Category		Title
NFR	5.B.2	Biological treatment of waste – anaerobic digestion at biogas facilities
SNAP	091006	Biogas production
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Contents

1 Overview

This chapter covers the emissions from the biological treatment of waste by anaerobic digestion at biogas facilities. Feedstocks for anaerobic digestion can be any biodegradable organic material such as livestock manure and crops from agriculture, food waste from food processing industries, households and restaurants, and organic waste from municipalities. The 2014 nomenclature for reporting (NFR), used for the international reporting of emission inventory data, introduced the new source category '5.B.2 Biological treatment of waste — anaerobic digestion at biogas facilities'.

2 Description of sources

2.1 Process description

Anaerobic digestion is a natural process by which biomass is broken down by naturally occurring microorganisms in the absence of oxygen. These microorganisms digest the biomass and release a methane-rich gas (biogas) that, if collected in a biogas plant, can be used to generate renewable heat and power. The remaining material (digestate) is rich in nutrients, so it can be used as a fertiliser.

The digestion process depends on the biomass of microbes, the substrate composition, the temperature in the digester, the dry matter content of the feedstock, the residence time in the digester and the biogas technology. Depending on the digestion technique and in order to improve the digestion process, feedstock pre-treatment, heating of the digester and mixing of feedstock can be useful.

2.2 Techniques

Technologies developed to digest biomass fall into the following categories:

1. wet or low solid digestion: operated at a dry matter content of less than 10 % (but the feedstock can have much higher solid content, which would be diluted upon entry);
2. dry or high solid digestion: operated at between a 15 % and 35 % dry solid content;
3. two- or multi-stage digestion: the development of multi-stage processes aimed to improve different stages of the digestion process, thus providing flexibility and better process control for the different stages of the anaerobic biochemical reactions.

The general concept of a biogas facility comprises the following stages:

1. pre-storage of feedstock
2. anaerobic digestion in the digester
3. storage of the digestate.

In practice, not all feedstock is stored before anaerobic digestion, but may be fed directly into the digester. The digester can consist of more than one gas-tight vessel. The storage of the digestate can be in a gas-tight vessel, an open tank or another storage facility. The storage may be combined with, or preceded by, treatment of the digestate, e.g. the separation of the liquid and solid fractions before storage. The possible treatment of the liquid fraction in a wastewater treatment plant, the combustion of the solid fraction and the utilisation of digestate as organic fertiliser are beyond the scope of Chapter 5.B.2 (see section 2.3).

2.3 Emissions

The storage of feedstock and digestate in open tanks, as well as their mechanical treatment, may cause emissions of the nitrogen (N) gases ammonia (NH_3) and nitric oxide (NO), as well as N2O, CH4, odour and dust. Anaerobic digestion is carried out in gas-tight vessels, and fugitive air emissions are unlikely to occur except during transfer to and from the digester and storage of feedstocks and digestate. However, fugitive emissions of biogas are possible from emergency vent valves and from poorly sealed water traps.

The emissions generated by the combustion of the biogas are addressed separately in Chapter 1.A.1.

This chapter (Chapter 5.B.2) considers the potential for NH_3 emissions from the following sources of biogas facilities:

1. during storage of feedstock on the premises of the biogas facility ([1]);
2. during storage of the digestate.

Agricultural crops used for biogas production (energy crops) are commonly stored as silage. As the pH of silage is low for conservation purposes, NH_3 emissions resulting from the storage of energy crops before anaerobic digestion are negligible.

As the digester is completely enclosed, no NH_3 emissions should occur. In the operation of a biogas plant however, instances of excess pressure might occur. In these cases, pressure valves might release some biogas (approximately 1 % of gas produced). For greenhouse gas calculations, these losses are relevant, as about 60 % of the gas volume is methane. The concentration of NH_3 in biogas is far lower (0.1–1 %), depending on the substrates being fermented. For most digestion processes, the leakage losses will therefore be less than 0.05 % of the nitrogen (N) content of the resulting digestate. Therefore, this source is here considered negligible.

Emissions of NO, odour and dust from anaerobic digestion at biogas facilities are not considered because they are likely to be insignificant.

2.4 Controls

Information on ways to reduce NH_3 emissions during storage of livestock manures is provided in Chapter 3B (e.g. rigid covers can reduce NH_3 emissions from storage of livestock slurry by about 80 %). No data are available on controlling emissions of NH_3 from storage of food wastes, but these are likely to be very small. The process of anaerobic digestion leads to elevated pH values and total ammoniacal nitrogen (TAN) contents. Therefore, it is strongly recommended that digestate is held in a covered store. The same measures as for livestock manures can be applied for the reduction of NH_3 emissions.

Information on general abatement technologies for NH_3 emissions from storage processes is given in the United Nations Economic Commission for Europe (UNECE) Framework Advisory Code of Good Agricultural Practice for Reducing Ammonia Emissions

([1]) NH_3 emissions from feedstock storage prior to the pre-storage on the premises of the biogas facility (e.g. the on-farm storage of livestock manures) are not considered in this chapter in order to avoid possible double counting. The on-farm storage of livestock manures is dealt with in Chapter 3.B.

(https://www.unece.org/fileadmin/DAM/env/documents/2014/AIR/WGSR/eb.air.wg.5.2001.7.e.pdf) and the draft *Guidance document on preventing and abating ammonia emissions from agricultural sources* https://www.unece.org/fileadmin/DAM/env/documents/2014/AIR/WGSR/eb.air.wg.5.2001.7.e.pdf). This guidance document also gives information on the emission reduction potential of a variety of abatement technologies in terms of a percentage of unabated storage. If the proportion of digestate stored with certain technologies is known, the emission factor (EF) for this proportion can be reduced by this value.

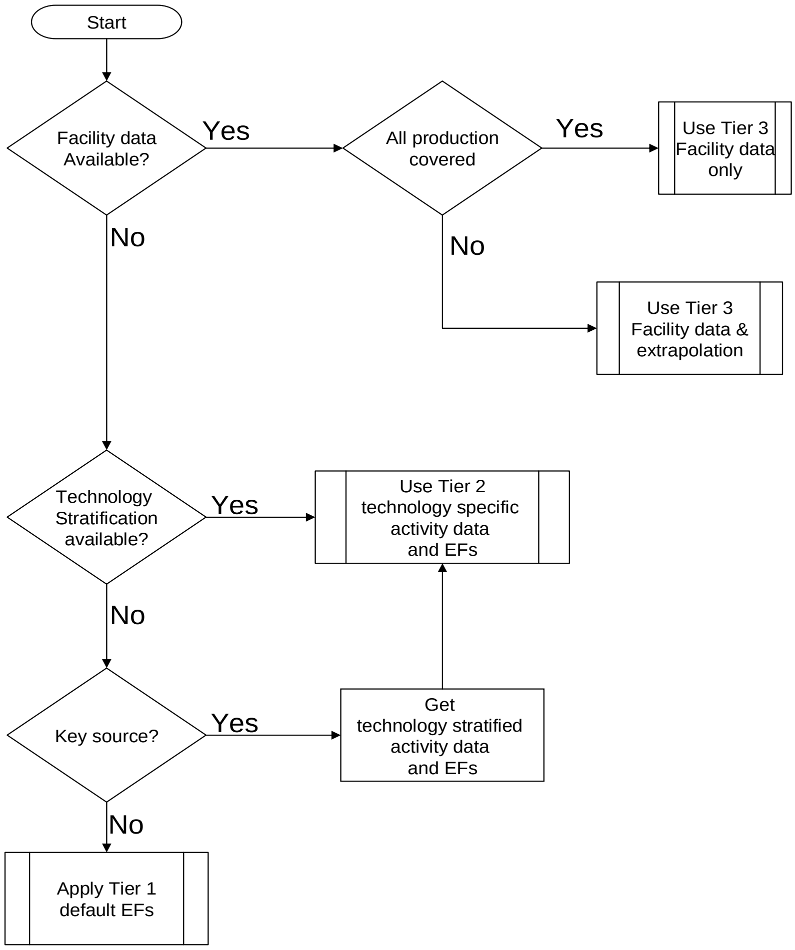
3 Methods

3.1 Choice of method

Figure 3.1 presents the procedure that should be used to select the methods for estimating emissions from this source category. The basic approach is outlined below.

- If detailed information is available, this should be used.
- If the source category is a key category, a Tier 2 or better method must be applied and detailed input data must be collected. The decision tree directs the user in such cases to the Tier 2 method, since it is expected that it will be easier to obtain the necessary input data for this approach than to collect the 'facility level' data needed for a Tier 3 estimate.
- The alternative to applying a Tier 3 method, that is, using a detailed process modelling at facility level, is included under 'facility data' in the decision tree.

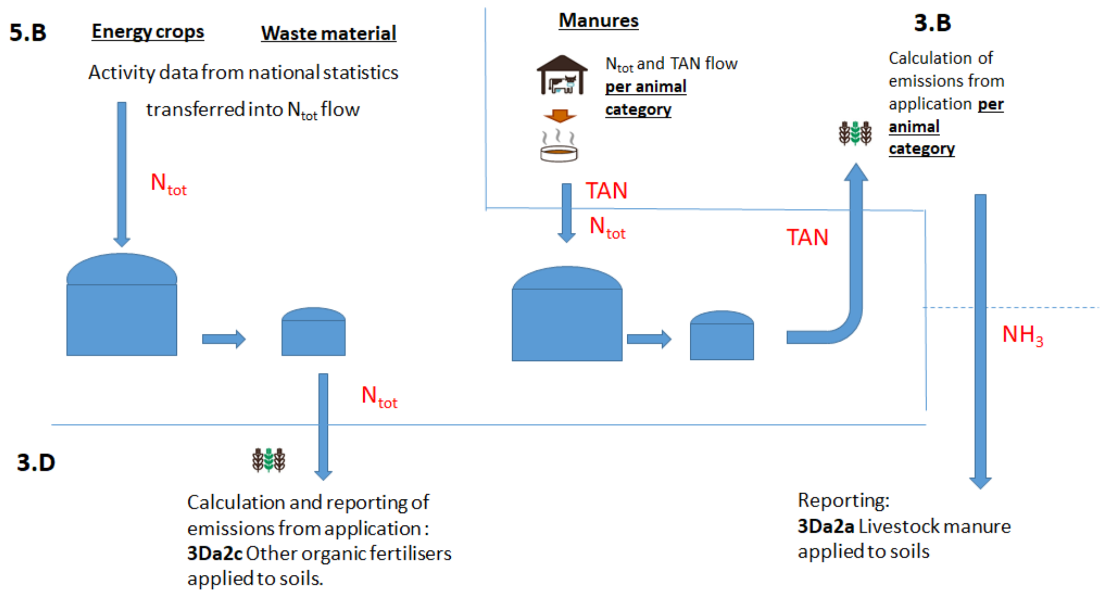
Figure 3.1 Decision tree for source category 5.B.2 Biological treatment of waste — anaerobic digestion at biogas facilities



3.2 Reporting emissions

As mentioned in chapter 3.B section 2.3, the Tier 2 method for calculating ammonia emissions from manure management follows a mass flow approach for total nitrogen (total-N) and total ammoniacal nitrogen (TAN). Therefore the emissions from application of digestates originating from livestock manure should be calculated in chapter 3.B, together with the emissions from application of untreated animal manures, and be reported under NFR code 3.D.a.2.a (Figure 3.2). Although being fully aware, that co-digestion of different feedstocks takes place, in 5.B.2, the digestion of manures should be calculated separately from the digestion of other organic wastes and of energy crops. The amount of total-N and TAN entering anaerobic digestion in manure must be consistent with formulae 22, 23, 28 and 29 in 3.B (chapter 3.4, Step 8). Emissions from spreading digestates resulting from digestion of manure are calculated in chapter 3B. Emissions from spreading digestates resulting from digestion of other organic wastes and energy crops are calculated in 3.D and reported under NFR code 3.D.a.2.c.

Figure 3.2 Reporting of emissions from anaerobic digestion at biogas facilities



If a Tier 1 approach is used, care should be taken not to double count emissions resulting from application of N excreted by livestock in 3.B According to Tier 1 in 3.B, emissions from manures are calculated based on animal places, including emissions from application. In this case, all N excreted by livestock is accounted for. Therefore no N from digested manures calculated in 5.B.2 should be considered for calculating emissions in 3.B if a Tier 1 approach is used in 3.B.

3.3 Tier 1 default approach

3.3.1 Algorithm

The Tier 1 approach estimates the total emission, E_{NH3} (in kg NH_3 per year), from:

$$E_{\mathrm{NH3}} = AR_{\mathrm{feedstock}} \times EF_{\mathrm{NH3\text{-}N,\,Tier\,1}} \times 17/14 \qquad (1)$$

where $AR_{feedstock}$ is the total annual amount of N in feedstock, in kg a^{-1}; and $EF_{NH3\text{-}N, Tier 1}$ is the Tier 1 NH_3-N EF related to N in feedstock, in kg NH_3-N per kg N. If no specific N amount is available from national data, $AR_{feedstock}$ is calculated by multiplying the total fresh weight of feedstock (tonnes a^{-1}) by the dry matter content of the feedstock (kg kg^{-1}) and the concentration of N in the feedstock dry matter (kg N per kg DM).

3.3.2 Default emission factor

The default EF (Table 3.1) is the total of the Tier 2 EFs provided in section 3.4.2. The range of uncertainty (95 % confidence interval) is estimated in accordance with section 3.4.2.

Table 3.1 Tier 1 EFs for source category 5.B.2 Biological treatment of waste — anaerobic digestion at biogas facilities

Tier 1 EFs					
	Code	Name			
NFR source category	5.B.2	Biological treatment of waste — anaerobic digestion at biogas facilities			
Fuel	NA				
SNAP (if applicable)	091006	Biogas production			
Technologies/practices					
Region or regional conditions	NA				
Abatement technologies	See section 2.4				
Not applicable	As, Cu, Ni, Se				
Not estimated	NO_x, CO, NMVOC, SO_2, TSP, PM_{10}, $PM_{2.5}$, BC, HCB, Pb, Cd, Hg, Cr, Zn, HCH, PCBs, PCDD/F, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene				
Pollutant	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	
NH_3-N	0.0275	kg NH_3-N per kg N in feedstock	0.0163	0.0501	See text

Total nitrogen in digestate after storage is calculated using equation (2)

$$N_{tot,dig} = N_{tot,sub} - (E_{NH3} \times 14/17) \quad (2)$$

With:

$N_{tot,dig}$: Total amount of N in digestate after storage in kg a^{-1}

$N_{tot,sub}$: Total amount of N in the feedstock entering 5.B.2 in kg a^{-1}

E_{NH3}: Ammonia emitted in kg a^{-1}, calculated in equation (1)

3.3.3 Activity data

The Tier 1 method requires the total annual amount of N in the feedstock entering the biogas plants to be known. In case if the data are not available they can be derived from the amount of fresh matter, based on data gathered by statistical surveys or derived from proxy data, e.g. livestock numbers and excretion rates, as well as information (e.g. expert judgement) on the percentage of manure being digested in biogas plants.

Table 3. provides default factors for the conversion of fresh matter units into N units.

3.4 Tier 2 technology-specific approach

3.4.1 Algorithm

The Tier 2 approach estimates the total emission, E_{NH3} (in kg NH_3 per year), from:

$$E_{\mathrm{NH3}} = AR_{\mathrm{feedstock}} \times \sum_{\mathrm{stages}} EF_{\mathrm{NH3\text{-}N,\,stage\ i}} \times 17/14 \qquad (3)$$

where $AR_{feedstock}$ is the total annual amount of N in feedstock, in kg a^{-1}; and $EF_{NH3\text{-}N,\ stage\ i}$ is the NH_3-N EF for stage i (i is the pre-storage, digester, and storage of digestate) related to the **total N in feedstock** (kg NH_3-N per kg total N). If no specific N amount is available from national data, $AR_{feedstock}$ is calculated by multiplying the total fresh weight of feedstock (tonnes a^{-1}) by the dry matter content of the feedstock (kg kg^{-1}) and the concentration of N in the feedstock dry matter (kg N kg^{-1}).

As pointed out in section 2.3, NH_3 emissions from the digester or the system of digesters can be assumed to be negligible.

As mentioned in section 3.2, emissions from the field application of digestates resulting from biogas production should be calculated in chapter 3.B for digested manures and in 3.D.a.2.c for digested energy crops and organic waste. Therefore in 5.B.2, the N-flow should be calculated separately for manures on one hand and energy crops and wastes on the other hand. As emission factors in 3.B are based on TAN the TAN flow needs to be considered for manures. The emission factor in 3.D.a.2.c is based on total N, therefore no TAN flow needs to be considered for energy crops and waste.

For digested manures, the TAN and total-N in manure (TAN_{sub} and N_{tot} respectively, kg a^{-1}) are:

$TAN_{sub} = m_{biogas\_slurry\_TAN} + m_{biogas\_solid\_TAN}$ (4)

$N_{sub} = m_{biogas\_slurry\_N} + m_{biogas\_solid\_N}$ (5)

where $m_{biogas\_slurry\_TAN}$, $m_{biogas\_solid\_TAN}$, $m_{biogas\_slurry\_N}$ and $m_{biogas\_solid\_N}$ are obtained from equations 22, 23, 28 and 29 in chapter 3B.

The TAN in digestate that is returned to chapter 3B (for use in equation 35; m_{dig_TAN}) is calculated using equation 6:

$m_{dig\_TAN} = TAN_{sub} + f_{min} \times (N_{tot} - TAN_{sub}) - (E_{NH3} \times 14/17)$ (6)

where

m_{dig_TAN}: TAN in digestate after storage in kg a^{-1}

f_{min}: relative share of organic N entering the digester that is mineralized to TAN in the digester in kg kg^{-1}

E_{NH3}: NH3 emitted in kg a^{-1}, calculated from total N in equation (3)

The total-N in digestate that is returned to 3B (for use in equation 36; m_{dig_TAN}kg a^{-1}) is:

$m_{dig\_N} = N_{tot\_dig} - (E_{NH3} \times 14/17)$ (7)

If no national data are available for f_{min}, a value of 0.32 for the N-mineralization of organic N in manures digested in biogas plants is recommended as used in the German emission inventory (Haenel et al 2018).

As calculations in 3.B are differentiated for different animal categories, TAN flow for digestion should also be calculated separately for the respective animal categories.

For digested energy crops and waste, $N_{tot,dig}$ in digestate after storage is calculated using equation (2) replacing E_{NH3} from equation (1) by E_{NH3} from equation (3)

3.4.2 Tier 2 emission factors

The European Union (EU) reference document on best available techniques (BREF document) for 'Waste treatment industries' (EC, 2006) gives typical emission ranges for most pollutants, but there is no information for NH_3 emissions. This section presents the Tier 2 NH_3 EFs for anaerobic digestion at biogas facilities adopted from Cuhls et al. (2010). These EFs were derived from trials with municipal organic waste and green waste (gardening waste). For all stages, they were calculated by relating the stage-specific NH_3 emissions (if enclosed, before air scrubbing) to the total amount of fresh matter of the feedstock entering the biogas plants. However, because of the degradation of organic matter during the process, which might vary between the different feedstocks, fresh matter is an inappropriate entity for relating NH_3 emissions to. Hence, the EFs derived by Cuhls et al. (2010) were converted into units of kg NH_3-N per kg N in the feedstock. The input material for the German plants covered by the study of Cuhls et al (2010) are municipal organic wastes and green wastes (gardening wastes). These two substrates are used in approximately equal proportions for biogas production in Germany. Therefore, the arithmetic mean of the N content in fresh matter of municipal organic waste and green waste was used for the conversion. The data are provided in Table 3.4.

NH_3 emissions from the digester can be considered negligible (see section 2.3), hence an EF of zero is suggested.

Cuhls et al. (2010) only provide emission factors for the storage of separated digestate (solid and liquid fractions). Therefore, this emission factor for storage was estimated by adding the emission factors for the storage of the two digestate fractions after separation. It applies to open storage only; if the digestate is stored in closed storage, the ammonia emission can be considered negligible. Countries are encouraged to use more specific national emission factors.

According to Heldstab et al. (2015), p. 284, the uncertainties (95 % confidence interval) of the EFs provided by Cuhls et al. (2010) are estimated to be a factor of 1.75.

Table 3.2 Tier 2 EFs for source category 5.B.2 Biological treatment of waste — anaerobic digestion at biogas facilities; pre-storage of feedstock

Tier 2 EFs		
	Code	Name
NFR source category	5.B.2	Biological treatment of waste — anaerobic digestion at biogas facilities
Fuel	NA	
SNAP (if applicable)	091006	Biogas production
Technologies/practices	Pre-storage	
Region or regional conditions	NA	
Abatement technologies	See section 2.4	
Not applicable	As, Cu, Ni, Se	

Not estimated	NO_x, CO, NMVOC, SO_2, TSP, PM_{10}, $PM_{2.5}$, BC, HCB, Pb, Cd, Hg, Cr, Zn, HCH, PCBs, PCDD/F, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene				
Pollutant	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	
NH_3	0.0009	kg NH_3-N per kg N in feedstock	0.0005	0.0015	See text

Table 3.3 Tier 2 EFs for source category 5.B.2 Biological treatment of waste — anaerobic digestion at biogas facilities; storage of digestate (open storage)

Tier 2 EFs					
	Code	Name			
NFR source category	5.B.2	Biological treatment of waste — anaerobic digestion at biogas facilities			
Fuel	NA				
SNAP (if applicable)	091006	Biogas production			
Technologies/Practices	Storage of non-separated digestate				
Region or regional conditions	NA				
Abatement technologies	See section 2.4				
Not applicable	As, Cu, Ni, Se				
Not estimated	NO_x, CO, NMVOC, SO_2, TSP, PM_{10}, $PM_{2.5}$, BC, HCB, Pb, Cd, Hg, Cr, Zn, HCH, PCBs, PCDD/F, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene				
Pollutant	**Value**	**Unit**	**95 % confidence interval**		**Reference**
			Lower	**Upper**	
NH_3	0.0266	kg NH_3-N per kg N in feedstock	0.0152	0.0465	See text

3.4.3 Activity data

Surveys on the amounts of different types of feedstock are necessary to derive the necessary activity data on N entering anaerobic digestion. These cover all biodegradable organic materials including livestock manures, crops that are grown for energy production and other organic agricultural wastes, such as crop residues, that are used for anaerobic digestion at biogas facilities. According to the definition of the EFs (see section 3.4.2), the total N amounts of feedstock entering the biogas plants are required for calculating the emissions in the biogas process with the Tier 2 methodology.

The amounts of N and TAN in livestock manures to be digested should be derived from the corresponding N and TAN flows calculated in Chapter 3.B, section 3.4 (Step 8).

Table 3. gives the N contents of some possible feedstock types. These default values can be used to convert feedstock fresh matter into amounts of N. The figures in

Table 3. are based on German data, but are also in reasonable agreement with data from the United Kingdom (Webb, J., UK national atmospheric emission inventory team, personal communication, 2016). Countries are encouraged to use their own national data if available.

If dry matter contents differ substantially from those given in

Table 3., N contents can be corrected using the ratio of national to default dry matter contents. In particular, for municipal organic waste, green waste and food waste it is strongly recommended that national data are established, as N content can vary widely.

According to Heldstab et al. (2015), p. 284, the uncertainty of the activity data (95 % confidence interval) is estimated to range from –20 % to +20%.

Table 3.4 N content for various feedstock categories

Feedstock type	Dry matter content of fresh matter (kg kg^{-1})	N content of fresh matter (kg kg^{-1})
Municipal organic waste ([a])	0.40	0.0068
Green waste (grass, etc.) ([a])	Not available	0.0046
Food waste (food processing) [1)]	Not available	0.0051
Cattle slurry ([a])	0.10	0.0052
Pig slurry ([a])	0.06	0.0048
Cattle solid manure ([b])	0.25	0.0052
Pig solid manure ([b])	0.25	0.0060
Poultry manure ([b])	0.50	0.0175
Maize silage ([a])	0.35	0.0046
Grass silage ([a])	0.35	0.0094
Straw ([a])	0.86	0.0051

Sources: ([a])KTBL, (2013), ([b]) LfL (2013).

3.5 Tier 3 emission modelling and use of facility data

This guidebook does not provide a Tier 3 method because of the scarcity of sound methodologies with this approach. However, Wulf and Haenel (2014) proposed a method that could be considered by the countries to implement Tier 3 emission estimates for agricultural feedstock ([2]). A comprehensive description of this German methodology is given by Haenel et al. (2018).

4 Data quality

4.1 Completeness

A complete inventory for biogas facilities should estimate NH_3, NO, total suspended particles (TSP), particulate matter (PM) and non-methane volatile organic compounds (NMVOCs). However, at present, NO, TSP, PM and NMVOC emissions from biogas facilities cannot be reported, as no methods exist to calculate these emissions.

It is essential to include the complete range of feedstocks in the emission calculations and to ensure that emissions from the utilisation of digestate are reported properly (e.g. utilisation as fertiliser in section 3.D and incineration in Chapter 1.A).

4.2 Avoiding double counting with other sectors

Care should be taken not to double count emissions from biogas facilities. NH_3 emissions resulting from the storage of agricultural feedstocks not located on the premises of biogas facilities have to be considered in Chapter 3.B (Manure management).

In addition, emissions produced from the burning of the biogas produced in engines, boilers and/or turbines have to be reported in the relevant chapter (Chapter 1.A, Combustion). Emissions following the application to land of digestate derived from livestock manure are calculated in 3B and reported in 3Da2a.

([2])http://www.tfeip-secretariat.org/assets/Ag_Nature/2014/Biogasemission-inventoryTFEIP5.pptx

4.3 Verification

There are no direct methods to evaluate total inventory estimates of NH_3 emissions from the biological treatment of waste.

4.4 Developing a consistent time series and recalculation

There are no specific issues related to developing a consistent time series and recalculation.

4.5 Uncertainty assessment

General guidance on quantifying uncertainties in emission estimates is given in Part A, Chapter 5, 'Uncertainties', of the EMEP/EEA Guidebook (EMEP/EEA, 2016).

The uncertainties related to the EFs are addressed in section 3.4.2. It is good practice to consider that, from country to country, the composition of the treated waste may vary because of differences in waste definitions and fractionation. This could lead to country-specific EFs that are not comparable with those of other countries.

For more on the uncertainty of the activity data, see section 3.4.3.

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

There are no specific issues related to inventory quality assurance/quality control (QA/QC).

4.7 Gridding

There are no specific issues related to gridding.

4.8 Reporting and documentation

Emissions calculated with Equations 1 or 2 are to be reported under NFR 5.B.2.

It should be noted that emissions from the application of digestate to land need to be reported under NFR 3.D.a.2.c.

Documentation, detailing when and where the biogas facility inventory was checked and by whom, is required.

5 References

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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 Projections' (TFEIP's) Expert Panel on combustion and industry. Please refer to the TFEIP website (www.tfeip-secretariat.org/) for the contact details of the current expert panel leaders.