high. Furthermore, given the many different compounds, the large variation in chemical and physical properties, the wide variations in conditions in which they are formed and the applicability of measured emissions for one species to other species will result in large uncertainties.

Particulate matter

The EFs are only an initial estimate and, as such, provide only a broad indication of uncertainty. The variability presented in the recent studies suggests a particularly large uncertainty for the EFs that impact on the emission estimates. Further uncertainties may arise for livestock categories other than poultry with regard to determining the amount of time spent in livestock buildings, and the proportion of animals to which this applies.

Activity data uncertainties

There is likely to be greater uncertainty in estimates of activity data, although, for such data, a quantitative assessment of uncertainty is difficult to determine. Webb and Misselbrook (2004) reported that 8 of the 10 input data sets to which estimates of United Kingdom NH_3 emissions were the most sensitive were activity data. Uncertainty ranges for the default N excretion rates used for the IPCC calculation of N_2O emissions were estimated at about +50 % (source: judgement by IPCC Expert Group). However, for some countries, the uncertainty will be lower. Webb (2000) reported uncertainties for United Kingdom estimates of N excretion to range from ±7 % for sheep to ±30 % for pigs. Livestock numbers, (partial) EFs and frequency distributions are likely to be biased; data sets are often incomplete. For this edition of the Guidebook, no quality statements can be given other than those mentioned above. However, experts compiling livestock numbers, national 'expert judgement' estimates for EFs and frequency distributions are strongly advised to document their findings, decisions and calculations in order to facilitate the review of the corresponding inventories.

The first step in collecting data on livestock numbers should be to investigate existing national statistics, industry sources, research studies and FAO statistics. The uncertainty associated with populations will vary widely depending on source, but should be known within ±20 %. Often, national livestock population statistics already have associated uncertainty estimates, in which case these should be used. If published data are not available from these sources, interviews of key industry and academic experts should be undertaken.

4.6 Inventory quality assurance/quality control (QA/QC)

Guidance on the checks of the emission estimates that should be undertaken by the persons preparing the inventory are given in Part A, Chapter 6, 'Inventory management, improvement and QA/QC', of the *EMEP/EEA air pollutant emission inventory guidebook 2016* (EMEP/EEA, 2016)

It is good practice to ensure that the dietary information used in the calculation of N excretion is compatible with that used in the calculation of dry matter intake, as used in section 10.2.2 of the 2006 IPCC Guidelines (IPCC, 2006).

Activity data check

- The inventory agency should review livestock data collection methods, in particular checking that livestock category data were collected and aggregated correctly with consideration for the duration of production cycles. The data should be cross-checked with previous years to ensure the data are reasonable and consistent with reported trends. Inventory agencies should document data collection methods, identify potential areas of bias and evaluate the representativeness of the data.
- Manure management system allocation should be reviewed on a regular basis to determine if changes in the livestock industry are being captured. Conversion from one type of management system to another, and technical modifications to system configuration and performance, should be captured in the system modelling for the affected livestock.
- National agricultural policy and regulations may have an effect on parameters that are used to calculate manure emissions, and should be reviewed regularly to determine what impact they may have. For example, guidelines to reduce manure runoff into water bodies may cause a change in management practices, and thus affect the N distribution for a particular livestock category. Consistency should be maintained between the inventory and ongoing changes in agricultural practices.
- If using country-specific data for N excretion, the inventory agency should compare these values with the IPCC default values. Significant differences, data sources and methods of data derivation should be documented.

- The N excretion rates, whether default or country-specific values, should be consistent with feed intake data as determined through animal nutrition analyses.
- Country-specific data for feed intake in MJ and for the excretion of volatile substance used in the estimation of NMVOC emissions should be compared with the IPCC default values. Significant differences, data sources and methods of data derivation should be documented. Data on the degree of silage feeding should be gathered as this is a crucial factor for estimating NMVOC emissions.

Review of emission factors

- The inventory agency should evaluate how well the implied EFs compare with alternative national data sources and with data from other countries with similar livestock practices. Significant differences should be investigated.
- If using country-specific EFs, the inventory agency should compare them with the default factors and note differences. The development of country-specific EFs should be explained and documented, and the results peer reviewed by independent experts.
- Whenever possible, available measurement data, even if they represent only a small sample of systems, should be reviewed relative to assumptions for NH_3, NO and NMVOC emission estimates. Representative measurement data may provide insights into how well current assumptions predict NH_3, N_2O and NO emissions from manure management systems in the inventory area, and how certain factors (e.g. feed intake, system configuration, retention time) affect emissions. Because of the relatively small amount of measurement data available for these systems worldwide, any new results can improve the understanding of these emissions and possibly their prediction.

External review

The inventory agency should utilise experts in manure management and livestock nutrition to conduct expert peer reviews of the methods and data used. Although these experts may not be familiar with gaseous emissions, their knowledge of key input parameters for the emission calculation can aid in the overall verification of the emissions. For example, livestock nutritionists can evaluate N production rates to see if they are consistent with feed utilisation research for certain livestock species. Practising farmers can provide insights into actual manure management techniques, such as storage times and mixed-system usage. Wherever possible, these experts should be completely independent of the inventory process, in order to allow a true external review. If country-specific EFs, fractions of N losses, N excretion rates or manure management system usage data have been used, the derivation of or references for these data should be clearly documented and reported along with the inventory results under the appropriate source category. As a quality control, a N balance should be calculated, i.e. the total input of N (total amount of N in animal excretions plus total amount in bedding) should match the output of N (total of all emissions and N inputs to the soil).

4.7 Gridding

Ammonia

The EMEP requires NH_3 emissions to be gridded in order to calculate the transport of NH_3 and its reaction products in the air. Considering the potential for NH_3 to have local effects on ecology, NH_3 emission estimates should be disaggregated as much as possible. Given the dominance of livestock husbandry in the context of the emission of NH_3 in Europe, disaggregation is normally based on livestock census data. Spatial disaggregation of emissions from livestock manure management systems may be possible if the spatial distribution of the livestock population is known.

With respect to the modelling of atmospheric transport, transformation and deposition, a very high spatial resolution is desirable. However, the calculation procedures described in this guidebook may allow for a resolution in time of months, and may distinguish months of grazing and manure spreading from the rest of the year.

Nitric oxide

Spatial disaggregation of emissions from livestock manure management systems may be possible if the spatial distribution of the livestock population is known.

Non-methane volatile organic compounds

The Tier 1 methodology will provide spatially resolved emission data for NMVOCs on the scale for which matching activity data and frequency distributions of livestock buildings, storage systems and grazing times are available.

Particulate matter

Spatial disaggregation of emissions from livestock production may be possible if the spatial distribution of the livestock population is known.

4.8 Reporting and documentation

There are no specific issues related to reporting and documentation.

5 Glossary

AAP	Average annual population
AD	Anaerobic digestion
CRF	Common reporting format
EAGER	European Agricultural Gaseous Emissions Inventory Researchers Network
EF	Emission factor
FAO	Food and Agriculture Organization of the United Nations
FYM	Farmyard manure
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
IIASA	International Institute for Applied Systems Analysis

IPCC	Intergovernmental Panel on Climate Change
LMMS	Livestock manure management system
LU	Livestock unit
MJ	Megajoules
NAEM	National Air Emissions Monitoring
NFR	Nomenclature for Reporting
NMHC	Non-methane hydrocarbon
ROG	Reactive organic gas
TMR	Total mixed ration
TAN	Total ammoniacal nitrogen
VFA	Volatile fatty acid

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7 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projections' (TFEIP's) Expert Panel on Agriculture and Nature. Please refer to the TFEIP website (www.tfeip-secretariat.org/) for the contact details of the current expert panel leaders.

Annex 1

A1.1 Overview

A1.1.1 Ammonia

There have been large reductions in emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) resulting from power generation, industry and transport since 1980. Consequently, within the next decade, NH_3 emissions are expected to account for more than a quarter of all acidifying, and half of all eutrophying, emissions of atmospheric pollutants in Europe. Approximately 90 % of the total NH_3 emissions in Europe originate from agriculture, and the remainder are from industrial sources, households, pet animals and natural ecosystems.

A1.1.2 Nitric oxide and di-nitrogen

The processes of denitrification and nitrification, which release N_2O, also release NO and N_2. Whereas NO is a species reported as an air pollutant, estimates of N_2 emissions are only required to satisfy any mass balance calculation. Attempts to quantify NO emissions from manure storage show that these emissions are an order of magnitude of half the emissions of N_2O from soils receiving mineral fertiliser or livestock manures (Haenel et al., 2016).

A1.1.3 Non-methane volatile organic compounds

Emissions of NMVOCs from livestock husbandry originate from feed, especially silage, degradation of feed in the rumen, and partly digested and undigested fat, carbohydrate and protein decomposition in the rumen and in manure (Elliott-Martin et al., 1997; Amon et al., 2007; Alanis et al., 2008, 2010; Ngwabie et al., 2008; Feilberg et al., 2010; Parker et al., 2010; Trabue et al., 2010; Rumsey et al., 2012; Ni et al. 2012). Consequently, anything that affects the rate of feeding and manure management, such as the amount of formic acid added to silage, the management of silage heaps and livestock feeding, manure management in the livestock buildings and during storage, straw added to the manure and the duration of storage, and the technique used for manure application, will affect NMVOC emissions.

NMVOCs from feed are released from the open surface in the silage store or from the feeding table (Alanis et al., 2008, 2010; Chung et al., 2010), and NMVOCs formed in the rumen of animals are released through exhalation or via flatus (Elliott-Martin et al., 1997). NMVOCs formed in manure may be released inside the buildings or from the surface of manure stores (Trabue et al., 2010; Parker et al., 2010). These emissions depend on the temperature and the wind speed over the surface. NMVOCs released after manure application and during grazing are likely to have been formed prior to application/deposition, within the animal or in the manure management system.

A1.2 Description of sources

A1.2.1 Process description

Ammonia

NH_3 volatilisation is essentially a physico-chemical process which results from the equilibrium (described by Henry's law) between gaseous phase (g) NH_3 and NH_3 in solution (aq) (Equation A1). NH_3 in solution is, in turn, maintained by the NH_4^+–NH_3 equilibrium (Equation A2):

$$NH_3\ (aq) \leftrightarrow NH_3\ (g) \quad (A1)$$

$$NH_4^+\ (aq) \leftrightarrow NH_3\ (aq) + H^+\ (aq) \quad (A2)$$

High pH (i.e. a low concentration of hydrogen ions (H^+) in solution) favours the right-hand side of the equilibrium shown in Equation A2, resulting in a greater concentration of NH_3 in solution and also, therefore, in the gaseous phase. Thus, if the system is buffered at values of less than c. pH 7 (in water), the dominant form of ammoniacal-N (NH_x) will be NH_4^+ and the potential for volatilisation will be small. In contrast, if the system is buffered at higher pH values, the dominant form of NH_x will be NH_3 and the potential for volatilisation will be large, although other chemical equilibriums may serve to increase or decrease this.

Typically, more than half of the N excreted by mammalian livestock is excreted in the urine, and between 65 and 85 % of urine-N is in the form of urea and other readily mineralised compounds (for information on ruminants, see Jarvis et al., 1989; for pigs, see Aarnink et al., 1997). Urea is rapidly hydrolysed by the enzyme urease to ammonium carbonate ($(NH_4)_2CO_3$) and ammonium ions (NH_4^+) provide the main source of NH_3. Ammonium-N (NH_4^+-N) and compounds, including uric acid, that are readily broken down to NH_4^+-N, are referred to as TAN. In contrast, the majority of N in mammalian livestock faeces is not readily degradable (Van Faassen and Van Dijk, 1987); only a small percentage of this N is in the form of urea or NH_4^+ (Ettalla and Kreula, 1979) so NH_3 emissions are small enough (Petersen et al., 1998) for estimates of TAN at grazing or in buildings to be based on urine-N, although TAN may be mineralised from faecal-N during manure storage. Poultry produce only faeces, a major constituent of which is uric acid and this, together with other labile compounds, may be degraded to NH_4^+-N after hydrolysis to urea (Groot Koerkamp, 1994).

Urease is widespread in soils and faeces and, consequently, the hydrolysis of urea is usually complete within a few days (Whitehead, 1990). Urine also contains other N compounds such as allantoin, which may be broken down to release NH_3 (Whitehead et al., 1989).

The NH_4^+ in manure is mainly found in solution or loosely bound to dry matter, in which it exists in equilibrium with dissolved NH_3. Since the usual analytical methods cannot distinguish between NH_4^+ and NH_3 in manure, it is common to refer to the combination (NH_4^+ plus NH_3) as TAN. Published studies have confirmed the relationship between NH_3 emissions and TAN (for cattle: Kellems et al. (1979), Paul et al. (1998), James et al. (1999), Smits et al. (1995); for pigs: Latimier and Dourmad (1993), Kay and Lee (1997), Cahn et al. (1998)).

Non-methane volatile organic compounds

There has been some uncertainty over which NMVOCs originate from different manure types and which from other sources, such as animal breath. However, less than 20 volatile compounds in total were measured in significant amounts from manures but at different concentrations or ratios in the headspace according to whether the manure was from pigs, cattle or poultry (Trabue et al. 2010; Ni et al., 2012; US EPA, 2012). NMVOCs collected from the headspace of manure may be affected by the nature of the adsorbent used and the means of desorption into the selected separation/detection system. Zahn et al. (1997) also recognised that some non-polar hydrocarbons are emitted from pig slurry lagoons. Their comprehensive study demonstrated that fluxes of NMVOCs from deep basin or pit manure storage systems were 500- to 5 700-times greater than those from biogenic sources. Both Parker et al. (2010) and Zahn et al. (1997) recognised that the NMVOCs identified by either small-scale laboratory studies or under conditions more representative of commercial farms did not necessarily represent the compounds produced in the field or their rates of emission. In addition, several VOCs were identified as originating from ruminant breath (Elliott-Martin et al., 1997; Hobbs et al., 2004; Spinhirne et al., 2003, 2004; Cai et al., 2006a). Emissions of NMVOCs are not a large source and are seen as a dysfunction of the rumen (Moss et al. 2000). Some NMVOCs, e.g. acetone, may be emitted by cattle if they are suffering from, for example, ketosis. Emissions of volatile fatty acids (VFAs), a form of NMVOCs not associated with proteins, and phenols appear to remain constant in manure stores over time (Patni et al., 1985). More than 200 NMVOCs derived from livestock feeding operations have been identified (Montes et al., 2010). Similar to other compounds, the emission of NMVOCs is dependent on the temperature and ventilation rate within livestock buildings (Parker et al., 2010, 2012).

Although more than 500 volatile compounds originating from cattle, pigs and poultry have been identified (Ni et al., 2012), there is considerable uncertainty concerning the organic precursors in each manure type, from which the NMVOCs originate. Emissions include alcohols, aldehydes, acids, sulfides and phenols and, in the case of pig slurry, indoles. Some of the major compounds are listed in Table A1.1. Recently, dimethyl sulfide (DMS) has been identified as originating from ruminant breath. Table A1.2 gives the percentage distribution of the most common NMVOCs found in the NAEM study, which includes NMVOC measurements from 16 different animal production (US EPA, 2012).

Table A1.1 Sources and processes of NMVOC formation

NMVOC	Precursor or process	
	Amino acids ([a])	Process
Methanol	NA	Pectin demethylation
Ethanol	NA	Fermentation
Acetaldehyde	NA	Fermentation
Acetic acid	NA	Fermentation
Acetone	NA	Fat metabolism
Trimethylamine	All	Organic N methylation
2-methyl propanoic acid	Valine	
3-methyl butanoic acid	Isoleucine	
2-methyl butanoic acid	Leucine	
Methanethiol	Methionine	
Dimethyl sulfide	Cysteine	
4-methyl phenol	Tyrosine	
4-ethyl phenol	Tyrosine	
Indole	Tryptophan	
3-methyl indole	Tryptophan	

Notes: 'NA' indicates no amino acid as source.
(a) Source: from Mackie et al. (1998).

Table A1.2 Percentage distribution of different NMVOCs from buildings for different animal types (estimated from US EPA, 2012)

Poultry	%	Cattle	%	Pigs	%
2,3-Butanedione	9.9	2,3-Butanedione	0.3	2,3-Butanedione	4.3
Dimethyl disulfide	5.1	Dimethyl disulfide	0.5	Dimethyl disulfide	1.0
Acetaldehyde	4.0	Acetaldehyde	6.7	Acetaldehyde	8.8
2-Butanone	5.8	2-Butanone	2.4	2-Butanone	10.2
Isopropanol	23.0	Isopropanol	7.0	Isopropanol	19.3
Pentane	3.6	Pentane	3.4	Pentane	4.6
Dimethyl sulfide	2.8	Dimethyl sulfide	1.3	Dimethyl sulfide	3.7
Acetic acid	7.3	Acetic acid	2.9	Acetic acid	7.8
Hexanal	2.3	Hexanal	0.2	Hexanal	2.3
Ethyl acetate	0.4	Ethyl acetate	18.7	Ethyl acetate	2.1
Hexane	4.9	Hexane	0.3	Hexane	1.2
Propionic acid	1.7	Propionic acid	1.0	Propionic acid	7.1
Pentanal	1.8	Pentanal	0.2	Pentanal	2.5
Phenol	1.8	Phenol	1.0	Phenol	3.6
1-Butanol	0.9	1-Butanol	0.6	1-Butanol	1.9
2-Pentatone	0.9	2-Pentatone	0.1	2-Pentatone	0.9
4-Methyl-phenol	1.2	4-Methyl-phenol	1.2	4-Methyl-phenol	6.0
Butanoic acid	< 0.0	Butanoic acid	< 0.0	Butanoic acid	1.6
Heptanal	1.0	Heptanal	0.2	Heptanal	1.7
Butanal	1.1	Butanal	0.1	Butanal	1.8
Octanal	0.8	Octanal	0.2	Octanal	1.5
Methyl cyclopentane	2.0	Methyl cyclopentane	0.1	Methyl cyclopentane	0.3
Nonatal	0.7	Nonatal	0.5	Nonatal	1.7
Toluene	2.0	Toluene	1.0	Toluene	0.4
n-Propanol	1.4	*n*-Propanol	41.3	*n*-Propanol	2.3
2-Butanol	0.5	2-Butanol	1.3	2-Butanol	0.5
4-Ethyl-phenol	0.1	4-Ethyl-phenol	< 0.0	4-Ethyl-phenol	0.3
1-Pentanol	0.1	1-Pentanol	< 0.0	1-Pentanol	< 0.0
Dimethyl trisulfide	0.2	Dimethyl trisulfide	< 0.0	Dimethyl trisulfide	0.2
2-Methyl-propenoic acid methyl ester	10.8	2-Methyl-propenoic acid methyl ester	< 0.0	2-Methyl-propenoic acid methyl ester	< 0.0
2-Methyl-propenoic acid	< 0.0	2-Methyl-propenoic acid	0.2	2-Methyl-propenoic acid	< 0.0
2-Methyl-hexanoic acid	< 0.0	2-Methyl-hexanoic acid	0.1	2-Methyl-hexanoic acid	< 0.0
Propyl propenoic ester	< 0.0	Propyl propenoic ester	0.2	Propyl propenoic ester	< 0.0
Indole	1.5	Indole	0.1	Indole	< 0.0
Benzaldehyde	0.3	Benzaldehyde	0.1	Benzaldehyde	< 0.0
o-Xylene	0.3	*o*-Xylene	< 0.0	*o*-Xylene	< 0.0
Decanal	< 0.0	Decanal	0.2	Decanal	< 0.0
n-Propyl acetate	< 0.0	n-Propyl acetate	4.8	n-Propyl acetate	< 0.0
Benzene	< 0.0	Benzene	0.3	Benzene	0.2
Menthanol	< 0.0	Menthanol	1.7	Menthanol	< 0.0
Dimethyl sulfone	< 0.0	Dimethyl sulfone	< 0.0	Dimethyl sulfone	0.2
Ethanol	< 0.0	Ethanol	0.1	Ethanol	< 0.0
D-limonene	< 0.0	D-limonene	0.1	D-limonene	< 0.0
Total	100	Total	100	Total	100

Particulate matter

It may be expected that housing systems with litter (solid manure) produce greater dust emissions than livestock buildings without litter (slurry), because bedding material such as straw consists of loose material, which is easily made airborne by disturbance (Hinz et al., 2000). Takai et al. (1998) found greater inhalable dust concentrations in English dairy cow buildings with litter than in German dairy cubicle houses with slurry-based systems. The calculated emission rates for PM differed, too. However, PM emissions have also been found to be 50 % less in a deep-litter system because the dust is incorporated into the bed and held there by the moisture. Animal activity does not cause as much suspension of material if the litter is moist (CIGR Working Group, 1995).

Emissions of PM occur from both housed and free-range livestock. However, the lack of available emissions measurements for free-range livestock means that the development of EFs has focused on housed livestock.

A1.2.2 Reported emissions

Ammonia

Laubach et al. (2013) estimated that 89 % of the total NH_3 emissions measured from grazing arose from deposited urine.

Jarvis et al. (1989) found annual NH_3 emissions of 7 kg N ha^{-1} from a grass/clover pasture grazed by beef cattle. This was c. 4 % of the estimated N fixation by the clover (160 kg N ha^{-1} a^{-1}) and c. 70 % of NH_3 emissions from grazed grassland given 210 kg N ha^{-1} a^{-1}. Jarvis et al. (1991) measured NH_3 emissions from pastures grazed by sheep, including an unfertilised clover monoculture. Emissions of NH_3 from the unfertilised grass/clover pasture (2 kg N ha^{-1} a^{-1}) were less than from an unfertilised grass field (4 kg N ha^{-1} a^{-1}), while emissions from the pure clover pasture (11 kg N ha^{-1} a^{-1}) were greater than from grassland given 420 kg N ha^{-1} a^{-1}. These losses were smaller (by a factor of three) than losses from pastures grazed by cattle (Jarvis et al., 1989). Ledgard et al. (1996) measured an annual NH_3 emission of 15 kg ha^{-1} from unfertilised grass/clover grazed by dairy cattle. There are considerable uncertainties related to generalising from these limited data. Differences in emissions are likely to be the result of variation in temperature, soil type and livestock type. In addition, if unfertilised grassland is cut and left in the field for an extended period, decomposition may result in some emissions.

Non-methane volatile organic compounds

An exhaustive list of over 130 volatile compounds identified in livestock buildings housing cattle, pigs and poultry was compiled by O'Neill and Phillips (1992) in a literature review. More recent compilations by Schiffman et al. (2001) and Blunden et al. (2005) identified over 200 VOCs in air from buildings housing pigs confirming most of the previous emission profiles. Ni et al. (2012) identified over 500 compounds. The compounds most frequently reported in these investigations, which were heavily biased towards piggeries, were *p*-cresol, VFAs and phenol. Concentrations of these compounds in the atmosphere display wide variations, e.g. the concentration of *p*-cresol varies from 4.6×10^{-6} to 0.04 mg m^{-3} and the concentration of phenol varies from 2.5×10^{-6} to 0.001 mg m^{--3}. The alcohols ethanol and methanol have been reported as the dominant emissions from buildings housing dairy cattle and sheep (Ngwabie et al., 2005; US EPA, 2012), and these vastly exceed VFA and *p*-cresol abundances. VOCs are also known to be adsorbed to airborne PM (Bottcher, 2001; Oehrl et al., 2001; Razote et al., 2004; Cai et al. 2006b), thus representing an additional emission pathway and odour nuisance.

A major attempt to quantify the NMVOC emissions from livestock buildings and manure stores was made in the NAEM study that covered 16 locations in the USA with dairy cattle, sow and pig finishing facilities, as well as egg layer and broiler farms (US EPA, 2012). The measurements were made over two consecutive years from 2007 to 2009. NMVOC measurements were made with both canister sampling combined with mass spectrometry and NMHC.

The estimated NMVOC EF is based on an average emission measured in the NAEM study for dairy cows, sows, layers and broilers. If both NMVOC and NMHC were measured, an average of the two values was used. NMHCs are converted to NMVOCs by multiplying with the mass fraction of the most common NMVOCs compared with NMHCs. The emissions from the NAEM study are converted to European standards with a conversion of MJ feed intake data and VS excretion, which corresponds to data in the 2006 IPCC Guidelines (IPCC, 2006). Measurements in the NAEM study indicate that the emission depends on temperature and ventilation rates. However, because of the significant variation of the measured emission, the data are not robust enough to introduce a climate-dependent EF for the EMEP area.

For cattle, emissions from only dairy buildings were measured. These emissions include those from silage feeding in the building, enteric fermentation, flatus and from manure stored inside the building. A conversion to 'other cattle' has been made according to the relative intake of energy (in MJ). For all other livestock, the conversions are based on the differences in excreted VSs to allow for differences in productivity.

Measured emissions from dairy buildings in the NAEM study include emissions from silage, which is a major source. The major emissions from silage are ethanol and VFAs. There is a large uncertainty with regard to the fraction that is derived from the silage. Alanis et al. (2008) found, for a Californian dairy farm, that the total mixed rations (TMRs) (silage feed) were responsible for approximately 68 % of estimated VFA emissions. Chung et al. (2010) found that 93–98 % of the emissions that contributed to O_3 formation from six dairies came from the feed. In the distribution of the EFs for emissions from silage on the feeding table and emissions from other sources in the building (enteric, other feeding stuff and manure store inside the building), values of 85 % from the silage and 15 % from other sources are used. This factor will affect the emission estimate from farms not using silage for feeding. In the NAEM study, propanol accounted for up to 50 % of the emission from cattle, poultry and pig buildings (Table A1.2). Chung et al. (2010) found only alcohol emissions from the feed (ethanol and propanol) and nothing from the flushing lane, bedding, open lots or lagoons. This gives rise to questions regarding the origin of the high propanol measurements in the NEAM study, as poultry and pigs are not normally fed with silage.

The methodology for silage stores is based on measured distribution between silage stores and buildings (Alanis et al., 2008; Chung et al., 2010), combined with a temperature correction to account for European temperatures (Alanis et al., 2010; El-Mashad et al., 2010; Hafner et al., 2010). Emissions were measured under warmer conditions (20°C) than the European average. A correction factor from 20°C to 10°C was therefore made that was equal to 25 % of the emissions from silage on the feeding table.

The NMVOC measurements in the NAEM study from lagoons are difficult to translate to manures stored in slurry tanks. Therefore, the fraction of NMVOC emissions between housing and storage was based on the same fraction as for the NH_3 emission. This relationship is documented by, among others, Hobbs et al. (2004), Amon et al. (2007) and Feilberg et al. (2010). The same methodology is used to calculate the NMVOC emissions resulting from the application of manure by using the fraction of NH_3 emissions resulting from application compared with emissions from buildings. However, it should be mentioned that if national NH_3 data are used, this will not necessarily reduce the emission estimate, as low NH_3 emission rates based on low N feeding will not reduce the primary dry matter in feed and the excreted volatile substances, which are the primary source for NMVOCs. For the Tier 1 EFs, the distribution in Table 3.9 was used. The use of national NH_3 emission estimates is strongly recommended. Rumsey et al. (2012) found, when upscaling the emission from pigs in North Carolina, USA, that housing was responsible for 68.8–100 % of the total emissions. This large proportion may be unlikely under European conditions, as the use of large aerated lagoons is not common practice in Europe.

NMVOC emissions from grazing animals are assumed to be small as there is little or no silage feeding and no manure to store. However a small amount will be emitted from enteric fermentation and from flatus. The estimation of emissions from grazing animals is based on Shaw et al. (2007) who measured reactive organic gas (ROG) emissions from lactating and non-lactating dairy cows for two subsequent days in an emission chamber. Based on the feed composition it is assumed that the feeding was without silage, although alfalfa was included. It is assumed that alfalfa was in the form of hay. The estimated ROG is assumed to be equivalent to NMVOC.

A1.2.3 Controls

Ammonia

The adoption of techniques to reduce NH_3 emissions needs to be taken into account when estimating national NH_3 emissions. This is most easily done using a Tier 3 approach, in which the EF for the appropriate stage of manure management can be reduced by the proportion of NH_3 emission achieved by the abatement technique. The average reductions in NH_3 emissions that can be achieved by recognised abatement techniques can be found in UNECE (2007).

Information will also be needed on the proportions of livestock housed in reduced-emission buildings, the proportion of manures stored under cover and the proportion of manures applied by reduced-emission techniques.

Nitric oxide

Meijide et al. (2007) reported a reduction in NO emissions of c. 80 % when the nitrification inhibitor dicyandiamide (DCD) was added to pig slurry before application to land, although unabated emissions were only 0.07 % of N applied.

Non-methane volatile organic compounds

Further examples of abatement techniques include the provision of only small amounts of feed on the feeding table; the use of high-quality feed with a high digestibility, which reduces the amount of substrate for NMVOC formation; and the immediate removal of urine and manure from cubicles for cattle, the fast removal of slurry for pigs, belt drying of manure inside the poultry houses for laying hens and the limited stirring of manure in manure stores. Systems already described for reducing NH_3 emissions from storage facilities, such as natural and artificial floating crust and floating mats, give some odour reduction because of the reduction in the emissions of NMVOCs (Mannebeck, 1986; Zahn et al. 2001; Bicudo et al., 2004; Blanes-Vidal et al., 2009).

Particulate matter

Techniques have been investigated to reduce concentrations of airborne dust in livestock buildings. Measures such as wet feeding, including fat additives in feed, oil and/or water sprinkling, are some examples of techniques that prevent excessive dust generation within the building.

End-of-pipe technologies are also available to reduce PM emissions significantly, in particular filters, cyclones, electrostatic precipitators, wet scrubbers and biological waste air purification systems. Although many of these are currently considered too expensive, technically unreliable or insufficiently user friendly to be widely adopted by agriculture, air scrubbers are considered to be category 1 abatement options by the UNECE (2007).

Shelterbelts (the planting of, for example, trees and shrubs as screens around the building to remove airborne PM) may also reduce the dispersal of PM emitted from buildings to a certain extent.

When applicable abatement techniques become available, the methodology will be developed to allow the calculation of the corresponding PM emissions.

A1.3 Methods

A1.3.1 Tier 1 approach

Particulate matter

In order to develop EFs expressed per AAP, transformation factors are needed for the conversion of livestock units into AAP. In addition, inhalable and respirable dust concentrations have to be transformed into the corresponding PM concentrations. However, the resulting 'correction factors' have to be used with care, because the representativeness of these factors is poorly understood. As a consequence, this Tier 1 methodology is considered very uncertain.

Table A1.3 Measured dust emissions (all data except horses: Takai et al., 1998; horses: Seedorf and Hartung, 2001)

Code	Livestock category	Housing type	Emissions	
			ID, mg LU^{-1} h^{-1}	RD, mg LU^{-1} h^{-1}
3B1a	Dairy cattle	slurry	172.5	28.5
		solid	89.3	28.0
3B1a	Non-dairy cattle including young cattle, beef cattle and suckling cows.	slurry	113.0	13.7
		solid	85.5	16.0
3B1a	Non-dairy cattle (calves)	slurry	127.5	19.5
		solid	132.0	27.3
3B4e	Horses	solid	448.5	47.5
		solid ([a])	55.0	n.a.

Notes:
([a])Wood shavings.
h, Animal head; ID, inhalable dust; LU, livestock unit; n.a., not available; RD, respirable dust.
Sources: Takai et al., 1998 (all data except horses); Seedorf and Hartung, 2001 (data on horses).

In order to get mean emissions per animal head, mean values of these data have to be divided by the average weight of the animals in the corresponding category. Livestock unit (LU) is here defined as a unit used to compare or aggregate numbers of different species or categories, and is equivalent to 500 kg live weight. The weights used are given in Table A1.4. These values have also been used for the conversion to EF per animal in other studies.

Table A1.4 Conventional livestock units and weights of livestock on which the N excretion estimates in Table 3.9 were based

Code	Livestock type	Weight of animal used for N_{ex} estimate (kg)
3B1a	Dairy cattle	600
3B1b	Non-dairy cattle (beef cattle)	340
3B1b	Non-dairy cattle (calves)	150
3B2	Sheep	50
3B3	'Swine' (fattening pigs)	65
3B3	'Swine' (piglets)	20
3B3	'Swine' (sows)	225
3B4a	Buffalo	700
3B4d	Goats	50
3B4e	Horses	500
3B4f	Mules and assess	350
3B4gi	Laying hens	2.2
3B4gii	Broilers	1.0
3B4giii	Turkeys	6.8
3B4giv	Other poultry (ducks)	2.0
3B4giv	Other poultry (geese)	3.5
3B4h	Other animals (fur animals)	NA

In the cases for which PM EFs are not directly available, the quantities of inhalable and respirable dust have to be transformed into quantities of PM_{10} and $PM_{2.5}$. Transformation factors for cattle were derived from a 24-hour PM monitoring survey that was performed in a cubicle house with dairy cows and calves, housed on a slatted floor and a solid floor with straw. The 1-day survey was conducted with an optical particle counter, which recorded the mass concentrations of total dust, PM_{10} and $PM_{2.5}$. The result of this investigation was used to calculate the conversion factor for PM_{10} (Seedorf and Hartung, 2001), while the conversion factor for $PM_{2.5}$ was determined later (Seedorf and Hartung, personal communication). For horses, a transformation factor similar to that for cattle was assumed. Overall, the real quantitative relationships between dust fractions have to be verified in future. Nevertheless, for a very first estimate, some of these transformation factors are compiled in Table A1.5.

Table A1.5 Transformation factors for the conversion of inhalable dust into PM_{10} and $PM_{2.5}$

Code	**Livestock type**	**Transformation factor for PM_{10}, kg PM_{10} kg $(ID)^{-1}$**	**Transformation factor for $PM_{2.5}$, kg $PM_{2.5}$ kg $(ID)^{-1}$**
3B1a	Dairy cattle	0.46 (a)	0.30 (b)
3B1b	Other cattle	0.46 (a)	0.30 (b)
3B4e	Horses (c)	0.46 (a)	0.30 (b)

Note:

(a)The same conversion factor for horses is assumed as for cattle (Seedorf and Hartung, 2001).

(b)Seedorf (personal communication).

(c)The transformation factor for $PM_{2.5}$ relates to respiratory dust and not inhalable dust.

ID, inhalable dust.

The resulting EFs in kg $animal^{-1}$ a^{-1} are listed in Table A1.6.

Table A1.6 EFs for inhalable dust, respirable dust, PM_{10} and $PM_{2.5}$

Code	Livestock category	Housing type	Animal weight, kg animal^{-1}	Conversion factor, LU animal^{-1}	EFs			
					ID, kg AAP^{-1} a^{-1}	RD, kg AAP^{-1} a^{-1}	PM_{10}, kg AAP^{-1} a^{-1}	$PM_{2.5}$, kg AAP^{-1} a^{-1}
3B1a	Dairy cattle	Slurry	600	1.2	1.81	0.30	0.83	0.54
		Solid	600	1.2	0.94	0.29	0.43	0.28
3B1b	Beef cattle	Slurry	350	0.7	0.69	0.08	0.32	0.21
		Solid	350	0.7	0.52	0.10	0.24	0.16
3B1b	Calves	Slurry	150	0.3	0.34	0.05	0.15	0.10
		Solid	150	0.3	0.35	0.07	0.16	0.10
3B2	Sheep	Solid			0.14		0.056	0.017
3B4a	Buffalos	Slurry	700	1.4	2.12	0.35	0.97	0.63
		Solid	700	1.4	1.10	0.34	0.50	0.33
3B4d	Goats	Solid			0.139		0.056	0.017
3B4e	Horses	Solid ([a])	500	1.0	0.48		0.22	0.14
3B4f	Mules and asses	Solid	350	0.7	0.34		0.16	0.10
3B4giv	Ducks	Solid	2	0.004	0.14	0.018	0.14	0.018
3B4giv	Geese	Solid	3.5	0.007	0.24	0.032	0.24	0.032
3B4h	Fur animals	Solid					0.0081	0.0042

Notes:
([a]) Wood shavings.
ID, inhalable dust; n.a. not available; RD, respirable dust.

For cattle, the Tier 1 EFs are based on the solid/liquid distribution of the livestock manure management systems (LMMSs). The LMMS solid/liquid distribution in the EU-27 for dairy cattle is 49/51 and for non-dairy cattle is 59/41, according to EU reporting to the UNFCCC in 2011. Based on these values, the LMMS solid/liquid distribution is assumed to 50/50 for dairy cattle and 60/40 for other cattle.

The EFs given in Table A1.7 are mainly of a similar order of magnitude to those used in the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model for livestock operations accessible at http://www.iiasa.ac.at/). However, for cattle, there is a clear discrepancy between the values presented in Table 3.5 and GAINS EFs. This may be caused by the use of different measurement techniques. More work is required to understand the observed differences, and the EFs presented here and in the GAINS model should therefore be used with caution.

A1.3.2 Tier 2 technology-specific approach

Ammonia

Tables A1.7 to A1.9 give the EFs used in the national inventories of the EAGER group. The Tier 2 EFs used in this chapter were derived as averages of these national EFs. References to the national models are given in the footnotes for each table.

The EFs used in the Tier 2 mass-flow approach to calculate emissions of N_2O-N during manure storage are based on the default IPCC EFs and are given in Table A1.7. The IPCC EFs are expressed as proportions of total N at excretion. In order to convert from the IPCC EF to EFs as proportions of TAN in manures entering storage, the IPCC EF is divided by the proportion of TAN in manure-N entering storage, as illustrated in Table A1.7. The proportions of manure-N as TAN were calculated using the example spreadsheet that accompanies this chapter.

Table A1.7 Derivation of default Tier 2 EF for direct N_2O emissions from manure management. Annex Table A1.8 explains how the manure storage types referred to here relate to those used by IPCC

Storage system	IPCC default EF, kg N_2O-N (kg N_{ex})$^{-1}$	Proportion of TAN in manure at storage ([a])	EF, kg N_2O-N (kg TAN entering store)$^{-1}$
Cattle slurry without natural crust	0	0.50	0
Cattle slurry with natural crust	0.005	0.50	0.01
Pig slurry without natural crust	0	0.65	0
Cattle manure heaps, and solid	0.02	0.25	0.08
Pig manure heaps, and solid	0.02	0.40	0.05
Sheep and goat manure heaps, and solid	0.02	0.30	0.07
Horses, mules and asses manure heaps, and solid	0.02	0.25	0.08
Layer manure heaps, solid	0.02	0.55	0.04
Broiler manure heaps, solid	0.02	0.65	0.03
Turkey and duck manure heaps, solid	0.02	0.60	0.03
Goose manure heaps, solid	0.02	0.60	0.03
Buffalo manure heaps, solid	0.02	0.25	0.08

Note:

([a]) Based on output from the European Agricultural Gaseous Emissions Inventory Researchers (EAGER) network (http://www.eager.ch/).

Table A1.8 Examples of EFs used for individual stages of manure management, expressed as percentages of TAN [a) Housing]

Livestock category	Housing type	Denmark	Germany	Netherlands	Switzerland	United Kingdom
3B1a Dairy cows	Slurry	17.0	19.7	17.7	16.7	31.5
3B1a Dairy cows	Solid					22.9
3B1a Dairy cows	Tied		6.6			
3B1b Other cattle	Slurry					31.5
3B1b Other cattle	Solid	10.0	19.7	16.9	25.0	22.9
3B2 Sheep	Solid	25.0	22.0	11.0		21.6
3B3 Fattening pigs	Slurry	25.0	30.0	31.1	20.0	33.2
3B3 Fattening pigs	Solid		40.0			25.0
3B3 Sows	Slurry		34.0			19.0
3B3 Sows	Solid		34.0			25.0
3B4a Buffaloes	Solid		19.7 ([a])			
3B4d Goats	Solid	25.0	22.0	11.0		21.6
3B4e Horses	Solid	25.0	22.0			
3B4e Mules and asses	Solid	25.0	22.0 ([b])			
3B4gi Laying hens	Solid	35.7	9.4	57.9		37.4
3B4gii Broilers	Litter	36.0	12.9	20.0	57.0	8.1
3B4giii Turkeys	Litter	35.7	52.9	32.1		19.2
3B4giv Ducks	Litter	35.7	11.4	32.1		17.5
3B4giv Geese	Litter	35.7	57.0			
3B4h Fur animals	NA	30.0	27.0			

([a])In the German inventory, buffaloes are included in the category 'Other cattle'.

([b])In the German inventory, mules and asses are included in the category 'Horses'.

Table A1.9 Examples of EFs used for individual stages of manure management, expressed as percentages of TAN [b) Storage]

Livestock category	Housing type	Denmark	Germany	Netherlands	Switzerland	United Kingdom
3B1a Dairy cows	Slurry	18.0	15.0	19.2	27.7	15.7
3B1a Dairy cows	Solid					34.8
3B1b Other cattle	Slurry	31.3				15.7
3B1b Other cattle	Solid	8.6	60.0	2.5	30.0	34.8
3B2 Sheep	Solid	10.0	60.0	5.0		34.8
3B3 Fattening pigs	Slurry	14.0	15.0	15.9	12.0	13.0
3B3 Fattening pigs	Solid		60.0			29.6
3B3 Sows	Slurry		15.0			13.0
3B3 Sows	Solid		60.0			29.6
3B4a Buffaloes	Solid		16.7			40.0
3B4d Goats	Solid	10.0	60.0	5.0		34.8
3B4e Horses	Solid	10.0	60.0			11.8
3B4f Mules and asses	Solid	10.0	60.0			11.8
3B4gi Laying hens	Solid	16.7	8.1			17.8
3B4gii Broilers	Litter			15.0		
3B4giii Turkeys	Litter	25.0	6.5	45.0		17.8
3B4giv Ducks	Litter	25.0	6.5	45.0		17.8
3B4giv Geese	Litter	25.0	6.5			
3B4h Fur animals	NA	8.5				

Table A1.10 Examples of EFs used for individual stages of manure management, expressed as percentages of TAN [c) Spreading]

Livestock category	Housing type	Denmark	Germany	Netherlands	Switzerland	United Kingdom
3B1a Dairy cows	Slurry	61.3	50.0	68.0	48.0	43.0
3B1a Dairy cows	Solid					81.0
3B1b Other cattle	Slurry					43.0
3B1b Other cattle	Solid	64.4	90.0	100.0	60.0	81.0
3B2 Sheep	Solid		90.0	100.0		81.0
3B3 Fattening pigs	Slurry	26.0	25.0	68.0	48.0	33.0
3B3 Fattening pigs	Solid		90.0			81.0
3B3 Sows	Slurry		25.0			33.0
3B3 Sows	Solid		90.0			81.1
3B4a Buffaloes	Solid		55.0			
3B4d Goats	Solid		90.0	100.0		81.0
3B4e Horses	Solid		90.0			
3B4f Mules and asses	Solid		90.0			
3B4gi Laying hens	Solid		90.0	55.0		63.0
3B4gii Broilers	Litter	64.0	90.0	100.0	14.0	63.0
3B4giii Turkeys	Litter		90.0	55.0		63.0
3B4giv Ducks	Litter		90.0	55.0		63.0
3B4giv Geese	Litter		90.0			
3B4h Fur animals	NA					

Table A1.11 Examples of EFs used for individual stages of manure management, expressed as percentages of TAN [d) Grazing]

Livestock category	Denmark	Germany	Netherlands	Switzerland	United Kingdom
3B1a Dairy cows	12.0	12.5	13.3	6.7	7.7
3B1b Other cattle					5.8
3B2 Sheep		7.5	7.5		13.3
3B3 Fattening pigs					
3B3 Sows					
3B4a Buffaloes					12.5
3B4d Goats		7.5	7.5		13.3
3D4e Horses, mules and asses					35.0
3D4f Mules and asses					35.0
3B4gi Laying hens					
3B4gii Broilers					
3B4giii Turkeys					
3B4giv Other poultry					
3B4h Fur animals					

Further information on these EFs can be found in the following publications:

- Hutchings et al., 2001 (Denmark);
- Haenel et al., 2016 (Germany);
- 'MAM' model (Groenwold et al., 2002), and 'FarmMin' model (Evert Van et al., 2003);
- Reidy et al., 2007 (Switzerland);
- Webb and Misselbrook, 2004 (United Kingdom).

The amounts of straw used and the N inputs ($m_{bedding}$) are provided in Step 7 of subsection 3.3.1 and in the example spreadsheet.

A1.4 Tier 3 emission modelling and use of facility data

Other factors, in addition to those listed in section 2.2.1, which influence NH_3 emissions and which may be taken into account using Tier 3 methodologies, are listed below:

- the amount and N content of feed consumed;
- the efficiency of the conversion of N in feed to N in meat, milk and eggs and, hence, the amount of N deposited in excreta;
- climatic conditions in the building (e.g. temperature and humidity) and the ventilation system;
- the storage system of the manure outside the building, i.e. open or covered slurry tank, loose or packed heap of solid manure;
- any treatment applied to the manure such as aeration, separation or composting.

The way in which manure is managed greatly influences emissions of NH_3, since the processes that govern the emission of N species differ among solid, liquid (slurry) and FYM. The addition of litter with a large carbon to N ratio to livestock excreta will promote the immobilisation of TAN in organic N and hence reduce NH_3 emissions. The nature of FYM varies considerably; if it is open and porous, nitrification may take place, whereas if the manure becomes compact, denitrification may occur. Both processes mean that N can be lost as NO, N_2O and N_2. It is therefore necessary to specify the type of manure produced and to account for variations in manure management.

NH_3 emissions from livestock manures during housing and storage and as a result of field application also depend on:

- the temperature and ventilation rates within buildings;
- the size of the soiled surface;
- contact of the manure with ambient air (or cover on the manure store);
- the properties of the manure, including viscosity, TAN content, C content and pH;
- soil properties such as pH, cation exchange capacity, calcium content, water content, buffer capacity and porosity;
- the meteorological conditions including precipitation, solar radiation, temperature, humidity and wind speed;
- the method and rate of application of livestock manures, including, for arable land, the time between application and incorporation, and the method of incorporation;
- the height and density of any crop present.

Particulate matter

The mass flows of emitted particles are governed by the following parameters (examples in parentheses), thus causing uncertainties in terms of predicted emissions (Seedorf and Hartung, 2001):

- building design and operation:
  - ventilation (forced vs naturally ventilated);
  - climate (temperature and relative humidity);
  - type of floor (partly or fully slatted);
  - geometry and positions of inlets and outlets (re-entrainment of deposited particles caused by turbulence above the surfaces within the building);
- livestock bedding:
  - type of material (straw or wood shavings);
  - physical properties of the material;
  - quantity and quality (e.g. straw, chopped straw, wood shavings, sawdust, peat, sand, use of de-dusted bedding materials, mixtures of different materials, litter moisture, supplementation with de-moisturing agents, used mass of bedding material per animal);
- livestock management:
  - animal activity (species, circadian rhythms, young vs adult animals, caged vs aviary systems);
  - time in housing (whole year vs seasonal housing);
  - feeding systems (dry vs wet, automatic vs manual, feed storage conditions);
  - manure systems (liquid vs solid, removal and storage, manure drying on conveyor belts).
  - Type of housed livestock (poultry vs mammals).

A1.4.1 Activity data

Ammonia

Table A1.12 Default values for other losses needed in the mass-flow calculation, related to EF for TAN input to storage

EF	Slurry	Solid
EF_leachateN	NA	12.0 ([a])

Notes:
([a])As a proportion of TAN entering storage (Webb and Misselbrook, 2004).
NA, not applicable.

Record of updates

Table A1.13 Summary of updates to calculation methodologies and EFs made during the 2015 revision of this chapter

Emission type	Tier 1 Methodology	Tier 1 EFs	Tier 2 Methodology	Tier 2 EFs
NH_3	Not updated	Updated to divide Tier 1 EFs among housing; storage and yard areas; spreading; grazing	Not updated	Not updated
NO	Not updated	Not updated	NA	NA
NMVOC	Updated	Updated	Updated	Updated
PM	Updated	Updated	NA	NA

NA, not applicable.

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