Category		Title
NFR:	**3.B**	**Manure management**
SNAP:	**100901** **100902** **100903** **100904** **100905** **100906** **100907** **100908** **100909** **100910** **100911** **100912** **100913** **100914** **100915**	**Dairy cows** **Other cattle** **Fattening pigs** **Sows** **Sheep** **Horses** **Laying hens** **Broilers** **Other poultry** **Goats** **Fur animals** **Mules and asses** **Camels** **Buffalo** **Other animals**
ISIC:		
Version	**Guidebook 2013**	
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Contents

1 Overview

Ammonia (NH_3) emissions lead to the acidification and eutrophication of natural ecosystems. Ammonia may also form secondary particulate matter (PM). Nitric oxide (NO) and non-methane volatile organic compounds (NMVOCs) are involved in the formation of ozone, 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 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. Those emissions take place from buildings housing livestock and outdoor yard areas, from manure stores, following land spreading of manures and during grazing. Emissions of PM arise mainly from feed, and also from bedding, animal skin or feathers, and take place from buildings housing livestock. Emissions of nitrous oxide (N_2O) also occur, and are accounted for here where necessary for accurate estimation of NH_3 and NO, but are not reported here, being a greenhouse gas.

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

Livestock excreta and manures are currently estimated to account for only *ca*. 2 % of total NO and NMVOC emissions. However, there is considerable uncertainty concerning the NMVOC emissions from this source; Hobbs et al. (2004) estimated emissions from livestock production could be *ca*. 7 % of total UK emissions.

Emissions from pig and poultry houses represent around 30 and 55 % respectively of agricultural PM_{10} emissions; the remainder is mainly produced by arable farming. Livestock housing is estimated to produce between 9 and 35 % of total emissions as PM_{10}.

This chapter covers emissions from manure management, including animal husbandry and emissions following application of manures to land. Emissions of greenhouse gases from excreta deposited in fields by grazing animals are dealt with by Intergovernmental Panel on Climate Change (IPCC) under Agricultural Soils. However, in this Guidebook, emissions from this source are calculated in this chapter. This is because the Tier 2 methodology developed to calculate NH_3 emissions from livestock production treats those 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 NH_3 emissions from subsequent sources to be estimated (see Appendix A1). Nevertheless, grazing emissions are reported in NFR category 3.D.a.3 ‘Urine and dung deposited by grazing animals’. Calculation and reporting are separate processes, and hence calculation methods can be carried out together for several reporting categories. Where methods do not allow separation of the necessary reporting categories, a country can report all emissions under one category and use IE (‘included elsewhere’) for the other. Such an approach will be necessary when emissions are calculated using the Tier 1 approach.

In the remainder of this chapter, the comment ‘see Appendix A’, indicates that further information is provided in the Appendix under the same section heading prefixed A.

2 Description of sources

There are five main sources of emissions from animal husbandry and manure management:

- livestock feeding (PM)
- livestock housing and holding areas (NH_3, PM, NMVOCs)
- manure storage (NH_3, NO, NMVOCs)
- field-applied manure (NH_3, NO, NMVOCs)
- manure deposited during grazing (NH_3, NO, NMVOCs)

2.1 Process description

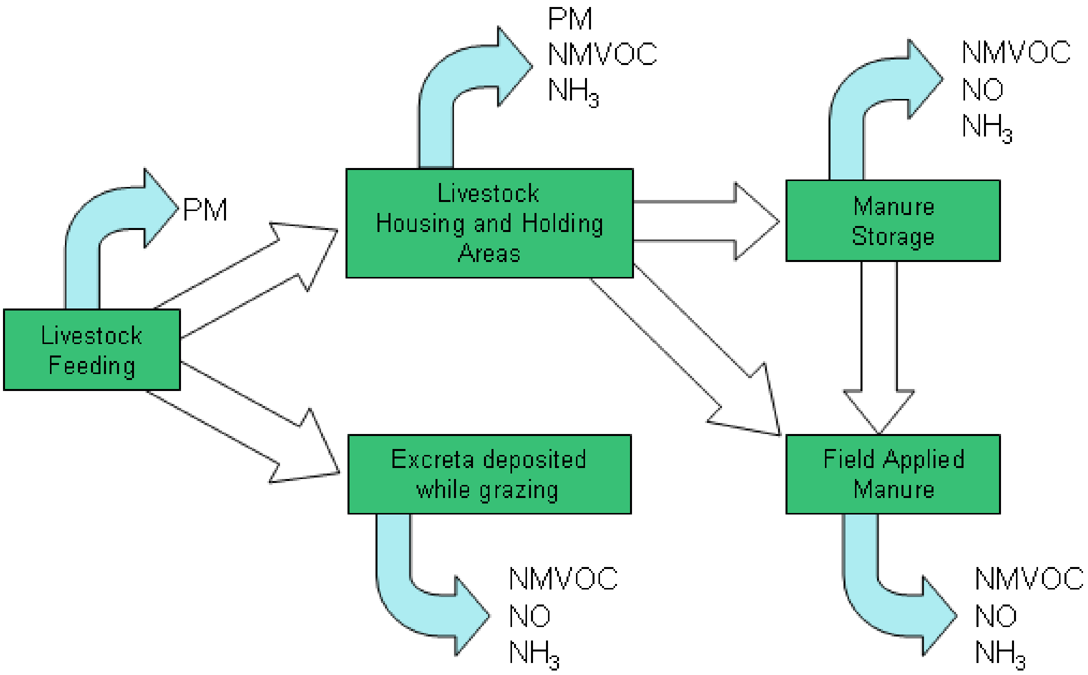

Figure 2-1 Process scheme for source category 3.B, Manure management

2.1.1 Ammonia

Ammonia 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 emission from manure management is the N excreted by livestock. Typically, more than half of the N excreted by mammalian livestock is in the urine, and between 65 and 85 % of urine-N is in the form of urea and other readily-mineralised compounds (ruminants: Jarvis et al., 1989; pigs: Aarnink et al., 1997). Urea is rapidly hydrolysed by the enzyme urease to ammonium carbonate ($(NH_4)_2CO_3$) and ammonium (NH_4^+) ions provide the main source of NH_3. Ammonium-N (NH_4^+-N) and compounds, including uric acid, which are readily broken down to NH_4^+-N, are referred to as total ammoniacal-N (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 emission is sufficiently small (Petersen et al., 1998) for estimates of total ammoniacal N (TAN) at grazing or in buildings to be based on urine-N, albeit 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).

Ammonia is emitted wherever manure is exposed to the atmosphere; in livestock housing, manure storage, after manure application to fields and from excreta deposited by grazing animals (note that although the NH_3 emission from grazing animals is calculated here, it should be reported under NFR 3.D, 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 Appendix A2.1.

2.1.2 Nitric oxide

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 describing NO emissions from manure management (Groenestein and van Faassen, 1996). Nitric oxide emission from soils is generally considered to be a product of nitrification. Increased nitrification is likely to occur following application of manures and deposition of excreta during grazing.

2.1.3 NMVOCs

NMVOC emissions from animal husbandry originates from feed, especially silage, degradation of feed in the rumen, and from partly digested and undigested fat, carbohydrate and protein decomposition in the rumen and in manure (Ni et al. 2012, Feilberg et al. 2010, Ngwabie et al. 2008, Amon et al. 2007, Alanis et al. 2008, 2010, Elliot-Martin et al. 1997, Trabue et al. 2010, Rumsey et al. 2011, Parker et al. 2010). Consequently, anything that affects the rate of feeding and manure management, such as the amount of formic acid added to silage, management of silage heaps and animal feeding, manure management in the animal housing and storage, straw added to the manure and the duration of storage and the technique used for manure application, will affect NMVOC emissions. Sites of emission include livestock buildings, yards, and manure stores, fields to which manure is spread and fields grazed by livestock. Emissions take place from manure managed in solid form or as slurry. 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 (Elliot-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. Only a limited number of studies have been undertaken on NMVOC emissions from animal 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 issues.

2.1.4 Particulate matter (PM)

The main source of PM emission is from 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. Bedding materials such as straw or wood shavings can also give rise to airborne particulates. Poultry and pig farms are the main sources of PM. Emissions from poultry houses also arise from feathers and manure, while emissions from pig houses arise from skin particles, faeces and bedding (Aarnink and Ellen, 2008). Animal activity may also lead to re-suspension of previously settled dust into the atmosphere of the livestock building (re-entrainment).

2.2 Techniques

2.2.1 Ammonia

Ammonia emissions from livestock production depend on many factors including:

- the amount and N content of feed consumed;
- the efficiency of conversion of N in feed to N in meat, milk and eggs and, hence, the amount of N deposited in excreta;
- the proportion of time spent by animals indoors and outside, e.g. at pasture or on yards or, buildings and on 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 manure is stored inside the building;
- climatic conditions in the building (e.g. temperature and humidity) and the ventilation system;

  the storage system of the manure outside the building: 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 excretion of N, and the subsequent emissions of NH_3, varies between livestock species (e.g. cattle, pigs). Within a livestock species, there are large differences between 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.

The way in which manure is managed greatly influences emissions of NH_3, since the processes that govern the emission of N species differ between solid, liquid (slurry) and FYM. The addition of litter with a large carbon:nitrogen ratio to livestock excreta will promote immobilization 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.

Note:

The pathways for emission of N species are shown in Figure 2–2.

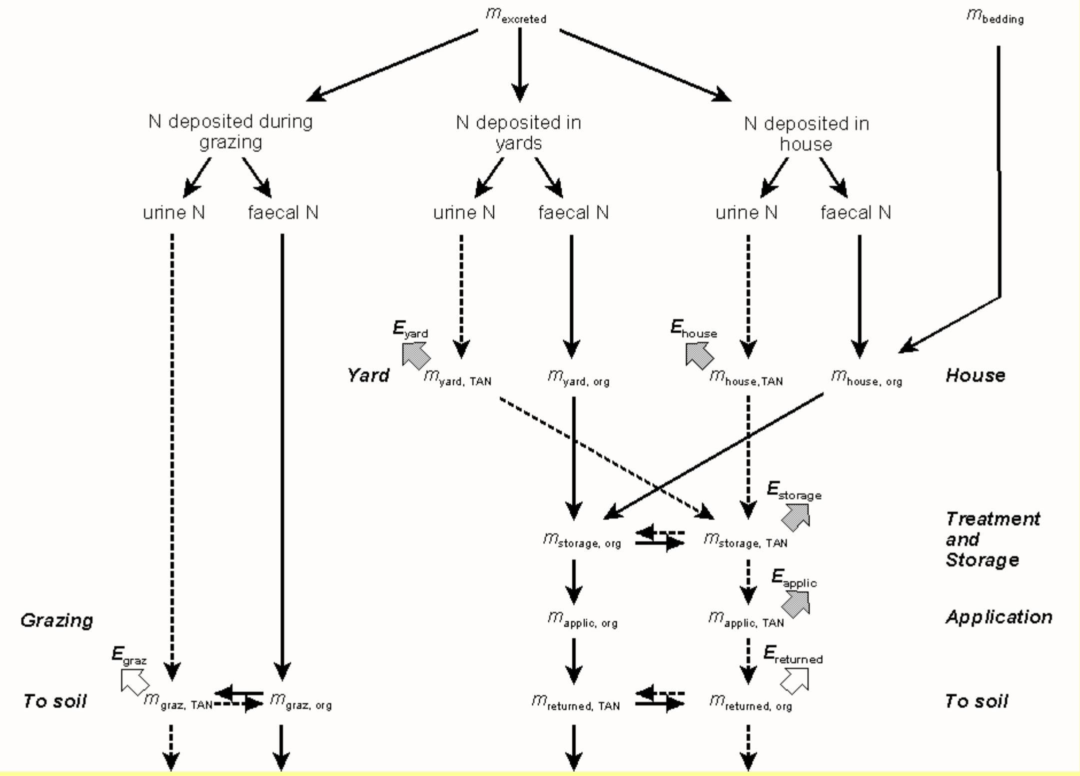

Figure 2–2 N flows in the manure management system.

Notes:

m mass from which emissions may occur. Narrow broken arrows: TAN; narrow continuous arrows: organic N. The horizontal arrows denote the process of immobilization in systems with bedding occurring in the house, and the process of mineralization during storage. Broad hatched arrows denote emissions assigned to manure management: E emissions of N species (E_{yard} NH_3 emissions from yards; E_{house} NH_3 emissions from house; E_{storage} NH_3, N_2O, NO and N_2 emissions from storage; E_{applic} NH_3 emissions during and after spreading. Broad open arrows mark 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 (Dämmgen and Hutchings, 2008). See subsection 3.3.1 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 NH_3 accurately it is necessary to follow the fate of the two fractions of N separately.

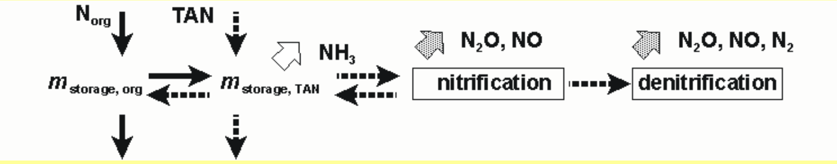

Figure 2-3 Processes leading to the emission of gaseous N species from manure (TAN = total ammoniacal N)

Ammonia emissions from livestock manures during and after field application depend on:

- 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;
- 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 method of incorporation;
- the height and density of any crop present.

2.2.2 Nitric oxide

Nitric oxide may be produced during nitrification and denitrification as indicated in Figure 2-2.

2.2.3 NMVOCs

Over 500 volatile compounds originating from cattle, pigs and poultry have been identified (Ni et al. 2012, Shiffmann et al., 2001), although only ca. 20 compounds were considered significant by Hobbs et al. (2004) and US EPA (2012), accounting for 80-90 % of the total emission. The wide range of compounds have very different physical and chemical properties. Variations in chemical activity, water solubility and the extent to which they bind to surfaces presents significant challenges to the measuring methodology which again may yield high uncertainties and to difficulties in the interpretation of measured data.

Emissions of NMVOC occur from silage, manure in the barns, outside manure stores, field application of manure and from grazing animals. There are a lack of emission estimates with respect to feeding with silage, outdoor manure stores, manure application and grazing animals. The large majority of research has focused on emission from housed animals. The emission estimates provided here are thus based on assumed proportions of the emission which occurs in the animal house (for detailed explanation please refer to Appendix A).

2.2.4 PM

Emissions of PM occur from both housed and free-range animals. Because of the lack of available emission data for free-range animals, the definition of emission factors (EFs) has focused on housed animals. The mass flows of emitted particles are governed by the following parameters (examples in brackets), thus causing uncertainties in terms of predicted emissions (Seedorf and Hartung, 2001):

- physical density and particle size distribution of livestock dust;
- type of housed animals (poultry vs. mammals);
- type of feeding system (dry vs. wet, automatic vs. manual, feed storage conditions);
- type of floor (partly or fully slatted);
- the use of bedding material (straw or wood shavings);
- the manure system (liquid vs. solid, removal and storage, manure drying on conveyor belts);
- animal activity (species, circadian rhythms, young vs adult animals, caged vs aviary systems);
- ventilation rate (summer vs. winter, forced vs naturally ventilated);

- geometry and positions of inlets and outlets (re-entrainment of deposited particles caused by turbulence above the surfaces within the building);
- indoor climate in the building (temperature and relative humidity);
- the time-period of housing (whole year vs. seasonal housing);
- the management (all-in and all-out systems, with periods of empty livestock building due to cleaning and disinfection procedures vs. continuously rearing systems);
- secondary sources due to farmers' activities (tractors, walking through the building to check on livestock);
- cleaning practices (forced air vs. vacuum).

2.3 Emissions

2.3.1 Ammonia

Estimates of NH_3 emissions from agriculture indicate that in Europe 80-90 % originate from animal 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 the UK, dairy cows account for 32 % of the total from agriculture while other cattle account for 25 % of the agriculture total (Misselbrook et al., 2006). 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 minor sources, although sheep are a significant source for some countries.

It is important to consider the relative size 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 following application of manures to land, each of which typically account for 30–40 % of NH_3 emissions 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 TAN in urine deposited directly on pastures is quickly absorbed by the soil. The proportion of emission from buildings and following manure spreading will decrease as the proportion of the year spent at pasture increases.

The wide-scale introduction of abatement techniques, while 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 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 in subsection 2.2.1 above. In practice, results may be summarised to provide 'average' EFs per animal for each stage of emission for the main livestock classes and management types, or to provide total annual EF. Total NH_3 emissions are then scaled by the numbers of each class of animals in each country.

For minor sources, emissions may be reported using a Tier 1 methodology. For key sources, it is good practice to use a Tier 2 or Tier 3 methodology. This means that for each livestock category, the emissions from grazing, animal housing, manure treatment and storage as well as field application or disposal need to be specified.

2.3.2 Nitric oxide

Very few data are available on emissions of NO from manures during housing and storage that may be used as a basis for compiling an inventory (Groenestein and van Faassen, 1996). Emissions of NO are estimated to quantify the N mass balance for the Tier 2 methodology for calculating NH_3 emissions. Such estimates may be used as an estimation of NO emissions during housing and storage.

2.3.3 NMVOCs

A list of the principal NMVOCs, from the main emission sources, and a classification of the VOCs according to their importance, was included in the protocol to address reducing VOC emissions and their transnational flows (United Nations Economic Commission for Europe (UNECE), 1991). The 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 OH-radicals.

Some of the major NMVOCs released from agricultural barns can be seen in Appendix A. In the context of the Guidebook, NMVOCs are defined as ‘all those organic compounds other than methane which can produce photochemical oxidants by reaction with nitrogen oxides in the presence of sunlight’ (UNECE, 1991). A large US study (US EPA, 2012) showed that up to 50 % of the NMVOC emission from animal husbandry consist of iso-propanol and n-propanol, followed by acetaldehyde and short-chained acids (acetic acid, propionic acid, butanoic acid). Ethyl acetate was only found in significant quantities in cattle housing. Sulphur compounds can be a major source. In the NAEM study (US AEP, 2012), dimethylsulphide (DMS) accounted for 1-3 % of the NMVOC emissions. However,dimethyl disulphide (DMDS) was found in larger concentrations in poultry housing.

2.3.4 PM

In order to calculate PM emissions in detail, it would be necessary to have quantitative data on all the factors noted in subsection 2.2.4 above. In practice, the data available allow the use only of average EF for each livestock sub-category.

Further information on emissions is given in Appendix A2.3.

2.4 Controls

The abatement of emissions of N species can be achieved by a number of methods. Reducing N inputs and hence N excretion has the potential to reduce all N losses.

2.4.1 Ammonia

There are a number of potential methods for reducing NH_3 emissions. With any of these methods, it is essential that due care is taken to ensure that conserved N is made available as a crop nutrient and does not cause other environmental problems via run-off, nitrate (NO_3) leaching or N_2O emission.

In summary, there are five approaches to reducing NH_3 loss:

- nitrogen management;
- livestock feeding strategies to reduce N and/or TAN excretion;

- reduce emissions from housing systems;
- reduce emissions during storage;
- reduce emissions during and after spreading.

Measures to reduce NH_3 emissions from manure management are listed and explained in Appendix A2.4.1, while detailed descriptions of measures can be found in http://www.unece.org/fileadmin/DAM/env/documents/2012/EB/N_6_21_Ammonia_Guidance_Document_Version_20_August_2011.pdf

2.4.2 Nitric oxide

Meijide et al. (2007) reported a reduction in NO emissions of *ca*. 80 % when the nitrification inhibitor dicyandiamide (DCD) was added to pig slurry before application to land, albeit unabated emissions were only 0.07 % of N applied. The use of nitrification inhibitors has been proposed to reduce emissions of N_2O, so their use may have an additional benefit in curtailing those of NO.

2.4.3 NMVOCs

Techniques which reduce NH_3 and odour emissions may also be considered effective in reducing the emission of NMVOCs from livestock manure (Appendix A2). Reduction possibilities include the immediate covering of silage stores (pits) and minimising the area of silage available to feeding animals. Further examples include provision of only small amounts of feed on the feeding table, high feed quality with a high digestibility because it lower the substrate for NMVOC formation, immediate removal of urine and manure from cubicles for cattle, fast removal of slurry for pigs and belt drying of manure inside the poultry houses for laying hens and limited stirring of manure in manure stores. Systems already described for reducing NH_3 emissions from storage such as natural and artificial floating crust and floating mats give some odour reduction due to reduction of the emission of NMVOC (Mannebeck, 1986, Blanes-Vidal et al., 2009, Bicudo et al. 2004, Zahn et al. 2001).

2.4.4 PM

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 indoor techniques preventing excessive dust generation. Shelter belts may also give some reduction in the dispersal of PM emitted from buildings. End-of-pipe technologies are also available to reduce PM emissions significantly, in particular filters, cyclones, electrostatic precipitators, wet scrubbers or biological waste air purification systems. While 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).

When applicable abatement techniques become available, EFs will be added in the methodology to calculate the PM_{10} emissions.

3 Methods

3.1 Choice of method

The decision tree below provides a guide to the choice of method for estimating emissions.

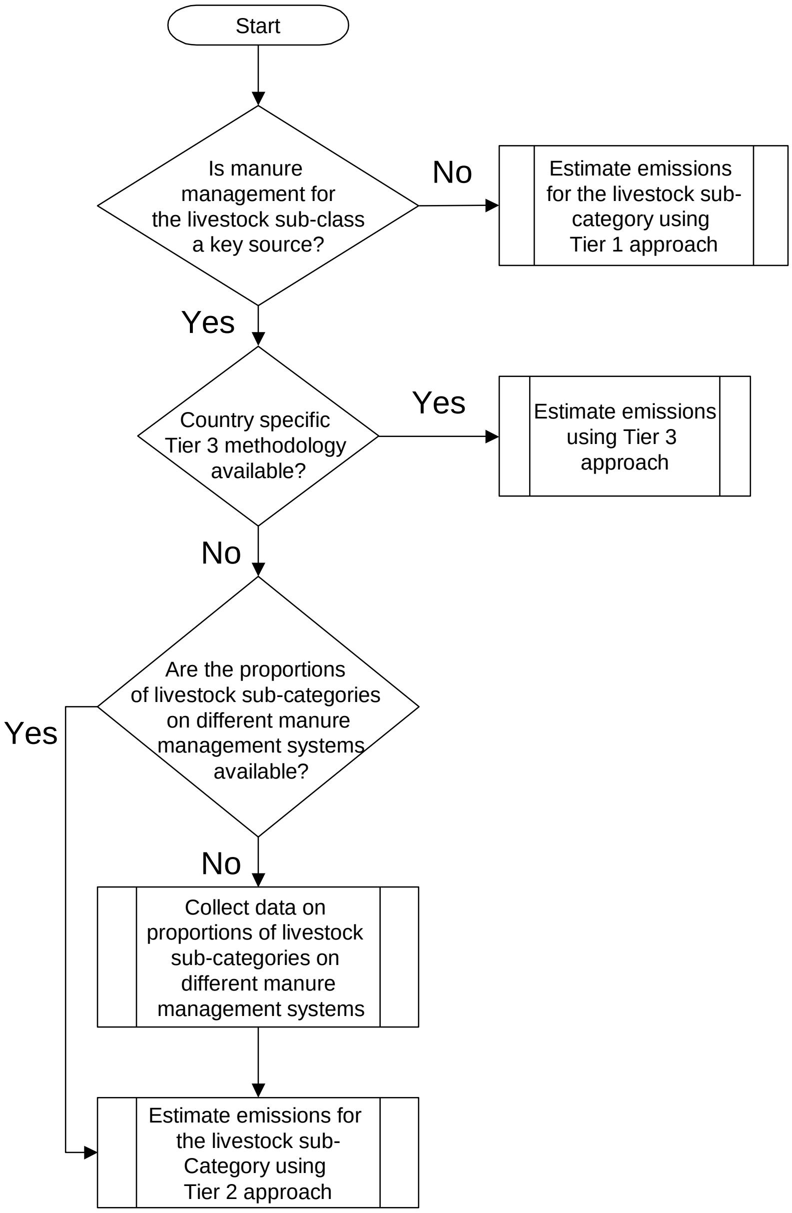

Figure 3-1 Decision tree for source category 3.B Manure management

3.1.1 Ammonia

In most, if not all, countries, the main livestock categories will be key sources for NH_3 and it is good practice for emissions to be calculated using at least a Tier 2 approach. However, the Tier 1 approach may be used for livestock categories that play only a minor role in the inventory.

The approach required is that:

- if detailed information is available, use it;

- if the source category is a key source, it is good practice to use a Tier 2 or better method and to collect detailed input data. The decision tree directs the user in such cases to the Tier 2 method, since it is expected that the necessary input data with respect to N excretion and manure management systems will be available, but the country-specific EFs needed for a Tier 3 estimate are not available;
- the alternative of applying a Tier 3 method is recommended for those countries with enough data to enable the enumeration of country-specific EFs. Those countries that have developed a mass-flow approach to calculating national NH_3-N emissions should use that approach subject in compliance with subsection 4.6 of the present chapter.

3.2 Tier 1 default approach

3.2.1 Algorithm

Step 1 is to define appropriate livestock categories and obtain the annual average number of animals in each category (see subsection 3.3.1 of the present chapter). The aim of the categorisation is to group types of livestock that are managed similarly (typical examples are shown in Table 3–1).

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

Step 3 is to find the default EF for each livestock category from subsection 3.2.2 of the present chapter.

Step 4 is the calculation of the pollutant emissions, $E_{pollutant\_animal}$ for each livestock category, using the respective annual average population of each category, AAP_{animal} and the relevant EF $EF_{pollutant\_animal}$:

$$E_{pollutant\_animal} = AAP_{animal} \cdot EF_{pollutant\_animal} \qquad (1)$$

where

AAP_{animal} = number of animals of a particular category that are present, on average, within the year. For a fuller explanation, see IPCC (2006).

Ammonia

The Tier 1 method entails multiplying the average annual population (AAP) in each livestock class; by a single default EF, expressed as kg AAP^{-1} a^{-1} NH_3. This EF includes emissions during grazing for ruminant livestock and emissions following spreading of manures for all livestock categories. This means that when using the Tier 1 methodology for an animal category, emissions should be reported under NFR 3.B alone and no emissions from grazing should be reported for the animal category under NFR 3.D.a.3.

3.2.2 Default emission factors

The default EFs are listed below, categorised according to pollutant and then source. Users wishing to see the same EFs categorised according to source and then pollutant are directed to Appendix B.

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, default N excretion data and default data on proportions of TAN in excreta and, where appropriate, default data on the length of the grazing period. Where 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 class 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. Further information on the derivation of these EFs is given in Appendix A.3.2.

Table 3.1 Default Tier 1 EF (EF_{NH3}) for calculation of NH_3 emissions from manure management. Figures are annually averaged emission kg AAP^{-1} a^{-1} NH_3, as defined in subsection 3.3.1 of the present chapter.

SNAP	Livestock	Manure type	EF_{NH3} (kg a^{-1}. AAP^{-1} NH_3)
100901	Dairy cows	slurry	39.3
100901	Dairy cows	solid	28.7
100902	Other cattle (including young cattle, beef cattle and suckling cows)	slurry	13.4
100902	Other cattle	solid	9.2
100903	Fattening pigs	slurry	6.7
100903	Fattening pigs	solid	6.5
100904	Sows	slurry	15.8
100904	Sows	solid	18.2
100904	Sows	outdoor	7.3
100905 +100911	Sheep (and goats)	solid	1.4
100906 +100912	Horses (and mules, asses)	solid	14.8
100907	Laying hens (laying hens and parents)	solid	0.48
100907	Laying hens (laying hens and parents)	slurry	0.48
100908	Broilers (broilers and parents)	litter	0.22
100909	Other poultry (ducks)	litter	0.68
100909	Other poultry (geese)	litter	0.35
100909	Other poultry (turkeys)	litter	0.95
100910	Fur animals		0.02
100913	Camels	solid	10.5
100914	Buffalo	solid	9.0

Sources: Default grazing periods for cattle were taken from Table 10A 4-8 of IPCC chapter 10: Emissions from Livestock and Manure Management, default N excretion data for Western Europe from Table 10.19, also given in Table 3-8, together with the housing period on which these EFs are based.

Sheep are here defined as mature ewes with lambs until weaning. To calculate emissions for lambs from weaning until slaughter, or other sheep, adjust the EF quoted in Table 3–1 according to the ratio of annual N excretion by the other sheep to that of the mature ewe. 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. See subsection 3.2.3 of the present chapter for details of how the activity data should be calculated. The default EF presented in Table 3–1 were calculated using the Tier 2 approach outlined in subsection 3.2.1 below using default EF for each emission derived from those used in the mass-flow models evaluated by the EAGER group (Reidy et al., 2007 and in preparation and references cited therein).

Nitric oxide

The default Tier 1 EFs were calculated using the Tier 2 methodology for NH_3. Emissions of NO need to be estimated in the mass flow approach in order to accurately calculate the flow of TAN. Output from those calculations is cited below to provide EFs for NO. The default Tier 1 EFs for NO have been calculated using the Tier 2 default NO-N EFs during manure storage, based on default N excretion data and default data on proportions of TAN in excreta and, where appropriate, default data on the length of the grazing period. Where 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 class 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 for NO

SNAP	Livestock	Manure type	EF_{NO} (kg a^{-1}. AAP^{-1} NO)
100901	Dairy cows	slurry	0.007
100901	Dairy cows	solid	0.154
100902	Other cattle (including young cattle, beef cattle and suckling cows)	slurry	0.002
100902	Other cattle	solid	0.094
100903	Fattening pigs	slurry	0.001
100903	Fattening pigs	solid	0.045
100904	Sows	slurry	0.004
100904	Sows	solid	0.132
100904	Sows	outdoor	0
100905 +100911	Sheep (and goats)	solid	0.005
100906 +100912	Horses (and mules, asses)	solid	0.131
100907	Laying hens (laying hens and parents)	solid	0.003
100907	Laying hens (laying hens and parents)	slurry	0.0001
100908	Broilers (broilers and parents)	litter	0.001
100909	Other poultry (ducks)	litter	0.004
100909	Other poultry (geese)	litter	0.001
100909	Other poultry (turkeys)	litter	0.005
100910	Fur animals	solid	0.0002
100913	Camels	solid	NA
100914	Buffalo	solid	0.043

Sources: Default grazing periods for cattle were taken from Table 10A 4-8 of IPCC chapter 10: Emissions from Livestock and Manure Management, default N excretion data for Western Europe from Table 10.19, also given in Table 3–8, together with the housing period on which these EFs are based.

NMVOCs

The default Tier 1 NMVOC emission factors are based on results from a study in the U.S.A. (US EPA, 2012). This National Air Emissions Monitoring study (NAEM) included NMVOC measurements from 16 different animal 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 IPCC default values for animal feed intake and excretion of VS (US EPA, 2012, IPCC 2006, Shaw et al. 2007). The emission factor 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 IPCC 2006 Guidelines. Please refer to Section A2.3 for a detailed explanation.

Silage is a major source of emissions, which indicates 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 length of the housing periods are shown in Table 3-8.

At present, there are few data available concerning the NMVOC emissions from manure storage and manure application. However, a correlation between the NH_3 emission and many of the different NMVOCs during housing has been found ($r^2 \approx 0.5$) (Feilberg et al. 2010). Therefore, emissions from manure stores and manure application are estimated as a fraction of those from livestock housing. The fraction is assumed to be the same ratio as for NH_3 emissions. Especially for manure application this methodology could be biased because the NMVOCs are formed in the manure during storage and released after manure application. This is partly in contradiction to NH_3 were the emission occurs both from the manure and after application because the NH_3 is formed in the manure during the degradation process and is in an equilibrium state with NH_4. Emissions from animals on grass are assumed to be low and estimates are based on Shaw et al. (2007).

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

Table 3-3 Default Tier 1 EF for NMVOC

		EF, with silage feeding	**EF, without silage feeding**
Code	**Livestock**	**NMVOC, kg AAP^{-1}. a^{-1}**	
100901	Dairy cows	17.937	8,047
100902	Other cattle[1]	8.902	3,602
100903	Fattening pigs[2]	-	0.551
100904	Sows	-	1.704
100905	Sheep	0.279	0.169
100911	Goats	0.624	0.542
100906	Horses	7.781	4.275
100912	Mules and Asses	3.018	1.470
100907	Laying hens (laying hens and parents)	-	0.165
100908	Broilers (broilers and parents)	-	0.108
100909	Other poultry (ducks, geese, turkeys)[3]	-	0.489
100910	Fur animals	-	1.941
	Rabbits	-	0.059
	Reindeer[4]	-	0.045
100913	Camels	-	0.271
100914	Buffalo	9.247	4.253

(1) Includes young cattle, beef cattle and suckling cows

(2) Includes piglets from 8 kg to slaughtering

(3) Based on data for turkeys

(4) Assume 100% grazing

Particulate matter

Emissions of PM occur from both housed and free-range animals. However, due to lack of available emission data, the estimated emission factors (EFs) are focused on housed animals.Knowledge of a variety of different parameters are important in order to determine emissions of PM, of which the most decisive parameters are feeding conditions, animal activity and bedding material. The PM EF is based on a study based upon north European barns with cattle, pig and poultry (Takai et al., 1998), with the exceptions of goats and fur animals for which the EFs are based on Mosquera and Hol (2011) and Mosquera et al. (2011). The EF for horses is based on Seedorf and Hartung (2001). Refer to Appendix A for detailed description.

Table 3.3 Default Tier 1 estimates of EF for particle emissions from animal 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})
100901	Dairy cows	1.38	0.63	0.41
100902	Other cattle (including young cattle, beef cattle and suckling cows)	0.59	0.27	0.18
100902	Calves	0.34	0.16	0.10
100903	Fattening pigs	0.75	0.34	0.06
	Weaners	0.21	0.10	0.02
100904	Sows	1.53	0.69	0.12
100905	Sheep	0.139	0.0556	0.0167
100911	Goats	0.139	0.0556	0.0167
100906	Horses	0.48	0.22	0.14
100912	Mules and asses	0.34	0.16	0.10
100907	Laying hens (laying hens and parents)	0.119	0.119	0.023
100908	Broilers (broilers and parents)	0.069	0.069	0.009
100909	Ducks	0.14	0.14	0.02
100909	Geese	0.24	0.24	0.03
100909	Turkeys	0.52	0.52	0.07
100910	Fur animals	0.018	0.0081	0.0042
100914	Buffalo	1.45	0.67	0.44

Source: Takai et al., 1998, Seedorf and Hartung et al. (2001), Mosquera and Hol, (2011), Mosquera et al. (2011).

3.2.3 Activity data

For Tier 1, data are required on animal 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://epp.eurostat.ec.europa.eu) or the Food and Agriculture Organization of the United Nations (FAO) Production Yearbook (FAO, 2005/2006) can be used.

The average annual population, 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 commonest are that the production is seasonal or because the building is being cleaned in preparation for the next batch of animals.

Table 3.4 Definitions of terms used in 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 (n_{places})	-	Average capacity for an animal 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 (t_{empty})	d	The average duration during the year when the animal place is empty (in d)
Cleaning period ($t_{cleanse}$)	d	The time between production cycle or rounds when the animal place is empty, e.g. for cleaning (in d)
Production cycle (n_{round})	-	The average number of production cycles per year
Number of animals produced (n_{prod})	a^{-1}	The number of animals produced during the year
Proportion dying (x_{ns})	-	Proportion of animals that die and are not sold

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

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

Where the duration of an animal life or the time that animals remain within a category is less than one 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 when the animal place is empty ($t_{cleanse}$):

2) $t_{empty} = n_{round} \cdot t_{cleanse}$ (3)

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

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

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

Particulate matter

Information is required on animal numbers or animal places, respectively, and for the prevailing housing systems or their frequency distribution.

3.3 Tier 2 technology-specific approach

3.3.1 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 N. The resultant estimates of NH_3-N emissions are then converted to NH_3. When 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 emissions 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 animal diets on gaseous N emissions, since the excretion of total N and TAN respond differently to such changes.

Such estimates 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 between real-world systems. This approach has several advantages over the Tier 1 methodology:

- 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 + N added in bedding minus the N emitted and 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 allowance 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 toward developing a Tier 3 methodology (see section 3.4 below).

Default values are provided for N excretion, proportion of TAN and emissions at each stage of manure management (Table 3–8). It is good practice for every country to use country-specific activity data. Appendix A (Table A3–7) explains the derivation of the default NH_3-N EF, which can be helpful for calculating country-specific EF for Tier 3. Country-specific EF 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 animal 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, where necessary, expert judgement.

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

In the following stepwise procedure, manure is assumed to be managed either as slurry or as solid. Slurry consists of excreta, spilt animal 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 in IPCC (2006); see Appendix Table A3–8 which relates storage categories commonly referred to in NH_3

inventories to the classification used by IPCC. Solid manure consists of excreta, spilt animal feed and drinking water and may also include bedding material. It is equivalent to the solid manure category in IPCC (2006). For situations where manure is separated into liquid and solid fractions, the liquid should be treated as if it were slurry.

Step 1 is the definition of livestock subcategories that are homogeneous with respect to feeding, excretion and age/weight range. Typical animal categories are shown in Table 3–1. The respective number of animals has to be obtained, as described in subsection 3.3.1 of the present chapter. Steps 2 through to 14 inclusive should then be applied to each of these subcategories and the emissions summed.

Step 2 is the calculation of the total annual excretion of N by the animals **(**N_{ex}; kg AAP^{-1} a^{-1}**).** Many countries have detailed procedures to derive N excretion rates for different livestock categories. If these are not available, the method described in IPCC (2006), chapter 10 (equations 10.32 and 10.33), should be used as guidance, where N_{ex} is the same as $Nex_{(T)}$. For convenience, default values are given in Table 3.5 below.

Step 3 is to calculate the amount of the annual N excreted that is deposited in 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 the 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 should always total 1.0.

$$m_{graz\_N} = x_{graz} \cdot N_{ex} \tag{5}$$

$$m_{yard\_N} = x_{yards} \cdot N_{ex} \tag{6}$$

$$m_{build\_N} = x_{build} \cdot N_{ex} \tag{7}$$

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

$$m_{graz\_TAN} = x_{TAN} \cdot m_{graz\_N} \tag{8}$$

$$m_{yard\_TAN} = x_{TAN} \cdot m_{yard\_N} \tag{9}$$

$$m_{build\_TAN} = x_{TAN} \cdot m_{build\_N} \tag{10}$$

If detailed national procedures for deriving N excretion rates which 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 3–8 should be used.

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 ($m_{build\_solid\_TAN}$).

$$m_{build\_slurry\_TAN} = x_{slurry} \cdot m_{build\_TAN} \tag{11}$$

$$m_{build\_slurry\_N} = x_{slurry} \cdot m_{build\_N} \tag{12}$$

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

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

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

Step 6 is to calculate the NH_3-N losses, E_{build}, from the livestock building and from the yards, by multiplying the amount of TAN m_{build_TAN} with the emission factor EF_{build} (NH_3-N) for both slurry and FYM

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

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

And by multiplying the amount of TAN, $m_{yard,TAN}$ with the emission factor EF_{yard}:

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

This will give emissions as kg NH_3-N.

Step 7 is only applied to solid manure. Its function is to allow for the addition of N in bedding for the animals ($m_{bedding}$) in these litter-based housing systems and to account for the consequent immobilization 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 are either passed to storage, or spread direct to the fields then calculated, remembering to subtract the NH_3-N emission from the livestock buildings.

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 3–6 below.

Table 3.5 Default values for length of housing period, annual straw use in litter-based manure management systems and the N content of straw

Livestock class	Housing period, d	Straw, kg AAP^{-1} a^{-1}	N added in straw, kg AAP^{-1} a^{-1}
Dairy cows (100901)	180	1 500	6.00
Other cattle (100902)	180	500	2.00
Finishing pigs (100903)	365	200	0.80
Sows (100904)	365	600	2.40
Sheep and goats (100905)	30	20	0.08
Horses, etc. (100906)	180	500	2.00
Buffalos (100914)	225	1500	6.00

The amounts of straw given are for the stated housing period. For greater or lesser 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 (f_{imm}) of TAN that is immobilised in organic matter when manure is managed as solid, as this immobilization will greatly reduce the potential NH_3-N emission during storage and after spreading (including from manures spread direct from buildings).

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

$$m_{ex\text{-}build\_solid\_N} = [m_{build\_solid\_N} + m_{bedding\_N} - E_{build\_solid}] \quad (19)$$

If data for f_{imm} are not available, it is recommended to use

$f_{imm} = 0.0067$ kg kg^{-1} (Kirchmann and Witter, 1989)

Step 8 is to calculate the amounts total-N and TAN stored before application to land. Not all manures are stored before spreading; some will be applied to fields direct from buildings. The proportions of slurry and FYM stored (x_{store_slurry} and x_{store_FYM}) therefore need to be known.

For slurry:

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

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

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

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

For solid:

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

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

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

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

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

The modified mass $mm_{storage,slurry,TAN}$, from which emissions are calculated are:

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

If data f_{min} are not available, it is recommended to use

$f_{min} = 0.1$ (Dämmgen et al. 2007)

Step 10 is to calculate the emissions of NH_3, N_2O, NO and N_2 (using the respective EFs $EF_{storage}$) and $mm_{storage\_TAN}$).

For slurry:

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

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

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

$$E_{storage\_solid} =$$

$$E_{storage\_solid\_NH3} + E_{storage\_solid\_N2O} + E_{storage\_solid\_NO} + E_{storage\_solid\_N2} + E_{storage\_solid\_N2}$$

$$= m_{storage\_solid\_TAN} \cdot (EF_{storage\_solid\_NH3} + EF_{storage\_solid\_N2O} + EF_{storage\_solid\_NO} + EF_{storage\_ solid\_N2} + EF_{storage\_solid\_N2}) \quad (30)$$

For both slurry and litter-based manures, default values for the EFs are given in Table 3.6 (N_2O), Table 3.7 (NH_3), and Table 3.7 (NO and N_2). Equations 28 and 29 provide the Tier 2 EF for NO.

Table 3.6 Default Tier 2 EF for direct N_2O emissions from manure management. Appendix Table A3–8 explains how the manure storage types referred to here relate to those used by IPCC

Storage system	**EF kg N_2O-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	0.08
Pig manure heaps, solid	0.05
Sheep and goat manure heaps, solid	0.07
Horse (mules and asses) manure heaps, solid	0.08
Layer manure heaps, solid	0.04
Broiler manure heaps, solid	0.03
Turkey and duck manure heaps, solid	0.03
Goose manure heaps, solid	0.03
Buffalo manure heaps, solid	0.08

The derivation of these EFs as a proportion of TAN is given in Appendix Table A3–6

Step 11 is to calculate the total-N and TAN ($m_{\text{applic\_N}}$ and $m_{\text{applic\_TAN}}$) that is applied to the field, remembering to subtract the emissions of NH_3, N_2O, NO and N_2 from storage.

For slurry:

$$m_{\text{applic\_slurry\_TAN}} = m_{\text{spread\_direct\_slurry\_TAN}} + mm_{\text{storage\_slurry\_TAN}} - E_{\text{storage\_slurry}} \tag{31}$$

$$m_{\text{applic\_slurry\_N}} = m_{\text{spread\_direct\_slurry\_N}} + mm_{\text{storage\_slurry\_N}} - E_{\text{storage\_slurry}} \tag{32}$$

For solid:

$$m_{\text{applic\_solid\_TAN}} = m_{\text{spread\_direct\_solid\_TAN}} + mm_{\text{storage\_solid\_TAN}} - E_{\text{storage\_solid}} \tag{33}$$

$$m_{\text{applic\_solid\_N}} = m_{\text{spread\_direct\_solid\_N}} + mm_{\text{storage\_solid\_N}} - EF_{\text{storage\_solid\_leach}} - E_{\text{storage\_slurry\_\_solid}} \tag{34}$$

The use of default values for N_2O as listed in Table 3–7 is recommended, whenever national data are not available.

Step 12 is to calculate the emission of NH_3-N during and immediately after field application, using an emission factor EF_{applic} combined with $m_{\text{applic\_TAN}}$.

For slurry:

$$E_{\text{applic\_slurry}} = m_{\text{applic\_slurry\_TAN}} \cdot EF_{\text{applic\_slurry}} \tag{35}$$

For solid:

$$E_{\text{applic\_solid}} = m_{\text{applic\_solid\_TAN}} \cdot EF_{\text{applic\_solid}} \tag{36}$$

Step 13 is to calculate the net amount of N returned to soil from manure ($m_{\text{returned\_N}}$ and $m_{\text{returned\_TAN}}$), after losses of NH_3-N, (to be used in calculations of NO emissions in Chapter 3.D).

For slurry:

$$m_{\text{returned\_slurry\_TAN}} = m_{\text{applic\_slurry\_TAN}} - E_{\text{applic\_slurry}} \tag{37}$$

$$m_{\text{returned\_slurry\_N}} = m_{\text{applic\_slurry\_N}} - E_{\text{applic\_slurry}} \tag{38}$$

For solid:

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

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

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 calculation of subsequent emission of NO in Chapter 3.D, Crop production and agricultural soils), was calculated in Step 3. However, in order to check the mass balance calculations here, the net return of soil during grazing needs to be calculated here as well, using the equivalent equation to that used to calculate net returns following manure application.

Step 14 is to calculate the NH_3-N emissions from grazing.

$$E_{graz} = m_{graz\_TAN} \cdot EF_{grazing} \qquad (41)$$

As a quality control, a N balance should be calculated, i.e. the total input of N (total amount of N in animal excretion + bedding) should match the output of N (total of all emissions and N inputs to the soil).

Step 15 is to sum all the emissions from the manure management system and convert them to the mass of the relevant compound:

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

$$E_{MMS\_NO} = (E_{storage\_NO\_slurry} + E_{storage\_NO\_solid}) \cdot 30/14 \qquad (43)$$

where E_{MMS_NH3} and E_{MMS_NO} are the emissions from the manure management system of NH_3 and NO respectively (kg).

An MS Excel spreadsheet with automatic calculation and error-checking is available as a separate file at the same location as the online version of this Guidebook.

3.3.2 Algorithm for NMVOC

NMVOC emissions are calculated as the sum of six different sources:

1. from silage stores;
2. from the feeding table if silage is used for feeding;
3. housing;
4. outdoor manure stores;
5. manure application; and
6. from grazing animals.

The emissions from housing include emissions from feeding stuff other than silage. As feeding with silage can be a large source, especially for dairy cows, two different methologies are given: one for ‘dairy cows plus other cattle’ and another one for the ‘remaining’ animal categories. The methodology for dairy cattle and other cattle is based on feed intake. The methodology for other animal categories is based on excreted volatile substance.

At present, there are few data available concerning NMVOC emissions. A correlation between the NH_3 emissions and many of the different NMVOCs during housing has been found ($r^2 \approx 0.5$) (Feilberg et al. 2010). Therefore, emissions from manure stores and manure application are estimated as fraction of those from livestock housing. The fraction is assumed to be the same ratio as for NH_3 emission.

Emissions from animals on grass are assumed to be low. The estimation of emissions from grazing animals is based on Shaw et al. (2007), who measured the ROG emission (Reactive Organic Gas) from lactating and non-lactating dairy cows for two subsequent days in an emission chamber. The estimated ROG is assumed as being equvalent to NMVOC emission.

Dairy cattle and other cattle:

$E_{\text{NMVOC\_i}} = AAP_{\text{animal\_}i} \cdot (E_{\text{NMVOC,silage\_store\_}i} + E_{\text{NMVOC,silage\_feeding\_}i} + E_{\text{NMVOC,house\_}i} + E_{\text{NMVOC,store\_}i} + E_{\text{NMVOC,appl.\_}i} + E_{\text{NMVOC,graz\_}i})$

where;

i = the *i*th animal category

$E_{\text{NMVOC,silage\_store\_}i} = MJ_{\_i} \cdot x_{\text{house\_i}} \cdot (EF_{\text{NMVOC,silage\_feeding\_}i} \cdot Frac_{\text{silage}})$

$E_{\text{NMVOC,house\_}i} = MJ_{\_i} \cdot x_{\text{house\_}i} \cdot (EF_{\text{NMVOC,house\_i}} \cdot Frac_{\text{silage}})$

$E_{\text{NMVOC,manure\_store\_}i} = E_{\text{NMVOC,house\_}i} \cdot x_{\text{house\_}i} \cdot (E_{\text{NH3,storage\_}i\text{\_}} / E_{\text{NH3,house\_}i})$

$E_{\text{NMVOC,appl.\_}i} = E_{\text{NMVOC,house\_}i} \cdot x_{\text{house\_}i} \cdot (E_{\text{NH3appl.\_}i}/E_{\text{NH3house\_}i})$

$E_{\text{NMVOC,graz\_i}} = MJ_{\_i} \cdot (1-x_{\text{house\_}i}) \cdot EF_{\text{NMVOC,graz\_}i}$

where;

$MJ_{\_i}$= Gross feed intake, MJ yr^{-1}. Values of feed intake in MJ should preferentially be country specific (refer to the annual reporting to UNFCCC (www.unfccc.org), Table4.A). If the data from the UNFCCC are used they should be multiplied with 365 to obtain MJ intake per year. If no country specific data on MJ feed intake are available, the default data given in IPPC 2006 Guidelines should be used. Conversion between dry matter intake and MJ can be made by multiplying the amount of dry matter with 18.45 (IPCC 2006, equation 10.24).

x_{house} = share of time the animals spend in the animal house in a year. If no national data is available refer to Table 3-8.

$Frac_{\text{silage\_}}$= Fraction of the feed in dry matter during housing which is silage out of the maxium share of silage possible in the feed composition. In practice the maxium silage in dry matter is approximately 50 % of the total dry matter intake. If silage feeding is dominant $Frac_{\text{silage}}$ should equal 1.0.

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

$E_{\text{NH3,storage\_}i}$, $E_{\text{NH3,house\_}i}$ and $E_{\text{NH3appl.\_}i}$: Ammonia emission. If no country specific data on total NH_3 emissions from housing, manure stores and manure application are available, it is recommended to use the default fraction estimated in Table 3-8.

All other animal categories than cattle:

$E_{\mathrm{NMVOC,silage\_store\_}i} = \mathrm{kg\ VS}_{\_\mathrm{i}} \cdot x_{\mathrm{house\_}i} \cdot (EF_{\mathrm{NMVOC,house\_}i} \cdot (EF_{\mathrm{NMVOC,\ silage\ feed\_}i} \cdot \mathrm{Frac}_{\mathrm{silage}})\ \cdot 0.25$

$E_{\mathrm{NMVOC,silage\_feeding\_}i} = \mathrm{VS}_{\_i} \cdot x_{\mathrm{house\_}i} \cdot (EF_{\mathrm{NMVOC,silage\_feeding\_}i} \cdot \mathrm{Frac}_{\mathrm{silage}})$

$E_{\mathrm{NMVOC,house\_}i} = \mathrm{kg\ VS}_{\_i} \cdot x_{\mathrm{house\_}i} \cdot (EF_{\mathrm{NMVOC,house\_i}})$

$E_{\mathrm{NMVOC,manure\_store\_}i} = E_{\mathrm{NMVOC,house\_}i} \cdot x_{\mathrm{house\_}i} \cdot (E_{\mathrm{NH3,storage\_i\_}} / E_{\mathrm{NH3,house\_}i})$

$E_{\mathrm{NMVOC,appl.\_}i} = E_{\mathrm{NMVOC,house\_}i} \cdot x_{\mathrm{house\_}i} \cdot (E_{\mathrm{NH3appl.\_}i}/E_{\mathrm{NH3house\_}i})$

$E_{\mathrm{NMVOC,graz\_}i} = \mathrm{kg\ VS}_{\_i} \cdot (1-x_{\mathrm{house\_}i}) \cdot EF_{\mathrm{NMVOC,graz\_}i}$

where;

kg $\mathrm{VS}_{\_\mathrm{i}}$ = kg excreted VS yr^{-1} for animal catory i, kg yr^{-1} .

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

Values of kg excreted VS should preferably be country specific and refer to the annual reporting to UNFCCC (www.unfccc.org) Table 3.B(a)s1. If the data from the UNFCCC are used they should be multiplied with 365 to obtain VS excretion per year. If no country specific data on VS excretion are available, it is recommended to use default data given in IPPC 2006 Guidelines.

3.3.3 Algorithm for PM

Calculations for PM_{10} and $PM_{2.5}$ emissions are based on the following equation:

$$E_{\mathrm{PMi}} = AAP_{\mathrm{animal}} \cdot x_{\mathrm{house}} \cdot \beta \cdot (x_{\mathrm{slurry}} \cdot EF_{\mathrm{slurry}} + (1-x_{\mathrm{slurry}}) \cdot EF_{\mathrm{solid}}) \qquad (44)$$

where

E_{PM}	PM_{10} or $PM_{2.5}$ emission for an animal category (in kg a^{-1}),
β	mass units conversion factor (β = 1kg kg^{-1}),
x_{house}	share of time the animals spend in the animal house (in a a^{-1}),
x_{slurry}	share of population kept in slurry based systems,
EF_{slurry}	PM_{10} or $PM_{2.5}$ EF for slurry based system (in kg AAP^{-1} a^{-1}),
EF_{solid}	PM_{10} or $PM_{2.5}$ EF for solid manure based system (in kg AAP^{-1} a^{-1}).

The methodology requires additional input data to the Tier 1 methodology. Estimates are needed for the proportion of the year the animals are in the animal housing (as opposed to grazing). For the cattle and pig categories, the proportion of manure that is handled as slurry rather than as a solid is needed.

3.3.4 Technology-specific emission factors

Ammonia

Table 3.7 shows the default NH_3-N EFs and proportions of TAN in the manure excreted.

Table 3.7 Default Tier 2 NH_3-N EF and associated parameters for the Tier 2 methodology for calculation of the NH_3-N emissions from manure management. EF as proportion of TAN

Code	Livestock	Housing period, d a^{-1}	N_{ex}	proportion of TAN	Manure type	EF $_{housing}$	EF $_{yard}$	EF $_{storage}$	EF $_{spreading}$	EF$_{grazing/outdoor}$
100901	Dairy cows	180	105	0.6	slurry	0.20	^{2}0.30	0.20	0.55	0.10
					solid	0.19	^{2}0.30	0.27	0.79	0.10
100902	Other cattle (young cattle, beef cattle and suckling cows)	180	41	0.6	slurry	0.20	^{2}0.53	0.20	0.55	0.06
					solid	0.19	^{2}0.53	0.27	0.79	0.06
100903	Fattening pigs (8–110 kg)	365	12.1	0.7	slurry	0.28	^{2}0.53	0.14	0.40	
					solid	0.27	^{2}0.53	0.45	0.81	
100904	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	^{2}0.25
100905 +100911	Sheep (and goats)	30	15.5	0.5	solid	0.22	^{2}0.75	0.28	0.90	0.09
100906 +100912	Horses (and mules, asses)	180	47.5	0.6	solid	0.22	NA	0.35	^{1}0.90	^{2}0.35
100907	Laying hens (laying hens and parents),	365	0.77	0.7	solid, can be stacked	0.41	NA	0.14	0.69	
100907	Laying hens (laying hens and parents),	365	0.77	0.7	slurry, can be pumped	0.41	NA	0.14	0.69	
100908	Broilers (broilers and parents)	365	0.36	0.7	solid	0.28	NA	0.17	0.66	
100909	Other poultry (turkeys)	365	1.64	0.7	solid	0.35	NA	0.24	0.54	
100909	Other poultry (ducks)	365	1.26	0.7	solid	0.24	NA	0.24	0.54	
100909	Other poultry (geese)	365	^{1}0.55	0.7	solid	0.57	NA	0.16	0.45	
100910	Fur animals	365	^{1}0.08	0.6	solid	0.27	NA	0.09	NA	
100913	Camels^{3}						NA			
	Buffalo^{1}	140	^{1}82.0	0.5	solid	0.20	NA	0.17	0.55	0.13

Sources: Default N excretion data were taken from Table 10.19 of IPCC chapter 10: Emissions from Livestock and Manure Management. Default EFs were taken from the work of the EAGER group

Notes:

[1] Taken from GAS-EM.

[2] Taken from NARSES.

The values for the proportion of TAN were the average from EAGER comparisons (Reidy et al., 2007 and expert judgement). Where figures were not available, the means used in the GAS-EM (Dämmgen et al., 2007) or NARSES models (Misselbrook et al., 2006, Webb and Misselbrook, 2004) were taken. The national EFs from which the values were derived, are given in Appendix A3, Table A3–7.

Table 3.8. Default values for other losses needed in the mass-flow calculation (from Dämmgen et al. 2007)

	proportion of TAN
$EF_{storage\_slurryNO}$	0.0001
$EF_{storage\_slurryN2}$	0.0030
$EF_{storage\_solidNO}$	0.0100
$EF_{storage\_solidN2}$	0.3000

NMVOC

NMVOC Tier 2 emission factors are based on measurements from the NAEM study (US EPA, 2012). The American emission levels have been converted to reflect agricultural conditions in Western Europe. It is good practice for all countries to use country specific activity data if data are available.

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

The emissions from housing are estimated as an average of NMVOC emissions and NMHC emissions. The NMHC measurements are converted to NMVOC. For broilers and fatteners, the emission estimates are converted to per 500 kg animal as the measurements covered a wide range of animal weights. These average data are then converted to Western European production levels as given in the IPCC 2006 guidelines and other default values in this guide book.

The NAEM study is whole barn measurements which include emission from feeding table, enteric fermentation and manure stored inside the barn. The barn measurements has 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 covers a wide range of climatic conditions. The measured data have a high variability and it has not been found feasible to include temperature correction functions for the different climatic conditions found in the EMEP area. The proposed emission factors are therefore average emission factors without correction for climatic conditions except for emissions from silage stores where a temperature correction factor from 20 °C to 10 °C is made (Alanis et al. 2010).

Table 3.9 Default NMVOC EF Tier 2 for dairy cattle and other cattle[1]

Code	Livestock	$EF_{NMVOC,silage\ feeding}$	$EF_{NMVOC,house}$	$EF_{NMVOC,graz}$
		Kg NMVOC kg MJ^{-1} feed intake		
100901	Dairy cows	0.0002002	0.0000353	0.0000069
100902	Other cattle[2]	0.0002002	0.0000353	0.0000069

([1]) Data from the NAEM study (US EPA, 2012) converted to European conditions

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

Table 3.10 Default NMVOC EF Tier 2 for other animal categories than cattle[1]

Code	Livestock	$EF_{NMVOC,silage\ feed.}$	$EF_{NMVOC,house}$	$EF_{NMVOC,graz}$
		Kg NMVOC kg VS excreted		
100903	Fattening pigs[2]		0.001703	
100904	Sows		0.007042	
100905	Sheep	0.010760	0.001614	0.00002349
100911	Goats	0.010760	0.001614	0.00002349
100906	Horses	0.010760	0.001614	0.00002349
100912	Mules and Asses	0.010760	0.001614	0.00002349
100907	Laying hens (laying hens and parents)		0.005684	
100908	Broilers (broilers and parents)		0.009147	
100909	Other poultry (ducks, geese, turkeys)[3]		0.005684	
100910	Fur animals		0.005684	
	Rabbits		0.001614	
	Reindeer		0.001614	0.00002349
100913	Camels	0.010760	0.001614	0.00002349
100914	Buffalo	0.010760	0.001614	0.00002349

([1]) Data from the NAEM study (US EPA, 2012) converted to European conditions

([2]) Include piglets from 8 kg to slaughtering

([3]) Based on data for broilers

Particulate matter

PM emissions depend, among other issues, upon the fertiliser type. This can be taken into account by using the Tier 2 methodology. The Tier 2 PM EF is based on measured data provided by Takai et al. (1998).

Table 3.11 Default Tier 2 EF for particle emissions from animal husbandry (housing),

Code	Livestock	Manure	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}
100901	Dairy cows	slurry	1,81	0,83	0,54
		solid	0,94	0,43	0,28
100902	Other cattle (including young cattle, beef cattle and suckling cows)	slurry	0,69	0,32	0,21
		solid	0,52	0,24	0,16
100902	Calves	slurry	0,34	0,15	0,10
		solid	0,35	0,16	0,10
100514	Buffalos	slurry	2,12	0,97	0,63
		solid	1,10	0,50	0,33
100903	Fattening pigs	slurry	0,70	0,31	0,06

		solid	0,83	0,37	0,07
100902	Weaners	slurry	0,36	0,16	0,03
		solid	0,00	0,00	0,00
100904	Sows	slurry	1,36	0,61	0,11
		solid	1,77	0,80	0,14
100907	Laying hens (laying hens and parents)	cages	0,025	0,025	0,003
		perchery	0,119	0,119	0,023

Source: Takai et al. (1998)

3.3.5 Activity data

Time spent on yard areas

The inclusion of emissions from yard areas does complicate the calculation since, in most cases, livestock will spend only a few hours per day on the 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 take account of the total time estimated to be spent on yards, such that the proportions of x_{build}, x_{yards} and x_{graz} will total 1.0. For example, if dairy cows are estimated to spend 25 % of their time on 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}.

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 the length of the grazing period for ruminants, how long manure is stored and the type of store and manure treatment used, and the method of manure application to land. For manures applied to tillage land, the interval before incorporation is also needed.

Table A3–8 describes the manure storage systems referred to in this chapter and makes comparison with the definitions of manure management systems used by IPCC.

3.4 Tier 3 emission modelling and 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 of the present chapter). Mass balance models developed by the reporting country may be used in preference to the structure proposed here. A Tier 3 method might also utilize 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. proportional reduction in emission compared with 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 could be modified as follows:

$$E_{build\_slurry} = m_{build\_slurry\_TAN} \cdot reduction\_factor \cdot EF_{build\_slurry}$$

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, requiring amendments to be made to their relevant EFs. The Tier 2 equations will require further amendment if abatement techniques are employed that remove N from the manure management system, e.g. biofilters used to clean the exhaust air from animal housing that denitrify captured N.

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

Technical support

A worked example of the use of these steps is provided in the accompanying spreadsheet file to this chapter, available from the EMEP/EEA Guidebook website

3.4.1 Abatement

Emissions of NH_3 during storage may be reduced by a range of measures including reducing the surface area to volume ratio of the store (20–50 % abatement), to fitting a solid roof, tent or lid to the store (80 % abatement). Following spreading of livestock manures to land, NH_3 emissions may be reduced by rapid incorporation into tillage land or application of slurries to tillage or grass land by reduced-emission slurry applicators such as injectors. Techniques for reducing emissions of NH_3 during housing, storage and following manure application, together with their abatement efficiencies, are given in Appendix A3, with further detail in UNECE (2012), which includes information on abatement measures from buildings housing livestock. Information on abatement techniques, in particular from livestock buildings, is available in Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs July 2003 (http://eippcb.jrc.es/reference/).

4 Data quality

4.1 Completeness

A complete inventory should estimate NH_3, NO and PM emissions from all systems of manure management for all livestock categories. Population data should be cross-checked between main reporting mechanisms (such as national agricultural statistics databases and Eurostat) to ensure that 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 chapter 10.2.

4.2 Avoiding double counting with other sectors

In cases where it is possible to split these emissions between 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

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 General Guidance Chapter 4, Time series consistency, of the Guidebook. 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, there may be evidence to modify these values over time. For example, milk yield and live weight gain may have increased with time, farmers may alter livestock feeding practices which could affect N excretion rates. Furthermore, the animal categories in a census may change. A particular system of manure management may change due to 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 implementation of mitigation measures has affected the time series of activity data or EF. Projections need to take account of likely changes in agricultural activities, not just changes to 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, IPPC and the Water Framework Directive.

4.5 Uncertainty assessment

4.5.1 Emission factor uncertainties

Ammonia

Uncertainties in NH_3 EFs vary considerably. A recent UK study indicated a 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, in 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 and sheep. The uncertainties of partial EFs have yet to be discussed. The overall uncertainty for the UK ammonia emissions inventory, as calculated using a Tier 3 approach, was ± 21 % (Webb and Misselbrook, 2004), while that for the Netherlands, also 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 as yet difficult to quantify nitrification and denitrification rates in livestock manures. In addition, the observed fluxes of NO show large temporal and spatial variation. 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, metabolizable carbon, duration of storage, and other aspects of treatment.

NMVOCs

The EFs included are first estimates and as such provide only broad indications of the likely range. The uncertainty associated with these emission factors is 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 a first estimate only and as such provide only a broad indication of uncertainty c. Further uncertainties may arise from estimates of grazing times.

4.5.2 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 eight of the ten input data to which estimates of UK 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 less. Webb (2000) reported uncertainties for UK estimates of N excretion to range from ± 7 % for sheep to ± 30 % for pigs. Animal numbers, (partial) EF 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 animal numbers, national expert estimates for EF and frequency distributions are strongly requested to document their findings, decisions and calculations to facilitate reviewing of their respective 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 can be undertaken.

4.6 Inventory quality assurance/quality control QA/QC

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 in IPCC (2006), Chapter 10.2.2.

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_{ex}, 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 MJ feed intake and for excretion of volatile substance used in the estimation of NMVOC emission 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 NMVOC emissions.

Review of emission factors

- The inventory agency should evaluate how well the implied EF and N excretion rates 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 to the default factors and note differences. The development of country-specific EF 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) are affecting 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 animal nutrition to conduct expert peer review of the methods and data used. While these experts may not be familiar with gaseous emissions, their knowledge of key input parameters to the emission calculation can aid in the overall verification of the emissions. For example, animal nutritionists can evaluate N production rates to see if they are consistent with feed utilization research for certain livestock species. Practicing 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. When country-specific EF, 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 excretion + bedding) should match the output of N (total of all emissions and N inputs to the soil).

4.7 Gridding

European Monitoring and Evaluation Programme (EMEP) require 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 emissions estimates should normally be disaggregated as much as possible. Given the dominance of animal husbandry in the emission of NH_3 in Europe, disaggregation is normally based on animal 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.

Further comments on other pollutants is given in Appendix A4.7.

4.8 Reporting and documentation

No specific issues.

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6 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection’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.

Appendix A.

A1 Overview

Ammonia

There have been large reductions in emissions of SO_2 and NO_x from power generation, industry and transport since 1980. In consequence, within the next two decades, NH_3 emissions are expected to account for over 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, the remainder are from industrial sources, households, pet animals and natural ecosystems.

Nitric oxide and di-nitrogen

The processes of denitrification and nitrification, which release N_2O, also release NO and di-nitrogen (N_2). Whereas NO is a species to be 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 from soils receiving mineral fertiliser or livestock manures (Dämmgen et al., 2007).

NMVOCs

In the context of this Guidebook, NMVOCs are defined as ‘all those artificial organic compounds other than methane which can produce photochemical oxidants by reaction with nitrogen oxides in the presence of sunlight’ (UNECE, 1991). These compounds contribute greatly to the odour associated with manure.

While some NMVOCs present a health risk and an environmental problem in their own right, they are of interest chiefly for their role in the formation of ozone (O_3), a respiratory irritant, and peroxy acetyl nitrate (PAN) (Grenfelt and Scholdager, 1984). Ozone production is driven by sunlight intensity and photolytic O_3 production is increased at greater nitrogen dioxide (NO_2) concentrations. In turn, NO_2 concentrations are increased by NMVOC and peroxide radicals. VOCs can also undergo oxidation and produce O_3 as a by-product. The oxidation of VOCs is dependent on the concentration of catalytic hydroxyl radicals that are produced primarily by sunlight and the presence of O_3 or formaldehyde.

These NMVOCs, together with some oxides of nitrogen (NO_x), make a significant contribution to O_3 formation in some rural areas (Chameides et al., 1988) and in urban areas (Howard et al. 2010). Ozone can be self-sustaining because it produces radicals that oxidise NMVOCs, which in turn produce O_3 during photolytic decay. The average concentration of O_3 at ground level has more than doubled in the last 100 years (Hough and Derwent, 1990). The frequency of such episodes is increasing (Hewitt and Street, 1992).

Recent studies have measured significant emissions of NMVOCs from livestock production (US EPA 2012, Amon et al. 2007, Rumsey et al. 2012, Feilberg et al. 2010, Chung et al. 2010, Spinhirne et al., 2004, Ngwabie et al., 2005). Two of the major sources are silage stores and feeding with silage (Alanis et al. 2008, 2010).

Particulate matter (PM)

Particulate matter is defined as particles of solid or liquid matter suspended in air. They are characterised by their origin (primary and secondary particles), their particle size, their composition and their potential physiological pathways.

Primary emissions are directly emitted by a source. Secondary particles are formed in the atmosphere by chemical reactions of certain gases that either condense or undergo chemical transformation to a species that condenses as a particle (Seinfeld, 1986). (The expression ‘secondary particle’ is also sometimes used to describe redispersed or resuspended particles.)

To make particle size comparisons possible, the so-called aerodynamic diameter (d_{ae}) is used to standardize the expression of different particle sizes. The aerodynamic diameter (d_{ae}) is the diameter (in µm) of an idealised spherical particle of unit density (1 g cm^{-3}) which behaves aerodynamically in the same way as the particle in question (e.g. with regards to its terminal settling velocity). It is used to predict where particles of different size and density may be deposited in the respiratory tract. Particles having the same aerodynamic diameter may differ in size and shape. Due to the heterogeneity of particles the sampling, characteristics of sampling devices have to be standardised. From that point of view the so-called collection efficiency (CE) is an important specification. The CE is usually expressed as the 50 % aerodynamic cut-off diameter (d_{50}). Such a d_{50} is generally assumed to be the size above which at least 50 % of particles larger than that size are collected. The CE is usually determined using monodisperse particles. The cut-off curves may vary in sharpness and will depend on the type of sampler (Henningson and Ahlberg, 1994).

Total suspended particulate matter (TSP) refers to the entire range of ambient airborne matter that can be collected, from the sub-micron level up to 100 µm in d_{ae}. Particles with a d_{ae} larger than 100 µm will not remain in air for a significant length of time.

PM_{10} is the fraction of suspended particulate matter in the air with d_{ae} less than or equal to a nominal diameter of 10 µm, which are collected with 50 % efficiency by a PM_{10} sampling device. These particles are small enough to be breathable and could be deposited in lungs, which may impair lung function.

A further TSP-related size fraction is $PM_{2.5}$, which describes particles with an aerodynamic diameter d_{ae} less than or equal to nominal 2.5 µm and capable of being collected by measuring devices with 50 % collection efficiency. Exposure to considerable amounts of $PM_{2.5}$ can cause respiratory and circulatory complaints in sensitive individuals. $PM_{2.5}$ also causes reductions in visibility and solar radiation due to enhanced scattering of light. Furthermore, aerosol precursors such as NH_3 (the source of which is mainly agriculture) form $PM_{2.5}$ as secondary particles through chemical reactions in the atmosphere.

For toxicological purposes, further dust classifications have been introduced, e.g. to characterise occupational settings. For this reason, the terms ‘inhalable dust’, ‘thoracic dust’ and ‘respirable dust’ were introduced.

To imitate the different breathable particle fractions (inhalable, thoracic, respirable) sampling criteria were defined by conventions, which define curves with the desired sampling performance of a sampler in terms of the fractional collection for particles up to 100 µm (Figure A1–1). Therefore, the term inhalable dust is widely used to describe dust qualities that might be hazardous when deposited anywhere in the respiratory system, including the nose and mouth. It has a d_{50} of 100 µm and consequently includes the big and the small particles. Consequently, many dust emission data relate to ‘inhalable dust’ (e.g. Takai et al., 1998).

The United States Environment Protection Agency (EPA, 2001a: 2001b) describes inhalable dust as that size fraction of dust which enters the respiratory tract, but is mainly trapped in the nose, throat, and upper respiratory tract. The median aerodynamic diameter of this dust is about 10 µm.

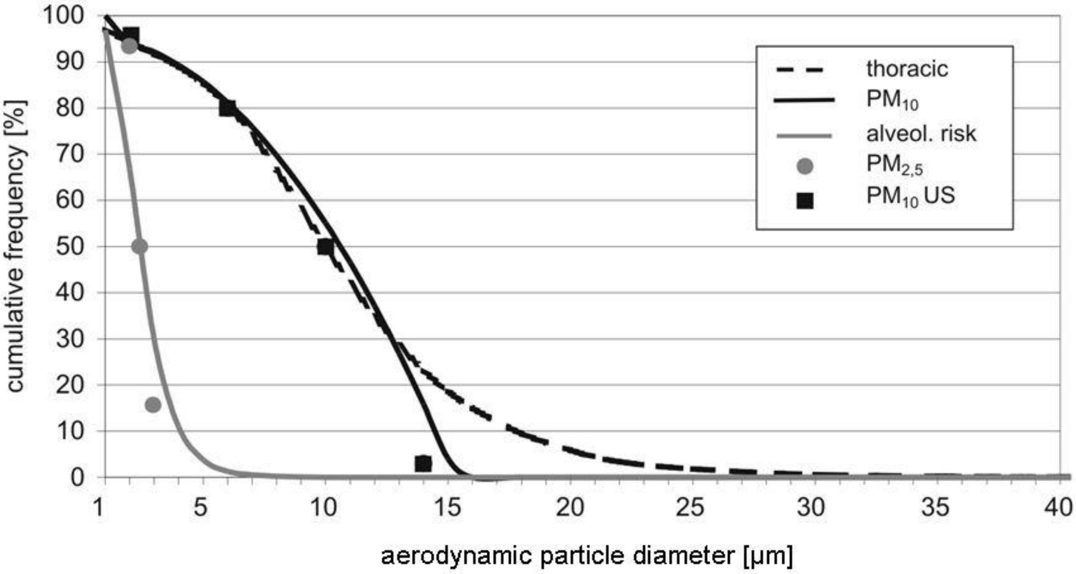

Figure A1–1 Sampling criteria for inhalable, thoracic and respirable particles expressed as percentage of TSP

According to Figure A1–1, the thoracic dust fraction is related to a d_{50} of 10 µm indicating particles, which are small enough to be deposited in the airways of the lung (e.g. bronchi). The term 'respirable dust' describes airborne particles, which are capable of invading the smaller airways and the alveoli of the lung, where the gas-exchange takes place. In the past, several definitions for respirable dust were proposed. Apart from definitions which specify respirable dust as particles with an aerodynamic diameter smaller than 7 µm, the Australian Standard AS 2985-1987 defines respirable dust as dust with a 50 % cut-off point of 5 µm. American Conference of Governmental Industrial Hygienists (ACGIH, 1998) defined respirable dust as having a 50 % cut-point of 3.5 µm. To reach world-wide consensus on the definition of respirable dust in the workplace, a compromise curve was developed with a 50 % cut-point of 4 µm. This standard definition is also implemented in CEN EN 481 (Anon (1993).

A2 Description of sources

A2.1 Process description

Ammonia

Ammonia volatilization is essentially a physic-chemical process which results from the equilibrium (described by Henry's law) between gaseous phase NH_3 and NH_3 in solution (equation A1), NH_3 in solution is in turn maintained by the NH_4^+ - NH_3 equilibrium (equation A2):

$$NH_3\,(aq) \leftrightarrow NH_3\,(g) \tag{A1}$$

$$NH_4^+\,(aq) \leftrightarrow NH_3\,(aq) + H^+\,(aq) \tag{A2}$$

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

Urease is widespread in soils and faeces and, in consequence, hydrolysis of urea is usually complete within a few days (Whitehead, 1990). Urine also contains other N compounds such as allantoin, which may also 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, where 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 ($NH_4^+ + NH_3$) as total ammoniacal-N (TAN). Published studies have confirmed the relationship between NH_3 emissions and TAN (Kellems et al., 1979; Paul et al., 1998; James et al., 1999; Smits et al., 1995 for cattle, and Latimier and Dourmad, 1993; Kay and Lee, 1997; Cahn et al., 1998 for pigs).

NMVOCs

There has been some uncertainty over which NMVOCs originate from different manure types and 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 (US EPA, 2012, Ni et al., 2012, Trabue et al. 2010). 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 NMVOCs identified that whether it was under either small-scale laboratory studies or under larger conditions, the estimates 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 (Cai et al. 2006a, Elliot-Martin et al., 1997; Hobbs et al., 2000; Spinhirne et al., 2003, 2004), although enteric emission of NMVOCs are not a large source as this is seen as a dysfunction of the rumen (Moss et al. 2000). Some amounts of e.g. acetone may be found from cattle if they are suffering from e.g. ketosis. Emissions of volatile fatty acids (VFAs, a form of NMVOCs not associated with proteins) and phenols appears to be rather constant in maure stores over time (Patni et al., 1995). Similar to other compounds the emission of NMVOC is dependent on temperature and ventilation rate within animal houses (Parker et al., 2010, 2012).

Although over 500 volatile compounds originating from cattle, pigs and poultry have been identified, there is considerable uncertainty concerning the organic precursors in each manure type, from which NMVOCs originate. Emissions include alcohols, aldehydes, acids, sulphides, and phenols and, in the case of pig slurry, indoles. Some of the major compounds are listed in Table A2–1. Recently, dimethyl sulphide (DMS) has been identified as originating from ruminant breath. In table A2-2 is given the percentage distribution of the most common NMVOCs found in the NAEM study, which include NMVOC measurements from 16 different animal production (US EPA, 2012).

Table A2–1 Sources and processes of NMVOC formation

NMVOC	Precursor or process	
	amino acids [1]	
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 Sulphide	Cysteine	
4-methyl phenol	Tyrosine	
4-ethyl phenol	Tyrosine	
Indole	Tryptophan	
3-methyl indole	Tryptophan	

Notes:

1. from Mackie et al. (1998).
2. NA: no amino acid as source.

Table A2–2 Percentage distribution of different NMVOC from buildings for different animal types (estimated from US EPA, 2012)

Poultry	Pct.	Cattle	Pct.	Swine	Pct.
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
iso-Propanol	23.0	iso-Propanol	7.0	iso-Propanol	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
Proanoice acid	1.7	Proanoice acid	1.0	Proanoice 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
Sum	100	Sum	100	Sum	100

A2.3 Emissions

Ammonia

Ammonia emissions from unfertilised grass, grazed by livestock, have been measured by Jarvis et al. (1989, 1991) and Ledgard et al. (1996). Jarvis et al. (1989) found annual NH_3 emissions of 7 kg ha^{-1} N from a grass/clover pasture grazed by beef cattle. This was *ca*. 4 % of the estimated N fixation by the clover (160 kg ha^{-1} a^{-1} N), and *ca*. 70 % of NH_3 emissions from grazed grassland given 210 kg ha^{-1}. a^{-1} N. 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 ha^{-1} a^{-1} N) were less than from an unfertilised grass field (4 kg ha^{-1} a^{-1}), whilst emissions from the pure clover pasture (11 kg ha^{-1} a^{-1} N) were greater than from grassland given 420 kg ha^{-1} a^{-1} N. These losses were smaller (by a factor of 3) than 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 in generalizing from these limited data. Differences in emission 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 emission.

Nitric oxide

Maljanen et al. (2006) reported emissions of NO from grazed pastures that were *ca*. 40 % of those of N_2O, compared with background emissions that were *ca*. 25 % of N_2O. Nitric oxide emissions increased with increasing soil temperature and with decreasing soil moisture. Emissions of NO are still poorly understood, but it is clear that there are differences in the mechanisms regulating N_2O and NO production. There are not enough data available to discuss the effect of grazing on NO emissions, but the localised very high N and C inputs caused by animal excreta are likely to stimulate NO production.

NMVOCs

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 pig buildings confirming most of the previous emission profiles. Ni et al. 2012 has identified > 500 compounds. The compounds most frequently reported in these investigations, which were heavily biased towards piggeries, were *p*-cresol, volatile fatty acids, and phenol. Concentrations of these compounds in the atmosphere display wide variations, e.g. the concentration of *p*-cresol varies from $4.6 \cdot 10^{-6}$ to 0.04 mg m^{-3} and of phenol from $2.5 \cdot 10^{-6}$ to 0.001 mg m^{-3}. The alcohols ethanol and methanol are recently reported as the dominant emissions from dairies and sheep-shed, (US EPA, 2012, Ngwabie et al., 2005), and vastly exceeded volatile fatty acid and *p*-cresol abundances. VOCs are also known to be adsorbed to airborne particulate matter (Bottcher, 2001; Oehrl et al., 2001; Razote et al., 2004, Cai et al. 2006b), representing an additional emission pathway and odour nuisance.

A major attempt to quantify the NMVOC emission from animal buildings and manure stores was done in the NAEM study covering 16 locations in the USA with dairy cattle, pig sows and 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 both with canister sampling combined with Mass-Spectrometry and NMHC (non-methane hydro carbons).

The estimated NMVOC emission factor is based on an average emission measured in the NAEM study for dairy cows, sow, egg layers and broilers. Where both NMVOC and NMHC were measured, an average of the two methods was used. NMHC are converted to NMVOC by multiplying with the mass fraction of the most common NMVOCs compared to NMHC. The emissions from the NAEM study are converted to European standards with a conversion of MJ feed intake data and VS excretion, which corresponds with data in the IPCC 2006 Guidelines (IPCC, 2006). Measurements in the NAEM study indicate that the emission depends on temperature and ventilation rate. However, due to the sigificant variation of the measured emission, the data is not strong enough to introduce a climate dependent emission factor for the EMEP area.

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

The measured emissions from dairy houses in the NAEM study include emissions from silage which is a major source. The major emission from silage is ethanol and fatty acids (VFA). There is a large uncertainty of the fraction which derivide from the silage. Alanis et al. (2008) found for a Californian dairy farm that the TMR (silage feed) were responsible for approximately 68 % estimated VFA emission. Chung et al. (2010) found that 93-98 % of the emission of the contribution to ozon formation from six dairies came from the feed. In the distribution of the emission factors for emissions from silage on the feeding table and emissions from other sources in the barn (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 especially farms not using silage as feeding. In the NAEM study, propanol accounted for up to 50 % of the emission in cattle, poultry and pig houses (Table A2-2). 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 raises questions on the origin of the high propanol measurements in the NEAM study, as poultry and pigs are normally not fed with silage.

The methodology for silage stores are based on measured distribution between silage stores and buildings (Alanis et al. 2008, Chung et al. 2010) combined with a temperature correction to European temperatures (Alanis et al. 2010, Hafner et al. 2010, El-Mashad et al. 2010). The distribution between the sources are measured under warm conditions (20°C) which is higher than the average conditions in Europe. A correction factor from 20°C to an average of 10°C is therefore made equal to 25 % of the emission the silage on the feeding table.

The NMVOC measurements in the NAEM study from lagoons are difficult to transfer to traditional European manure stores in slurry tanks. Therefore, the fraction of NMVOC emission between housing and storage was based on the same fraction as for the ammonia emission. This relationship is amongst others documented by Amon et al. (2007), Feilberg et al. (2010) and Hobbs et al. (2004). The same methodology is used for calculation of the NMVOC emission from application of manure by using the fraction of NH_3 emission from application compared to emissions from housing. 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 nitrogen feeding will not reduce the primary dry matter in feed and excreted volatile substance which is the primary source for NMVOC. For the Tier 1 emisions factors the distribution in Table 3-8 was used. It is strongly recommended to use national ammonia emission estimates. Rumsey et al. (2012) found in an upscaling of the emission from pigs in North Carolina, USA, that housing was responsible for 68.8-100 % of the total emission. This high share could be questioned 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 low as there is no or limited silage feeding and no manure storing. However a small amount will be emitted from enteric fermentation and from flatus. The estimation of emissions from grazing animal is based on Shaw et al. (2007) who measured the ROG emission (Reactive Organic Gas) 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 originates from hay. The estimated ROG is assumed as beeing equvalent to NMVOC.

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 so many disturbances if the litter is moist (Anon., 1995).

Emissions will vary according to the quality and quantity of bedding material (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), frequency of litter removal (e.g. weekly vs. monthly), variations in livestock density and its impact on dust movement caused by the animal’s activities, such a leaving the building for milking, or randomly high ventilation rates in cubicle houses resulting in greater emission rates in comparison with litter-based systems. In conclusion, more data are needed on emission rates of particulates in order to better determine both mean emission rates and variability of emission rates due to various environmental and management factors and is therefore also a target for prospective verification procedures.

A2.4 Controls

Ammonia

Livestock feeding strategies

Livestock feeds are prepared in order to provide enough carbohydrate to meet energy needs and protein to meet protein needs. However, because feeds are often based on grass or soya, they often contain more protein than is needed for livestock growth. Matching protein intake in feed to that needed for production reduces N excretion. Moreover, since surplus protein-N is mainly excreted in the form of urea, reducing protein intake will give a disproportionately greater reduction in NH_3 emissions.

Nitrogen management

The potential to reduce emissions of NH_3 from careful management of N applied to crops is limited, as emissions take place at the soil surface, before applied N has entered the pool of soil N, hence even applications of manure-N carefully balanced to meet crop requirements will be subject to loss if the manure is surface applied. Any benefits are most likely to be greatest on grassland, where the risk of unnecessarily large N concentrations in forage will be reduced, decreasing the potential for NH_3 emissions from grazed pastures.

Reduce emissions from housing systems

Techniques for reducing NH_3 emissions from naturally-ventilated buildings include grooved flooring, the frequent removal of manure and manure cooling. For loose-housed cattle, increases in the amounts of straw used for bedding may reduce NH_3 emissions. This approach has the advantage that, by immobilizing TAN in straw, there will be no subsequent increase in NH_3 emissions from manure storage or spreading. Emissions from buildings may also be reduced by reducing the floor area contaminated by excreta. Emissions from poultry buildings may be greatly reduced if the DM of the manure is 60 % or more. For housing with forced ventilation, chemical or biological scrubbing of the exhaust air can substantially reduce NH_3 and PM emissions.

Reduce emissions during storage

Techniques to reduce NH_3 emissions during storage are summarised in Table A2–2.

Table A2–2 Ammonia emission abatement measures for cattle and pig slurry storage (UNECE, 2007)

Abatement Measure	NH_3 Emission Reduction (%)[(a)]	Applicability	BAT [(b)] available for IPPC Pig Farms?
'Tight' lid, roof or tent structure	80	Concrete or steel tanks and silos. May not be suitable on existing stores.	Yes — but decisions taken on a case by case basis
Plastic sheeting [(c)] (floating cover)	60	Small earth-banked lagoons.	Yes — but decisions taken on a case by case basis
Plastic sheeting [(c)] (floating cover)	60	Large earth-banked lagoons and concrete or steel tanks. Management and other factors may limit use of this technique.	Yes — but decisions taken on a case by case basis
'Low technology' floating covers (e.g. chopped straw, peat, bark, LECA balls, etc.) (Cat. 2)	40	Concrete or steel tanks and silos. Probably not practicable on earth-banked lagoons. Not suitable if materials likely to cause slurry management problems.	Yes — but decisions taken on a case by case basis
Natural crust (floating cover)	35–50	Higher dry matter slurries only. Not suitable on farms where it is necessary to mix and disturb the crust in order to spread slurry frequently.	Yes — but decisions taken on a case by case basis
Replacement of lagoon, etc. with covered tank or tall open tanks (H> 3 m)	30 - 60	Only new build, and subject to any planning restrictions concerning taller structures.	Not assessed
Storage bag	100	Available bag sizes may limit use on larger livestock farms.	Not assessed

Notes:

(a) Emission reductions are agreed best estimates of what might be achievable across UNECE. Reductions are expressed relative to emissions from an uncovered slurry tank/silo.

(b) BAT: Best Available Techniques.

(c) Sheeting may be a type of plastic, canvas or other suitable material.

Reduce emissions during and after land spreading

Abatement methods for spreading manures on land have some of the greatest potential to reduce NH_3 emissions and are among the most cost-effective. Emissions following the spreading of manures to land are one of the two largest sources and NH_3 conserved at earlier stages of manure management may be lost if emissions following spreading are not controlled. Emissions following application of slurry may be reduced if the slurry is applied in narrow bands (trailing hose), if the slurry is placed beneath the crop canopy (trailing shoe) or placed below the soil surface (injection). Those techniques, which entail little or no soil disturbance can be used on grassland as well as on tillage land. Incorporation of slurry and solid manures into tillage land can reduce NH_3 emissions by up to 90 %. The reduction in emission varies according to method of incorporation, interval between manure application and incorporation and type of manure. Abatement tends to increase as the interval between spreading and incorporation decreases, as the amount of soil inversion increases and according to manure type, with abatement effectiveness in the order slurry > poultry manure > FYM. Some abatement efficiencies are given in Table A2–3.

Table A2–3 Abatement techniques for slurry and solid manure application to land* (UNECE, 2007)

Abatement measure	Type of manure	Land use	Emission reduction (%)	Limits to applicability
Trailing hose	Slurry	Grassland, arable land	30 Emission reduction may be less if applied on grass > 10 cm. Poor reductions on bare land in some situations	Slope of land (< 15 % for tankers; < 25 % for umbilical systems); not for slurry that is viscous or has a large straw content
Trailing shoe	Slurry	Mainly grassland	60**	Slope (< 15 % for tankers; < 25 % for umbilical systems); not viscous slurry, size and shape of the field, grass height should be > 8 cm, difficult when crop residues present
Shallow injection (open slot)	Slurry	Grassland	70**	Slope < 10 %, greater limitations for soil type and conditions, not viscous slurry**.**
Deep injection (closed slot)	Slurry	Mainly grassland, arable land	80	Slope < 10 %, greater limitations for soil type and conditions, not viscous slurry.
Broadcast application and incorporation by plough in one process	Slurry	Arable land	80	Only for land that can be easily cultivated
Broadcast application and immediate incorporation by plough	Slurry	Arable land	80–90	Only for land that can be easily cultivated
Immediate incorporation by disc			60–80	
Broadcast application and incorporation by plough within 12 h	Slurry	Arable land	30	(according to § 10)
Immediate incorporation by plough	FYM (cattle, pigs)		90	
Immediate incorporation by plough	Poultry manure		95	
Incorporation by plough within 12 h	Solid manure	Arable land	50 for cattle and pig 70 for poultry	

Incorporation by plough within 24 h	Solid manure	Arable land	35 for cattle and pig 55 for poultry

Notes:
1. */ Emissions reductions are agreed as likely to be achievable across the UNECE.
2. ** revised to incorporate conclusions of recent review.

A detailed description of the measures that can be taken to reduce NH_3 emissions from manure management can be found in ECE/EB.AIR/WG.5/2007/13 (http://unece.org/env/documents/2007/eb/wg5/WGSR40/ece.eb.air.wg.5.2007.13.e.pdf).

A3 Emission factors

A3.1 Tier 1 emission factors

Particulate matter

Transformations are needed to convert livestock units into AAP. In addition, inhalable and respirable dust concentrations have to be transformed into the respective 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, the methodology is considered a first estimate methodology rather than a simpler methodology.

Table A3–1 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}
100901	Dairy cattle	slurry	172.5	28.5
		solid	89.3	28.0
100902	Other cattle (including young cattle, beef cattle and suckling cows)	slurry	113.0	13.7
		solid	85.5	16.0
100902	Calves	slurry	127.5	19.5
		solid	132.0	27.3
100903	Fattening pigs	slurry	612.3	66.0
		solid	725.5	71.0
100903	Weaners	slurry	1 021.0	75.5
		solid	n.a.	n.a.
100904	Sows	slurry	345.8	47.8
		solid	448.5	47.5
100906	Horses	solid$^{1)}$	55	n.a.
100907	Laying hens	cages	636.3	78.3
		perchery	3 080.7	595.3
	Broilers	solid	3 965.8	517.5

Notes:
1. n.a.: not available; ID: inhalable dust; RD: respirable dust.
2. $^{1)}$ Wood shavings.

In order to get mean emissions per animal head, means of these data have to be divided by the average weight of the animals in the respective 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. A list of relevant LUs is given in Table A3–2.

Table A3–2 Conventional livestock units, and weights of livestock on which the N excretions estimates in Table 3–5 were based

Code	Livestock type	Weight kg animal^{-1}	Weight of animal used for N_{ex} estimate (kg)	Transfer factor LU animal^{-1}
100901	Dairy cows	600 to 650	600	1.2–1.3
100902	Other cattle	450 to 650	340	0.9–1.3
100902	Calves	50 to 150	NA	0.1–0.3
100903	Fattening pigs		65	0.3
100903	Piglets		NA	0.01
100904	Sows		225	0.3
100905	Sheep		50	0.1
100906	Horses		500	1.0
100907	Laying hens		2.2	0.0044
100908	Broilers		0.9	0.0020
100909	Other poultry (turkeys)		6.1	
100909	Other poultry (ducks)		4.2	
100909	Other poultry (geese)		1.8	
100910	Fur animals		NA	
100913	Camels		NA	
100913	Buffalo		700	

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 made in a cubicle house with dairy cows and calves, housed on slatted floor and solid floor with straw. The one-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, pers. comm.). The conversion factors for pigs were derived from Louhelainen et al. (1987). Horses were assumed to have a transformation factor similar to cattle. For poultry, this methodology makes the assumption that the concentration of inhalable dust is approximately the same as that of PM_{10}, and that the concentration of respirable dust may be considered to be of the same order of magnitude as that of $PM_{2.5}$. However, simultaneous measurements of inhalable dust and PM_{10} in a turkey barn have recently shown that the mean ratio between both dust fractions was *ca*. 0.6 (Schütz et al. 2004). 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 A3–3.

Table A3–3 Transformation factors for the conversion of inhalable dust (ID) 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)$^{-1}$
101001	Dairy cows	[1]0.46	[2]0.30
101002	Other cattle	[1]0.46	[2]0.30
101003	Fattening pigs (including weaners)	[3]0.45	0.08
101004	Sows	0.45	0.08
101006	Horses[4]	[1]0.46	[2]0.30
100907, 100908, 100909	Poultry	1.0	[4]1.0

Note:

1. Seedorf and Hartung (2001), the same conversion factor for horses is assumed as for cattle
2. Seedorf (personal communication).
3. Louhelainen et al. (1987).
4. The transformation factor for $PM_{2.5}$ relates to respiratory dust and not inhalable dust.

The resulting EFs in kg animal^{-1} a^{-1} are listed in Table A3–4.

Table A3–4 EFs for inhalable dust, respirable dust, PM_{10} and $PM_{2.5}$

Code	Animal category	Housing type	Animal weight kg animal^{-1}	Conversion factor LU animal^{-1}	Emission factors EF			
					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}
100901	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
100902	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
100902	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
100903	Fattening pigs	slurry	65	0,13	0,70	0,08	0,31	0,06
		solid	65	0,13	0,83	0,08	0,37	0,07
100903	Weaners	slurry	20	0.04	0.36	0.026	0.18	0.029
		solid	20	0.04	n.a.	n.a.	n.a.	n.a.
100904	Sows	slurry	225	0,5	1,36	0,19	0,61	0,11
		solid	225	0,5	1,77	0,19	0,80	0,14
100906	Horses	solid$^{1)}$	500	1,0	0,48		0,22	0,14
100907	Laying hens	cages	2.2	0,0044	0,025	0,0030	0,025	0,0030
		perchery	2.2	0,0044	0,119	0,0229	0,119	0,0229
100908	Broilers	solid	1	0,0020	0,069	0,0091	0,069	0,0091
100505	Sheep	solid			0,139		0,056	0,017
100510	Fur animals	solid					0,0081	0,0042
100511	Goats	solid			0,139		0,056	0,017
100512	Mules and asses	solid	350	0,7	0,34		0,16	0,10
100514	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
100509	Ducks	solid	2	0,004	0,14	0,018	0,14	0,018
100509	Geese	solid	3,5	0,007	0,24	0,032	0,24	0,032

Notes:

1. n.a. not available.
2. $^{1)}$ wood shavings.

For cattle and swine, the tier 1 EFs are based on solid animal waste management systems (AWMS). The AWMS distribution for solid/liquid in EU27 for swine is 42/58 according to the EU reporting in 2011 to the UNFCCC. For dairy cattle the distribution is 49/51 and for non-dairy cattle 59/41. Based on that, the AWMS distrubtion for solid/liquid for dairy cattle is assumed to 50/50, for other cattle 60/40 and for swine 40/60.

The EFs EF_{PM10} and $EF_{PM2.5}$ given in Table A3–5 are mainly of a similar order of magnitude as those used in the The Regional **A**ir Pollution INformation and Simulation (RAINS) model for livestock operations (Klimont et al., 2002) (see Table A3–5). However, for cattle there is an obvious deviation in case of $EF_{PM2.5,}$ which might be caused by different detection methods used for $PM_{2.5}$ measurements (e.g. optical related measurements versus non-inertial sampling methods). Therefore, the proposed $EF_{PM2.5}$ for cattle and horses in Table A3–5 should in particular be used with care.

Table A3–5 PM_{10} emission factors EF_{PM10} as used in the RAINS model (Klimont et al. 2002)

Livestock type	EF_{PM10} kg animal^{-1}. a^{-1}	$EF_{PM2.5}$ kg animal^{-1}. a^{-1}
Poultry	0.0473	0.0105
Pigs	0.4376	0.0778
Dairy cattle	0.4336	0.0964
Other cattle	0.4336	0.0964
Other animals[1]	n.a.	n.a.

Notes:

1. [1]sheep, horses and fur animals.
2. n.a.: not available.

A3.3 Tier 2 technology-specific approach

Ammonia

For ammonia emissions during grazing, Pain et al. (1998) proposed a function of the form:

$$E_{NH3} = c + d\ TAN \qquad (A3)$$

which subsequently was applied to a variety of experimental data sets in Misselbrook et al. (2000)

with E_{NH3} = NH_3 emitted (kg NH_3-N a^{-1}),
c = -0.5 kg NH_3-N a^{-1},
d = 0.12 kg (kg NH_3-N)$^{-1}$,
TAN = TAN excreted (kg N a^{-1})

to estimate NH_3 emissions from grassland grazed by cattle. No distinction is made between emissions from cattle and sheep excreta. Equation (A3) was derived almost entirely from measurements of NH_3 emissions in North-West Europe. The relationship may not give accurate estimates of emissions from grazing in drier, or warmer climates. For ease of calculation, in the example spreadsheet, fixed EF as %TAN deposited during grazing have been used.

The tables below give the EF 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 below the table.

The EF used in the Tier 2 mass flow approach to calculate emissions of N_2O-N during manure storage are based on the default IPCC EF and are given in Table 3–6. The IPCC EFs are expressed as proportions of total N at excretion. In order to convert from the IPCC EF to EF 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 3–6 below. The proportions of manure-N as TAN were calculated using the example spreadsheet provided in Appendix B.

Table A3–6 Derivation of default Tier 2 EF for direct N_2O emissions from manure management. Appendix Table A3–7 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
Horse (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 EAGER group.

Table A3–7 Example partial emission factors (expressed as % of TAN)

a) Housing

Livestock category		Denmark	Germany	Netherlands	Switzerland	UK
100901 Dairy cows	slurry	17.0	19.7	17.7	16.7	31.5
100901 Dairy cows	solid					22.9
100902 Other cattle	slurry					31.5
100902 Other cattle	solid	10.0	19.7	16.9	25.0	22.9
100903 Fattening pigs	slurry	25.0	28.4	31.1	20.0	33.2
100903 Fattening pigs	solid		28.4			25.0
100904 Sows	slurry		23.9			19.0
100904 Sows	solid		23.9			25.0
100905 +100911 Sheep and goats	solid	25.0	30.0	11.0		21.6
100906 +100912 Horses, mules and asses)	solid	25.0	19.7			
100907 Laying hens	solid	35.7	33.8	57.9		37.4
100908 Broilers	litter	36.0	20.0	20.0	8.1	57.0
100909 Ducks	litter	35.7	11.4	32.1		17.5
100909 Geese	litter	35.7	78.9			
100909 Turkeys	litter	35.7	52.9	32.1		19.2
100910 Fur animals	NA	30.0	24.3			
100913 Camels	solid					
100914 Buffaloes	solid		19.7			

b) Storage

Livestock category		Denmark	Germany	Netherlands	Switzerland	UK
100901 Dairy cows	slurry	18.0	16.7	19.2	27.7	15.7
100901 Dairy cows	solid					34.8
100902 Other cattle	slurry	31.3				15.7
100902 Other cattle	solid	8.6	60.0	2.5	30.0	34.8
100903 Fattening pigs	slurry	14.0	15.0	15.9	12.0	13.0
100903 Fattening pigs	solid		60.0			29.6
100904 Sows	slurry		15.0			13.0
100904 Sows	solid		60.0			29.6
100905 +100911 Sheep and goats	solid	10.0	60.0	5.0		34.8
100906 +100912 Horses, mules and asses)	solid	10.0	60.0			11.8
100907 Laying hens	solid	16.7	8.1			17.8
100908 Broilers	litter			15.0		
100909 Ducks	litter	25.0	6.5	45.0		17.8
100909 Geese	litter	25.0	6.5			
100909 Turkeys	litter	25.0	6.5	45.0		17.8
100910 Fur animals	NA	8.5				
100913 Camels	solid					
100914 Buffaloes	solid		16.7			40.0

c) Spreading

Livestock category		Denmark	Germany	Netherlands	Switzerland	UK
100901 Dairy cows	slurry	61.3	55.0	68.0	48.0	43.0
100901 Dairy cows	solid					81.0
100902 Other cattle	slurry					43.0
100902 Other cattle	solid	64.4	90.0	100.0	60.0	81.0
100903 Fattening pigs	slurry	26.0	25.0	68.0	48.0	33.0
100903 Fattening pigs	solid		80.0			81.0
100904 Sows	slurry		25.0			33.0
100904 Sows	solid		80.0			81.1
100905 +100911 Sheep and goats	solid		90.0	100.0		81.0
100906 +100912 Horses, mules and asses)	solid		90.0			
100907 Laying hens	solid		90.0	55.0		63.0
100908 Broilers	litter	64.0	90.0	100.0	14.0	63.0
100909 Ducks	litter		45.0	55.0		63.0
100909 Geese	litter		45.0			
100909 Turkeys	litter		45.0	55.0		63.0
100910 Fur animals	NA					
100913 Camels	solid					
100914 Buffaloes	solid					55.0

d) Grazing

Livestock category		Denmark	Germany	Netherlands	Switzerland	UK
100901 Dairy cows	slurry	12.0	12.5	13.3	6.7	7.7
100901 Dairy cows	solid					
100902 Other cattle	slurry					5.8
100902 Other cattle	solid					
100903 Fattening pigs	slurry					
100903 Fattening pigs	solid					
100904 Sows	slurry					
100904 Sows	solid					
100905 +100911 Sheep and goats	solid		7.5	7.5		13.3
100906 +100912 Horses, mules and asses)	solid					35.0
100907 Laying hens	solid					
100908 Broilers	litter					
100909 Ducks	litter					
100909 Geese	litter					
100909 Turkeys	litter					
100910 Fur animals	NA					
100913 Camels	solid					
100914 Buffaloes	solid					12.5

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

- Denmark, Hutchings et al., 2001;
- Germany, Dämmgen et al., 2007;
- Netherlands, 'MAM', Groenwold et al., 2002; 'FarmMin', Evert Van et al., 2003;
- Switzerland, Reidy et al., 2007
- UK, Webb and Misselbrook, 2004.

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

A3.5 Activity data

Ammonia

Table A3–8 Comparison of manure storage types with those used in IPCC

Term	Definition	IPCC equivalent
Lagoons	Storage with a large surface area to depth ratio; normally shallow excavations in the soil	Liquid/slurry[1]. Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the animal housing, usually for periods less than one 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 due to 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 animal house, 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 animal confinement facility, usually for periods less than one year.
In-house deep litter	Mixture of excreta and bedding, accumulated on the floor of the animal house.	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 stabilization by the microbial reduction of complex organic compounds to CO_2 and CH_4, 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:

[1] In IPCC lagoons refers only to a particular type of lagoon, anaerobic lagoons, a type of liquid storage system designed and operated to combine waste stabilization and storage, storage may be for > 1 year. Lagoons referred to in this document are simply earth-banked alternatives to storage in tanks.

Table A3–9 Description of reduced -emission manure spreading techniques

Term	Description
Broadcast	
Trailing hose	These machines discharge slurry at or just above ground level through a series of hanging or trailing pipes. The width is typically 12 m with about 30 cm between bands. The technique is applicable to grass and arable land, e.g. for applying slurry between rows of growing crops.
Trailing shoe	Grass leaves and stems are parted by trailing a narrow shoe or foot over the soil surface and slurry is placed in narrow bands on the soil surface at 20–30 cm spacing. The slurry bands should be covered by the grass canopy so the grass height should be a minimum of 8 cm. The machines are available in a range of widths up to 7 or 8 m.
Open slot injection	Knives or disc coulters are used to cut vertical slots in the soil up to 5–6 cm deep into which slurry is placed. Spacing between slots is typically 20–40 cm and working width 6 m. The application rate must be adjusted so that excessive amounts of slurry do not spill out of the open slots onto the surface. The technique is not applicable on very stony soil nor on very shallow or compacted soils. The slope of the field may also be a limitation to applicability of injection.
Closed-slot injection	Slurry is fully covered after injection by closing the slots with press wheels or rollers fitted behind the injection tines. Shallow closed-slot injection is more efficient than open-slot in decreasing NH_3 emission. To obtain this added benefit, soil type and conditions must allow effective closure of the slot. The technique is, therefore, less widely applicable than open-slot injection. This technique can be shallow (5–10 cm depth) or deep (15–20cm).
Incorporation	Incorporating manure spread on the surface by ploughing is an efficient means of decreasing NH_3 emissions. The manure must be completely buried under the soil to achieve the efficiencies given in Table A2–2. Lesser efficiencies are obtained with other types of cultivation machinery. Ploughing is mainly applicable to solid manures on arable soils. The technique may also be used for slurries where injection techniques are not possible or unavailable. Similarly, it is applicable to grassland when changing to arable land (e.g. in a rotation) or when reseeding.
Bare soil	Soil which is not covered by the leaves of crops or weeds.

Table A3–10 Default values for other losses needed in the mass-flow calculation, related to EF for N_2O-N, or TAN input to storage

EF	Slurry	Solid
EF_storageNO %TAN	0.01	[1]1.0
EF_storageN_2 %TAN	0.30	[1]30.0
EF_leachateN	NA	[2]12.0

Notes:

1. [1]Multiply the EF_N2O in Table 3–6 by this factor.
2. [2]As a proportion of TAN entering storage.

Table A3–11 Summary of updates to calculation methodologies and EFs made during the 2012 revision of this chapter

Emission	Tier 1		Tier 2	
	Methodology	EFs	Methodology	EFs
NH_3	Not updated	Not updated	Not updated	Not updated
NO	Not updated	Not updated	NA	NA
NMVOC	Updated	Updated	Updated	Updated
PM	Not updated	Not updated	NA	NA

Note:
NA: not applicable

A4.7 Gridding and temporal disaggregation

Nitric Oxide

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

NMVOCS

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.

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