

CHAPTER 6

WASTEWATER TREATMENT AND DISCHARGE

[Parts shaded in grey – the unchanged text from the *2006 IPCC Guidelines*]

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6 WASTEWATER TREATMENT AND DISCHARGE

6.1 INTRODUCTION

This chapter presents an update of the Wastewater Treatment and Discharge chapter of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). The refinements laid out in this chapter provide clarity over how to apply the *2006 IPCC Guidelines* and definitions of treatment systems presented and introduce new and improved default values and emission factors based on further scientific research into the mechanisms associated with greenhouse gas emissions from wastewater treatment (including sludge treatment that occurs within the wastewater treatment plant). In addition, these refinements present an updated section on nitrous oxide emissions to better address emissions from domestic wastewater, including centralised treatment plants and plants that use biological nutrient removal techniques, and to include emissions from industrial wastewater.

This chapter is intended to be used in conjunction with the *2006 IPCC Guidelines*, as well as the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2014). This document is organised in the same manner as the *2006 IPCC Guidelines*; however, in some cases, we note where the proposed refinements expand on the existing Guidelines and present additional subsections to address that refinement. The remainder of this introduction provides elaboration to the *2006 IPCC Guidelines* by presenting a summary of the refinements compared to the *2006 IPCC Guidelines* and an updated Figure 6.1 and Table 6.1 noting where refinements have been added.

CHANGES COMPARED TO 2006 IPCC GUIDELINES

The *2006 IPCC Guidelines* included combined equations to estimate methane (CH₄) emissions from wastewater and from sludge removed from the wastewater. However, in some cases, this combined equation caused confusion among inventory compilers when calculating CH₄ emissions from aerobic systems with anaerobic sludge digestion. In these cases, some compilers estimated zero CH₄ emissions from well operated wastewater treatment systems, and then subtracted emissions associated with sludge digestion operations without first estimating the CH₄ emissions from sludge treatment, resulting in negative emissions. In this refinement, we elaborate on the proper way to use the equation in such situations, and we present an update to provide guidelines on the calculation of the organic component removed in sludge.

In addition, certain emission factors for CH₄ emissions from domestic and industrial wastewater treatment have been updated to reflect additional measurement data on emissions from septic systems and centralised wastewater treatment plants (WWTPs). For example, the *2006 IPCC Guidelines* state that “Wastewater in closed underground sewers is not believed to be a significant source of CH₄.” However, more recent research shows that significant amounts of CH₄ can be formed within closed sewer collection systems and enters centralised WWTPs as dissolved CH₄, where it is then liberated during treatment.

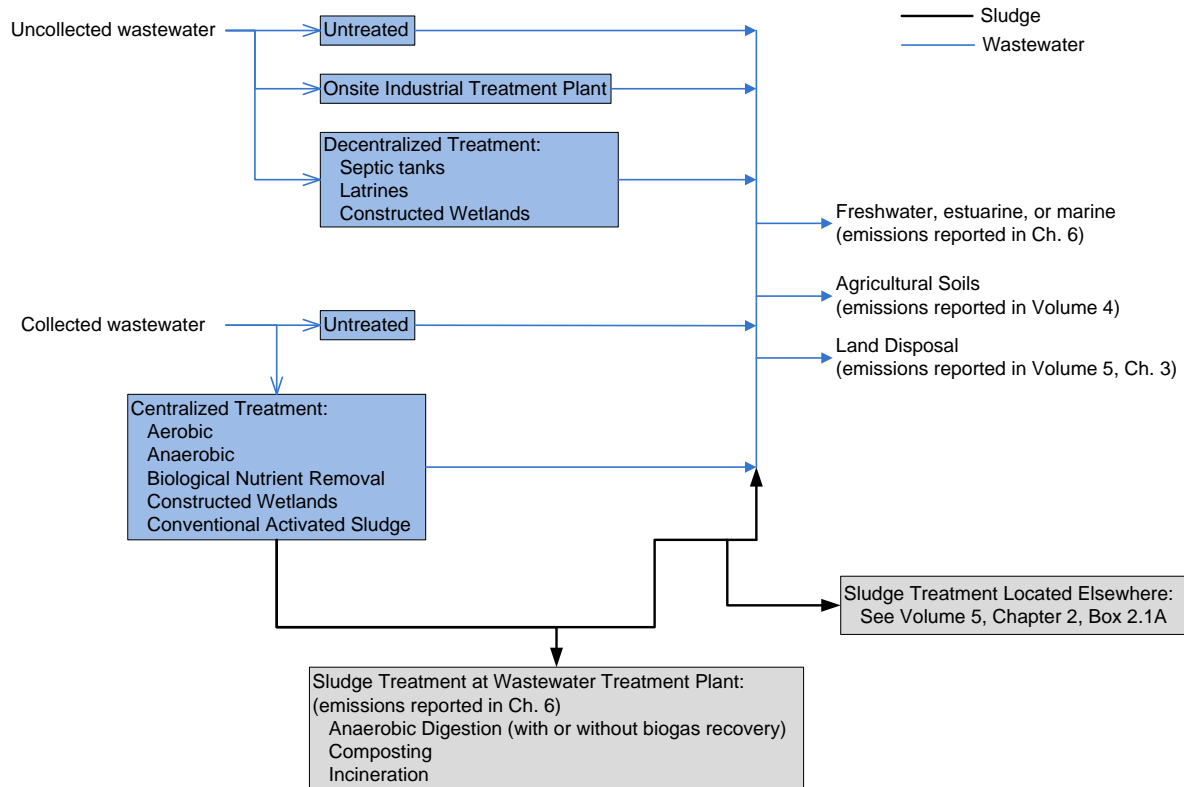
The *2019 Refinement* also includes new guidance on how to estimate nitrous oxide (N₂O) emissions from domestic and industrial wastewater and presents updated guidance to estimate N₂O emissions from centralised WWTPs. Furthermore, the N₂O emission factors for wastewater discharged to aquatic environments have been updated and the calculation of N₂O emissions from effluent discharged to aquatic systems has been updated to reflect the removal of nitrogen that occurs during treatment.

The *2006 IPCC Guidelines* state that “Carbon dioxide (CO₂) emissions from wastewater are not considered in the IPCC Guidelines because these are of biogenic origin and should not be included in national total emissions.” This is true for organic carbon present in wastewater derived from modern (biogenic) organic matter in human excreta or food waste. Annex 6A.1 presents a discussion of abiogenic (fossil) CO₂ emissions from wastewater treatment and discharge, where fossil organic carbon is present in wastewater or treatment sludge.

The remainder of this section includes additional discussion of the types of wastewater and sludge treatment systems in use, and the potential of those systems to generate CH₄ and N₂O emissions. Figure 6.1 and Table 6.1 has been updated to reflect the CH₄ and N₂O emission potential of wastewater and sludge treatment systems.

UPDATED FIGURE 6.1 AND TABLE 6.1

Figure 6.1 has been simplified to show the different pathways for wastewater treatment and discharge in blue, for wastewater that is not collected and for wastewater that is collected. The figure specifies whether the discharge or end use of the wastewater is reported in this chapter. Figure 6.1 also shows sludge treatment pathways in grey and clarifies whether the emissions are reported in this chapter. Table 6.1 has been updated to reflect the main wastewater treatment and discharge systems in developed and developing countries and their potential to emit CH₄ and N₂O.

Updated Figure 6.1 Wastewater treatment systems and discharge pathways

UPDATED TABLE 6.1 CH ₄ AND N ₂ O EMISSION POTENTIALS FOR WASTEWATER AND SLUDGE TREATMENT AND DISCHARGE SYSTEMS				
Types of treatment and disposal			CH ₄ and N ₂ O emission potentials	
Discharge from Collected or Uncollected Systems	Untreated or Treated Systems	Freshwater, estuarine, or marine discharge	While modulated by oxygen status, CH ₄ is generated in a range of freshwater and estuarine environments. Among them, stagnant or oxygen deficient environments are probable sources of N ₂ O.	
	Untreated	Sewers (closed and underground)	Likely source of CH ₄ /N ₂ O. However, little data exist to quantify emission factors that address the variation in sewer type and operational conditions.	
Collected	Treated	Aerobic treatment	Sewers (open)	Stagnant, overloaded open collection sewers or ditches/canals are likely significant sources of CH ₄ .
			Centralised aerobic wastewater treatment plants	May produce limited CH ₄ from anaerobic pockets. May also liberate CH ₄ generated in upstream sewer networks during turbulent and/or aerobic treatment processes. Poorly designed or managed aerobic treatment systems produce higher CH ₄ due to reduced removal of organics in sludge during primary treatment. Plants with nutrient removal processes are sources of CH ₄ and N ₂ O.
		Aerobic shallow ponds		Unlikely source of CH ₄ /N ₂ O. Poorly designed or managed aerobic systems produce CH ₄ .

UPDATED TABLE 6.1				
CH ₄ AND N ₂ O EMISSION POTENTIALS FOR WASTEWATER AND SLUDGE TREATMENT AND DISCHARGE SYSTEMS				
	Anaerobic treatment	Anaerobic lagoons	May be a significant source of CH ₄ . Insignificant source of N ₂ O.	
		Facultative lagoons ¹	Source of CH ₄ from anaerobic layer.	
		Constructed wetlands	May be source of CH ₄ and N ₂ O. See <i>2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands</i> (IPCC 2014).	
		Anaerobic reactors	May be a significant source of CH ₄ if emitted CH ₄ is not recovered and flared or upgraded.	
	Onsite sludge treatment ¹	Sludge anaerobic treatment in centralised aerobic wastewater treatment plant	Sludge may be a significant source of CH ₄ if emitted CH ₄ is not recovered and flared or upgraded. In addition, sludge digestion and handling may be a source of fugitive CH ₄ from biogas recovery and/or flaring operations. See Chapter 4 for more details.	
		Composting	May be significant source of CH ₄ and N ₂ O. See Chapter 4 for more details.	
		Incineration and open burning	Source of CH ₄ and N ₂ O. See Chapter 5 for more details.	
	Uncollected	Septic tanks		Frequent solids removal reduces CH ₄ production.
Open pits/Latrines		Pits/latrines are likely to produce CH ₄ when temperature and retention time are favourable.		

¹ For onsite sludge treatment, see Chapters 4 and 5 for emissions methodology, but note that emissions for onsite systems should be reported under the Wastewater Treatment and Discharge category.

CENTRALISED TREATMENT SYSTEMS

Centralised wastewater treatment systems may include a variety of processes, ranging from lagooning to advanced treatment technology designed for removing nutrients. Some wastewater may also be treated through the use of constructed (or semi-natural) wetland systems, which may be used as the primary method of wastewater treatment, or as a polishing treatment step following settling and biological treatment. Constructed wetlands develop natural processes that involve vegetation, soil, and associated microbial assemblages to trap and treat incoming contaminants (IPCC, 2014).

Sewer collection systems provide an environment conducive to the formation of CH₄, which can be substantial depending on the configuration and operation of the collection system (Guisasola et al, 2008). Recent research has shown that at least a portion of CH₄ formed with the collection system enters the centralised system where it contributes to CH₄ emissions from the treatment system (Foley et al, 2015). Although there are insufficient data to quantify emissions directly from the sewer collection system, the emission factors presented for centralised treatment plants account for dissolved methane entering the treatment systems.

Soluble organic matter is generally removed using biological processes in which microorganisms consume the organic matter for maintenance and growth. The resulting biomass (sludge) is removed from the effluent prior to discharge to the receiving stream. Microorganisms can biodegrade soluble organic material in wastewater under aerobic and/or anaerobic conditions, where the latter condition produces CH₄. During collection and treatment, wastewater may be accidentally or deliberately managed under anaerobic conditions. In addition, the sludge may be further biodegraded under aerobic or anaerobic conditions, such as with anaerobic digestion.

¹ Facultative organisms can function in the presence or absence of molecular oxygen. In a facultative lagoon, the layer of water near the surface contains dissolved oxygen due to atmospheric reaeration and algal respiration, a condition that supports aerobic and facultative organisms. The bottom layer of the lagoon includes sludge deposits and supports anaerobic organisms. The intermediate anoxic layer ranges from aerobic near the top to anaerobic at the bottom. (US EPA, 2002)

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The generation of N_2O may also result from the treatment of domestic wastewater during both nitrification and denitrification of the nitrogen (N) present, usually in the form of urea, ammonia, and proteins. These compounds are converted to nitrate (NO_3^-) through the aerobic process of nitrification. Denitrification occurs in an anoxic zone, where aerobic or facultative organisms oxidize nitrogen (e.g., nitrite, nitrate) in the absence of free oxygen) and results in the biological conversion of nitrogen into nitrogen gas (N_2), which is the main product of nitrification/denitrification processes. N_2O is an intermediate product of both processes but has typically been associated with denitrification. Research suggests that higher emissions of N_2O may in fact originate from nitrification (Ahn et al. 2010), and that N_2O may also result from other types of wastewater treatment operations (Chandran 2012). No matter where N_2O is formed it is usually stripped to the air in aerated parts of the treatment process.

A common example of a centralised treatment system configuration is an activated sludge wastewater treatment system. Following grit removal and primary treatment for solids removal, wastewater is sent to an activated sludge reactor for carbonaceous biochemical oxygen demand removal, followed by secondary clarification where solids are allowed to settle from the wastewater. Clarified effluent may be disinfected prior to discharge. Secondary clarifier sludge is pumped out from the bottom of the clarifier. Of this sludge, a portion is sent back to the activated sludge treatment process (return activated sludge) and the remainder (waste activated sludge) is combined with primary treatment sludge before being sent to sludge handling (such as gravity thickening). The thickened sludge may also be processed onsite in an anaerobic digester followed by further dewatering, such as by centrifuge. Recovered wastewater from thickening and dewatering operations, such as filtrate from the gravity thickener or centrate from the centrifuge) are returned to the influent stream at the headworks to the wastewater treatment system.

Although the CH_4 emissions from centralised aerobic plants may be small, they are not zero and may be substantial for some plants receiving sewage from expansive sewer networks. In addition, anaerobic conditions can form within the treatment system increasing the potential for CH_4 generation from an otherwise aerobic system.

CH_4 generated in the sewer system enters the treatment plant as dissolved methane and is emitted during turbulent/aerated treatment steps. These refinements introduce a new MCF associated with these systems, as well as an N_2O emission factor.

Sometimes conditions form that result in the wastewater treatment system becoming hydraulically or organically overloaded, which results in degraded performance of the plant. In these cases, organic matter and nutrients that would normally be removed by the system instead pass through and are discharged to the aquatic environment. The *2006 IPCC Guidelines* previous provided different emission factors for “well managed” centralised aerobic treatment systems versus “not well managed” centralised aerobic treatment systems. However, these refinements remove those factors and instead provide one factor for these types of systems. In the case of overloaded systems, the amount of organics removed by the system in sludge (S) should reflect the performance achieved by the system.

Other more advanced configurations of biological treatment have become more commonplace and are typically used for nutrient reduction. These “biological nutrient removal” (BNR) systems typically have a combination of aerobic, anaerobic, and anoxic treatment zones to further the removal of nitrogen and phosphorus, which also results in higher potential for CH_4 and N_2O emissions. This refinement presents new emission factors associated with these types of systems.

DECENTRALISED TREATMENT SYSTEMS OF DOMESTIC WASTEWATER (ONSITE SANITATION)

Depending on national circumstances, domestic wastewater not connected to a centralised wastewater treatment plant may be directly discharged in natural aquatic environments (rivers, lakes, oceans, etc.) or treated using onsite sanitation. The most common onsite treatment systems are holding tanks, septic systems and latrines.

A septic system is usually composed of a septic tank, generally buried in the ground, and a soil dispersal system. Solids and dense materials contained in the incoming wastewater (influent) settle in the septic tanks as sludge. Floatable material (scum) is also retained in the tank. The sludge settled on the bottom of the tank undergoes anaerobic digestion. Partially treated water is discharged in the dispersal system. The liquid fraction remains only some hours in the tank and the hydraulic retention time (HRT) varies from 24h to 72hr depending on the tank geometry. The solid fraction accumulates and remains in the tank undergoing anaerobic decomposition for several years. The solid retention time (SRT) depends on the sludge withdrawal frequency. The gas produced in the sludge during anaerobic digestion (mainly CH_4 and largely biogenic CO_2) rise to the liquid surface and are usually released through vents. The gases produced in the dispersal system (mainly N_2O and biogenic CO_2) are released through the soil.

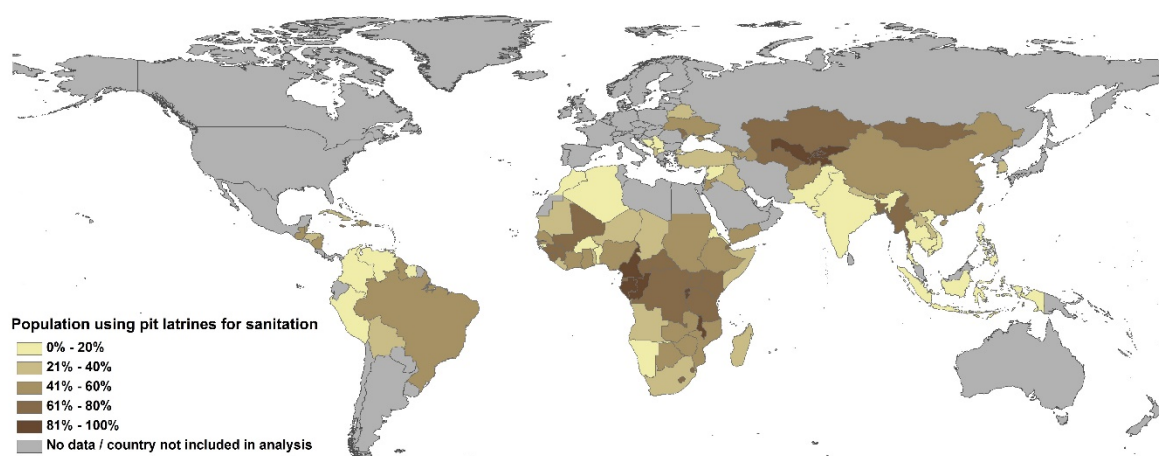
In some high-income countries, onsite aerated wastewater treatment systems are used and allow a more efficient treatment than septic tanks in reducing the organic load of domestic effluent. The process usually involves a first step of sedimentation and anaerobic digestion, a second step of aerobic treatment and last step of clarification and

disinfection. The treated effluent is discharged into the environment via surface irrigation or infiltration through an absorption trench.

A latrine usually consists of a slab over a pit which may be two meters or more in depth. There is a wide range of options for latrines (simple pit latrines, ventilated latrines, composting latrines, etc.) having in common that no water is used to flush excreta into the pit or only a little (e.g., pour flush latrines in which water is poured by hand). Pit latrines are utilised by more than 1.5 billion people throughout the world especially in low-income countries (see Figure 6.1a and Annex 6A.2). Pit latrine gaseous emissions depend in part on local groundwater level. Anaerobic conditions favourable to CH₄ emissions occur when the water table is high and the organic waste in the pit is submerged.

Where there are no latrines, people resort to defecation in open areas. Open defecation is not considered as a source of CH₄ as anaerobic conditions are unlikely.

Figure 6.1a. Percentage of low-income country populations using pit latrines as a primary sanitation facility (Graham and Polizzotto, 2013)



EMISSIONS FROM RECEIVING WATERS

Dissolved CH₄ and N₂O that is generated in sewers or present in untreated or primary treated discharges has the potential to be released (Short et al, 2014; Short et al, 2017). A strong correlation between the condition of the aquatic environment and the generation of CH₄ and N₂O has been observed (e.g., Smith et al, 2017). Therefore, where wastewater is then discharged to aquatic environments with eutrophic conditions (i.e., water bodies which are rich in nutrients and very productive in terms of aquatic animal and plant life), the additional organic matter in the discharged wastewater is expected to increase emissions. Many waterways are naturally eutrophic, while others have been altered by human impacts. In the case of CH₄, most freshwaters are highly supersaturated with CH₄ irrespective of recipient condition, so this refinement does not distinguish between eutrophic and oligotrophic waters, but it does distinguish between default waters (rivers and streams) and lakes and reservoirs where CH₄ emissions are higher.

6.1.1 Changes compared to 1996 Guidelines and Good Practice Guidance

Elaboration on the changes compared to the 2006 IPCC Guidelines are given in Section 6.1.

6.2 METHANE EMISSIONS FROM WASTEWATER

6.2.1 Methodological issues

Emissions are a function of the amount of organic waste generated and an emission factor that characterises the extent to which this waste generates CH₄.

Three tier methods for CH₄ from this category are summarised below:

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The Tier 1 method applies default values for the emission factor and activity parameters. This method is considered *good practice* for countries with limited data.

The Tier 2 method follows the same method as Tier 1 but allows for incorporation of a country specific emission factor and country specific activity data. For example, a specific emission factor for a prominent treatment system based on field measurements could be incorporated under this method. The amount of sludge removed for incineration, landfills, and agricultural land should be taken into consideration.

For a country with good data and advanced methodologies, a country specific method could be applied as a Tier 3 method. A more advanced country-specific method could be based on plant-specific data from large wastewater treatment facilities.

Wastewater treatment facilities that receive wastewater from collection systems, particularly pressurized sewers and gravity fed sewers that are closed, can liberate CH₄ in aerobic systems from dissolved CH₄ that enters the treatment system

Wastewater treatment facilities can include anaerobic process steps. CH₄ generated at such facilities can be recovered and combusted in a flare or energy device. The amount of CH₄ that is flared or recovered for energy use should be subtracted from total emissions through the use of a separate CH₄ recovery parameter. The amount of CH₄ which is recovered or flared is expressed as R in Equation 6.1.

Note that only a few countries may have sludge removal data and CH₄ recovery data. The default for sludge removal is zero, except where this refinement provides a default factor, such as for septic systems. The default for CH₄ recovery is zero. If a country selects to report CH₄ recovery, it is *good practice* to distinguish between flaring and CH₄ recovery for energy generation, which should be reported in the Energy Sector taking into account the avoidance of double counting emissions from flaring and energy used.

Emissions from flaring are not significant, as the majority of CO₂ emissions are of biogenic origin, and the CH₄ and N₂O emissions are very small so *good practice* in the Waste Sector does not require their estimation. However, if it is wished to do so these emissions should be reported under the Waste Sector. A discussion of emissions from flares and more detailed information are given in Volume 2, Energy, Chapter 4.2. Emission from flaring is not treated at Tier 1.

6.2.2 Domestic wastewater

6.2.2.1 CHOICE OF METHOD

An updated decision tree for domestic wastewater is included as updated Figure 6.2 and should be used to determine the tier approach that is applicable to the country.

This section is an update to the *2006 IPCC Guidelines* to resolve confusion in the use of Equation 6.1. In general, the overall steps for *good practice* in inventory preparation for CH₄ from domestic wastewater have been updated as follows:

Step 1: Use Equation 6.3 in the *2006 IPCC Guidelines* to estimate total organically degradable material in domestic wastewater (TOW). Use new Equation 6.3A to estimate TOW in wastewater prior to treatment for each wastewater treatment/discharge pathway or system, *j*, and each income group fraction *i* in inventory year.

Step 1A: Use Equations 6.3B and 6.3C to estimate the amount of organic component removed in sludge, *S*, from aerobic treatment plants and septic systems for each wastewater treatment/discharge pathway or system, *j*, and each income group fraction, *i*, in the inventory year.

Step 1B: Use Equation 6.3D to estimate total organically degradable carbon in wastewater effluent discharged (TOW_{EFFLUENT}).

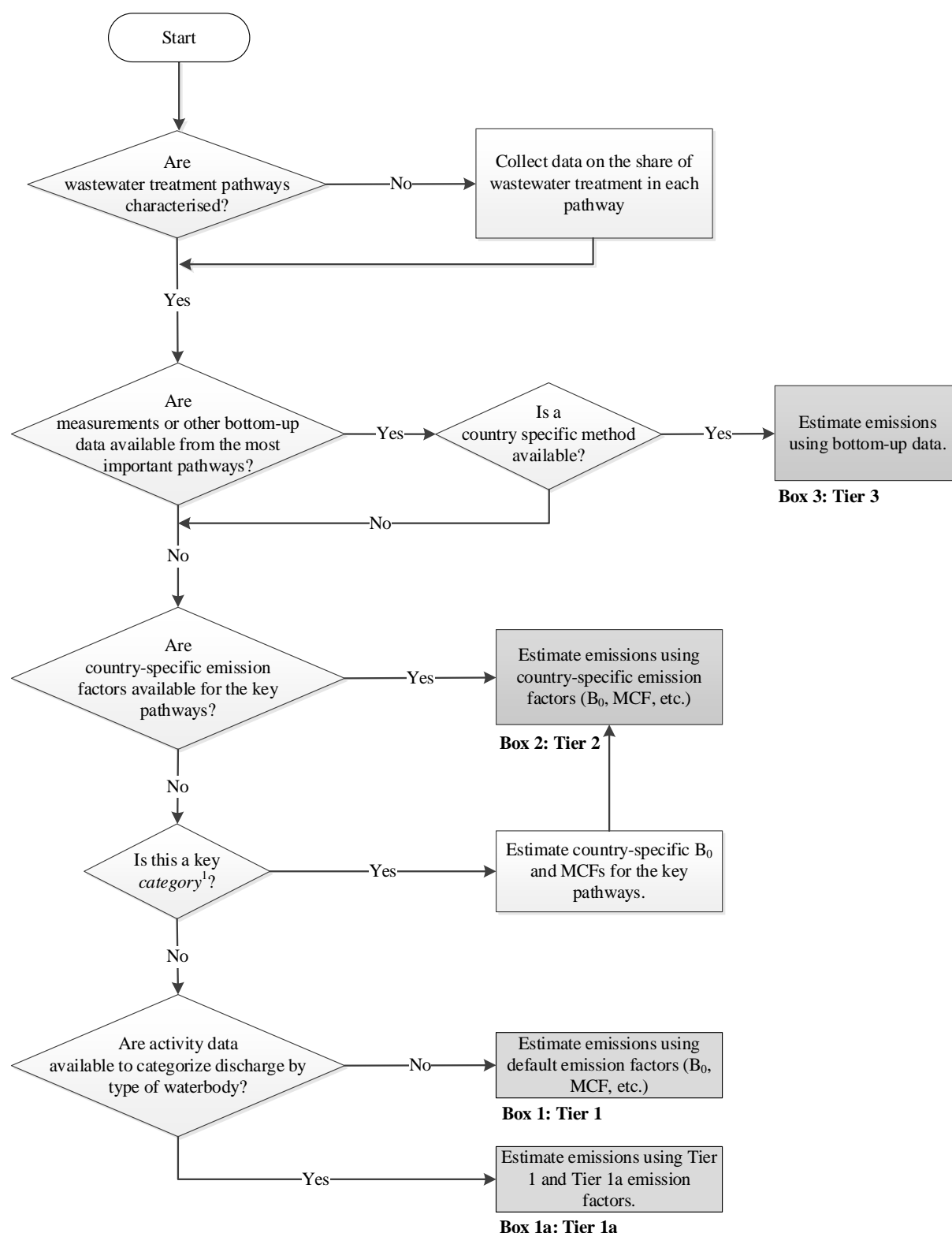
Step 2: Select the pathway and systems (See Figure 6.1) according to country activity data. Use Equation 6.2 or the updated Table 6.3 to obtain the emission factor for each domestic wastewater treatment/discharge pathway or system.

Step 3: Use new Equation 6.1A to estimate emissions and adjust for possible sludge removal and/or CH₄ recovery of treatment/discharge pathway or system, *j*, for each income group fraction *i* in inventory year. Use new Equation 6.1B to sum the emissions across all income groups.

These updates are presented because, in some cases, the original Equation 6.1 caused confusion among inventory compilers when calculating CH₄ emissions across multiple wastewater treatment/discharge pathways or systems

across multiple income groups. These updates allow for a more stepwise process in estimating emissions throughout the country.

Updated Figure 6.2 Decision tree for CH₄ emissions from domestic wastewater



¹ See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of key categories and use of decision trees.

Additional confusion arose in the estimation of emissions from aerobic systems with onsite anaerobic sludge digestion. In these cases, some compilers estimated zero CH₄ emissions from well operated wastewater treatment

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systems, and then subtracted CH₄ recovery associated with sludge digestion operations without first estimating the CH₄ emissions from onsite sludge treatment, resulting in negative emissions. For systems where onsite sludge treatment is practised, and appropriate statistics are available, it is *good practice* for countries to treat the wastewater treatment system and onsite sludge treatment system as separate pathways. As an example, for an activated sludge treatment process, calculate the emissions directly associated with the aerobic treatment system as one pathway, and calculate the emissions and any CH₄ recovery directly associated with the onsite sludge digestion system as a separate pathway using the emissions methodology provided in Chapter 4, Table 4.1. Net emissions from both systems should be summed together. In no circumstances should a country reports negative emissions.

Equation 6.1A should be used for every treatment and discharge pathway or system that is appropriate for the country, including the discharge of treated or untreated wastewater. For the discharge of treated wastewater, the TOW should reflect the organics in the wastewater as discharged.

Lastly, the use of the activity data *S*, organic component removed as sludge, is not explained in detail in the 2006 IPCC Guidelines. Please see Section 6.2.2.3 for additional guidance on how to estimate this value if country-specific data are not available.

NEW EQUATION 6.1A
TOTAL CH₄ EMISSIONS FROM DOMESTIC WASTEWATER FOR EACH INCOME GROUP AND
TREATMENT/DISCHARGE PATHWAY OR SYSTEM

$$CH_4 \text{ Emissions}_i = \sum_j \left[(TOW_{ij} - S_{ij}) \bullet EF_j - R_{ij} \right]$$

Where:

- CH₄ Emissions_{*i*} = CH₄ emissions in inventory year for income group fraction, *i*, kg CH₄/yr
- TOW_{*ij*} = organics in wastewater of treatment/discharge pathway or system, *j*, for each income group fraction *i* in inventory year, kg BOD/yr, See Equation 6.3A.
- S_{*ij*} = organic component removed as sludge from treatment/discharge pathway or system, *j*, for each income group fraction *i* in inventory year, kg BOD/yr, See Equations 6.3B and 6.3C.
- i* = income group: rural, urban high income and urban low income
- j* = each treatment/discharge pathway or system
- EF_{*j*} = emission factor for treatment/discharge pathway or system, *j*, kg CH₄/kg BOD. See Equation 6.2 or updated Table 6.3.
- R_{*ij*} = amount of CH₄ recovered or flared from treatment/discharge pathway or system, *j*, for each income group fraction *i* in inventory year, kg CH₄/yr

NEW EQUATION 6.1B
TOTAL CH₄ EMISSIONS FROM DOMESTIC WASTEWATER

$$CH_4 \text{ Emissions} = \sum_i [CH_4 \text{ Emissions}_i]$$

Where:

- CH₄ Emissions = CH₄ emissions in inventory year, kg CH₄/yr
- CH₄ Emissions_{*i*} = CH₄ emissions in inventory year for income group fraction, *i*, kg CH₄/yr
- i* = income group: rural, urban high income and urban low income

6.2.2.2 CHOICE OF EMISSION FACTORS

This section represents an update to Section 6.2.2.2 of the 2006 IPCC Guidelines.

As stated in the 2006 IPCC Guidelines, it is *good practice* to use country-specific data if available for emission factors, which are made up of B_o and MCF values. If a country chooses to introduce country-specific data for B_o, they must also update the MCF because the MCFs presented in Table 6.3 were developed using the default B_o.

values. However, if country-specific data are not available, a default value of 0.6 kg CH₄/kg BOD can be used. For domestic wastewater, a COD-based value of B_o can be converted into a BOD-based value by multiplying with a factor of 2.4. Annex 6A.3 provides further explanation of the basis for these default B_o values to allow countries to consider if these values are appropriate for the specific characteristics of their waste streams.

Because the B_o and MCF values must be used together, Table 6.3 now also includes the resultant default CH₄ emission factors for each wastewater treatment and discharge pathway. In addition, the MCFs in Table 6.3 of the 2006 IPCC Guidelines have been updated to reflect revisions to the following specific wastewater treatment and discharge pathways and systems.

DISCHARGE FROM TREATED OR UNTREATED SYSTEMS

Table 6.3 presents updated default MCFs associated with the discharge of wastewater to a water body and it is *good practice* to apply the Tier 1 MCF to discharges of both treated and untreated wastewater. The BOD of treated wastewater is typically 5–25 mg/L (Tchobanoglous et al, 2014; Hammer and Hammer, 2012), which provides a substrate for the formation of CH₄ in a receiving water body. Furthermore, much of the dissolved CH₄ that is generated in sewers is released either in the treatment plant headworks or to the receiving water body in the case of untreated or primary treated discharges (Short et al, 2014; Short et al, 2017). Recent research has demonstrated that even under oxic conditions, methanogenesis is feasible (Tang et al, 2016). Recent evidence points to the operation of both microbial and non-microbial methanogenic pathways in nature (e.g. Jugold et al, 2012) and strong relationships between the nutrient status of a receiving water body and the rate of generation of CH₄ have been observed (e.g. Smith et al, 2017). Despite this relationship, most rivers, estuaries and coastal waters are considerably supersaturated with CH₄, irrespective of their nutrient status (Grunwald et al, 2009; Lammers et al, 1995; Patra et al, 1998; Ward et al, 2017), while open oceans are slightly supersaturated (Tilbrook and Karl, 1995; Oudot et al, 2002; Castro-Morales et al, 2014). Supersaturated conditions occur when the rate of methanogenesis exceeds the rate at which the CH₄ is oxidised and/or transferred to the atmosphere and is important as it governs the driving force (mass transfer coefficient) and likely water-to-air CH₄ emission from a receiving environment. So, while the conditions of the receiving water body play a modulating role in relation to the rate of methanogenesis, the addition of organic matter from sewer discharges is generally expected to increase CH₄ emissions in freshwater and coastal environments. Recent reviews of measurements of CH₄ generation indicate that a significant proportion of the CH₄ emitted from freshwater systems has its origins in carbon deposited on sediments (Deemer et al, 2016) which is one reason why methanogenesis is more intense in lakes and reservoirs than fast-flowing rivers.

Using the same stoichiometric relationship as was used to calculate the default B_o value (see Annex 6A.3), a ratio of 0.938 kg C per kg COD is obtained. Deemer et al. (2016) performed an extensive review of measurements of CH₄ and CO₂ originating in aquatic systems, and independent measurements of both CH₄ and CO₂ emission fluxes around the world. Using these data in combination with information on the partitioning of global carbon flows in freshwater systems (Tranvik et al, 2009) and a default B_o of 0.25 kg CH₄/kg COD results in an MCF of 0.035 for rivers. This is also the default Tier 1 MCF for CH₄ generation for discharges to freshwater and coastal environments. However, where it is possible to separately identify discharges to slow-flowing systems such as lakes and reservoirs, a Tier 1a MCF of 0.19 is presented (see Table 6.3 and Annex 6A.4).

CENTRALISED, AEROBIC TREATMENT PLANTS

The MCF for centralised aerobic treatment plants has been updated in Table 6.3 to reflect the potential for generation of CH₄ from these systems. In addition, there are no longer separate MCFs for “well managed” and “not well managed” systems and it is *good practice* to estimate CH₄ from all centralised, aerobic treatment plants. If country-specific data are available to differentiate whether systems are overloaded or not well managed, these situations should be reflected in the calculation of TOW (for inflow overload) or S_{mass} (for systems that are not well managed and therefore not achieving the expected removal of sludge).

IMPACT OF TEMPERATURE ON DECENTRALISED TREATMENT SYSTEMS OF DOMESTIC WASTEWATER

Temperature affects wastewater treatment processes, in particular decentralised systems where no external supplemental heat is provided (uncontrolled temperature), and anaerobic digestion for which the optimal temperature is 30–38°C. At lower temperatures, the rate of anaerobic digestion decreases and CH₄ production becomes unlikely below 12°C. Inside septic tanks, the temperature is uncontrolled and is related to atmospheric temperature as well as volumes of hot and cold water used in the household. There is a gradient of temperature inside the septic tank: warmer in the bottom (sludge layer) and colder at the top (Leverenz, 2010). Therefore, in countries having seasonal temperature trends, when the temperature in septic tanks is getting cooler, the rate of digestion slows, the SRT increases, sludge accumulates, and CH₄ emissions decrease. When the liquid temperature warms, the rate of digestion increases, sludge accumulated during the cold season decomposes, gas solubility in the liquid decreases and CH₄ emissions increase. This situation corresponds to the ‘spring boil’ phenomenon (period of high emissions following a period of low emissions). Therefore, there is a seasonal variability of CH₄ emissions (Leverenz, 2010); however, at this time, insufficient data exist to establish a temperature-dependent

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436 emission factor associated with these systems. Countries that experience significant seasonal variations may wish
 437 to consider development of a country-specific emission factor.

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UPDATED TABLE 6.3 DEFAULT MCF VALUES AND RESULTANT EF ² FOR DOMESTIC WASTEWATER ¹				
Type of treatment and discharge pathway or system	Comments	MCF ¹ (Range)	EF ² (kg CH ₄ /kg BOD)	EF ² (kg CH ₄ /kg COD)
Discharge from treated or untreated system				
Discharge other than to reservoirs, lakes, and estuaries (Tier 1)	Most freshwater systems including rivers are supersaturated in CH ₄ . Nutrient oversupply will increase CH ₄ emissions.	0.035 ³ (0.004– 0.06)	0.021	0.009
Discharge to reservoirs, lakes, and estuaries (Tier 1a)	Environments where carbon accumulates in sediments have higher potential for methane generation.	0.19 ³ (0.08-0.27)	0.114	0.048
Untreated system				
Stagnant sewer	Open and warm	0.5 (0.4-0.8)	0.3	0.125
Flowing sewer (open or closed)	Fast moving, clean. (Insignificant amounts of CH ₄ from pump stations, etc)	0	0	0
Treated wastewater treatment system				
Centralised, aerobic treatment plant (see next two rows)	Some CH ₄ can be emitted from settling basins and other anaerobic pockets. May also emit CH ₄ generated in upstream sewer networks during turbulent and/or aerobic treatment processes. For treatment plants that are receiving wastewater beyond the design capacity, inventory compilers should judge the amount of organic material removed in sludge accordingly.			
• Conventional activated sludge (non-BNR) processes	Treatment processes designed and operated for BOD removal	0.028 ⁴ (0.0002-0.09)	0.017	0.007
• Biological nutrient removal (BNR) processes	Anaerobic-aerobic treatment processes designed and operated for BOD and nutrient removal	0.028 ⁴ (0.0002-0.09)	0.017	0.007
Anaerobic reactor (e.g., upflow anaerobic sludge blanket digestion (UASB))	CH ₄ recovery is not considered here.	0.8 (0.8-1.0)	0.48	0.2
Anaerobic shallow lagoon and facultative lagoons	Depth less than 2 metres, use expert judgment.	0.2 (0-0.3)	0.12	0.05
Anaerobic deep lagoon	Depth more than 2 metres	0.8 (0.8-1.0)	0.48	0.2
Constructed wetlands	See 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC 2014)			
Septic system	Septic systems emit CH ₄ from the tanks.	0.5 ⁵ (0.4-0.72)	0.3	0.125
Latrine	Dry climate, ground water table lower than latrine, small family (3–5 persons)	0.1 (0.05-0.15)	0.06	0.025
Latrine	Dry climate, ground water table lower than latrine, communal (many users)	0.5 (0.4-0.6)	0.3	0.125
Latrine	Wet climate/flush water use, ground water table higher than latrine	0.7 (0.7-1.0)	0.42	0.175
Latrine	Regular sediment removal for fertiliser	0.1	0.06	0.025
Onsite sludge treatment system				
Anaerobic digester for sludge	CH ₄ recovery is not considered here. See Chapter 4 for emissions methodology.	See Chapter 4, Table 4.1		
Composting	See Chapter 4 for emissions methodology.	See Chapter 4, Table 4.1		
Incineration and open burning	See Chapter 5 for emissions methodology.	See Chapter 5		
Sources:				

UPDATED TABLE 6.3
DEFAULT MCF VALUES AND RESULTANT EF² FOR DOMESTIC WASTEWATER¹

Type of treatment and discharge pathway or system	Comments	MCF ¹ (Range)	EF ² (kg CH ₄ /kg BOD)	EF ² (kg CH ₄ /kg COD)
¹ Based on expert judgment by Lead Authors of this section. ² Emission factors calculated using default B ₀ and default MCF. ³ See Annex 6A.4. ⁴ Czepiel et al, 1993; Daelman et al, 2013; Kozak et al, 2009; Kyung et al, 2015; Wang et al, 2011. ⁵ Leverenz et al., 2010; Diaz-Valbuena et al., 2011; Truhlar et al., 2016.				

6.2.2.3 CHOICE OF ACTIVITY DATA

The activity data for this source category is the total amount of organically degradable material in the wastewater (TOW). This parameter is a function of human population and BOD generation per person. It is expressed in terms of biochemical oxygen demand (kg BOD/year). The equation for TOW is given in the *2006 IPCC Guidelines* as Equation 6.3.

This section is updated to include new equations for the calculation of total organics in wastewater (TOW_{ij}) by income group and treatment/discharge pathway or system (see Equation 6.3A), and the amount of organic component removed as sludge from aerobic treatment plants and from septic systems (see Equations 6.3B and 6.3C, respectively). Note that the estimate of TOW_{ij} in Equation 6.3A is specific to the wastewater treatment system or pathway. For discharges of wastewater from treated or untreated systems, inventory compilers should estimate the amount of TOW in effluent (TOW_{EFFLUENT}) as shown in Equation 6.3D.

Inventory compilers should consider that sludge recovered from septic tanks may be transferred to centralised WWTPs. In these cases, it is *good practice* to include this additional organic load when estimating TOW in influent to the centralised WWTP.

The organic component removed from wastewater as sludge, *S* in Equations 6.1 and 6.4, is not explained in detail in the *2006 IPCC Guidelines*. This section provides an update through the introduction of Equations 6.3B and 6.3C, which provide default calculations of *S* for aerobic treatment plants and septic systems, respectively. For aerobic treatment systems, some inventory compilers incorrectly defined the variable “*S*” in Equation 6.1 as the mass of sludge removed rather than the organic component removed from wastewater as sludge. It is important to note that the organic component removed from wastewater as sludge is not equivalent to the mass (tonnes) of sludge produced from wastewater treatment. Instead, the organic component removed as sludge is a function of sludge produced from wastewater treatment (*S*_{MASS}) and a sludge factor (*K*_{REM}) which indicates how much organic matter is removed from the treatment process in sludge per ton of sludge produced. Table 6.12 provides factors associated with the amount of organics removed in sludge. Aerobic WWTPs with primary treatment remove about 0.5 kg of influent BOD per kg of primary sludge by sedimentation. The aerobic stage of treatment removes 1.5 kg BOD per kg of secondary sludge. The sludge produced in aerobic WWTP with primary sedimentation contains approximately 70% of primary sludge and 30% of secondary sludge by weight. Aerobic WWTPs without primary treatment remove about 1.16 kg BOD per kg of sludge, depending on process type. Countries where data are available should estimate a country-specific *K*_{REM} as a weighted average of sludge generated by individual processes.

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NEW TABLE 6.12 REMOVAL OF ORGANIC COMPONENT FROM WASTEWATER AS SLUDGE (K_{rem}) ACCORDING TO TREATMENT TYPE ¹		
Treatment Type	Default	Range
	(kg BOD/kg sludge)	
Raw sludge from primary sedimentation (mechanical treatment)	0.5	0.4 – 0.6
Raw sludge from secondary sedimentation (biological treatment, activated sludge)	1.5	1.45 – 1.65
Mixed primary and secondary raw sludge (aerobic wastewater treatment plants with primary treatment)	0.8	0.65 – 0.95
Mixed primary and secondary sludge anaerobically stabilised	1.0	0.8 – 1.2
Raw sludge (aerobic wastewater treatment plants without primary treatment)	1.16	1.0 – 1.5
Sources: ¹ Based on expert judgment by Lead Authors of this section using the following references: Pescod, 1992; Foladori et al, 2010; Serón et al, 2011; Gray, 2004.		

Concerning septic systems, emissions depend on the fraction of the population managing their septic system in accordance with the sludge removal instruction. The default value for F is 0.5 and corresponds to the situation where 50% of the population managing their septic system are complying with the sludge removal instruction. It is good practice to apply the default value in countries where there is no regulation or administrative requirements for sludge removal in septic systems. In countries with such regulations or requirements, some evidence of maintenance controls should be provided (for instance the existence of a local public service responsible for onsite sanitation). It is *good practice* to assess the F value using available data on sludge removal practices among the population using septic systems.

NEW EQUATION 6.3A TOTAL ORGANICS IN DOMESTIC WASTEWATER BY INCOME GROUP AND TREATMENT/DISCHARGE PATHWAY OR SYSTEM	
$TOW_{ij} = TOW \bullet U_i \bullet T_{ij}$	

Where:

- TOW_{ij} = total organics in wastewater in inventory year, kg BOD/yr, for income group i and treatment/discharge pathway or system, j .
- TOW = total organics in wastewater in inventory year, kg BOD/yr. See Equation 6.3 for TOW in wastewater prior to treatment and Equation 6.3D for TOW in wastewater effluent.
- U_i = fraction of population in income group i in inventory year. See Table 6.5.
- T_{ij} = degree of utilisation of treatment/discharge pathway or system, j , for each income group fraction

NEW EQUATION 6.3B ORGANIC COMPONENT REMOVED AS SLUDGE FROM AEROBIC TREATMENT PLANTS	
$S_{aerobic} = (S_{mass} \bullet K_{rem} \bullet 1000)$	

Where:

- $S_{aerobic}$ = organic component removed as sludge in aerobic treatment plants, kg BOD/yr
- S_{mass} = amount of sludge removed from waste water treatment as dry mass, tonnes/year
- K_{rem} = sludge factor, kg BOD/kg sludge. See Table 6.12.
- 1000 = conversion factor for tonnes to kilograms

NEW EQUATION 6.3C
ORGANIC COMPONENT REMOVED AS SLUDGE FROM SEPTIC SYSTEMS

$$S_{\text{Septic}} = TOW_{\text{Septic}} \bullet F \bullet 0.5$$

Where:

- S_{septic} = organic component removed as sludge in septic systems, kg BOD/yr
- TOW_{septic} = total organics in wastewater in septic systems inventory year, kg BOD/yr
- F = fraction of the population managing their septic system in compliance with the sludge removal instruction. The default value for F is 0.5 and corresponds to the situation where 50% of the population manage their septic system in compliance with the sludge removal instruction.
- 0.5 = fraction of organics in wastewater removed in sludge when septic tank is managed in accordance with sludge removal instructions.

NEW EQUATION 6.3D
TOTAL ORGANICS IN DOMESTIC WASTEWATER EFFLUENT

$$TOW_{\text{EFFLUENT}} = \sum_k [TOW \bullet FWT_k \bullet (1 - TOW_{\text{REM},k})]$$

Where:

- TOW_{EFFLUENT} = total organics in the wastewater effluent discharged to aquatic environments in inventory year, kg BOD/yr.
- TOW = total organically degradable material in domestic wastewater in inventory year, kg BOD/yr. See Equation 6.3.
- FWT_k = fraction of wastewater treated exclusively by each wastewater treatment type k in inventory year. See Table 6.5.
- k = each wastewater treatment type used in inventory year.
- TOW_{REM} = fraction of total wastewater organics removed during wastewater treatment per treatment type k . See Table 6.13.

NEW TABLE 6.13
WASTEWATER TREATMENT ORGANICS REMOVAL FRACTIONS (TOW_{REM})
ACCORDING TO TREATMENT TYPE

Treatment Type	Default	Range
No treatment	0	No range provided
Primary (mechanical)	0.40	0.25 – 0.50
Secondary (biological)	0.85	0.80 – 0.90
Tertiary (advanced biological)	0.90	0.80 – 0.95
Septic tank	0.50	0.50 – 0.60
Latrine	0	No range provided
Sources: ¹ Based on expert judgment by Lead Authors of this section using the following references: FAO, 1992; Schaider, et al, 2017; WEF, 2009		

Primary treatment involves mechanical processes such as screening, grit removal and sedimentation. Secondary treatment involves biological processes in which microorganisms convert inorganic and organic nutrients into settleable solids which can be removed by sedimentation and degradation metabolites which are transferred to the atmosphere. Secondary biological treatment processes may be augmented with chemical disinfection. Commonly used secondary treatment processes include: activated sludge; trickling filters; and lagoons. Tertiary treatment

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involves the use of advanced biological nutrient removal processes (nitrification–denitrification), and other physical and chemical processes. Pathways for organics removal (TOW_{REM}) include loss to sludge and biological decomposition.

6.2.2.4 TIME SERIES CONSISTENCY

No refinement

6.2.2.5 UNCERTAINTIES

This section provides an update to Table 6.7 to provide default uncertainty ranges for new or updated emission factor and activity data of domestic wastewater.

UPDATED TABLE 6.7 DEFAULT UNCERTAINTY RANGES FOR DOMESTIC WASTEWATER	
Parameter	Uncertainty Range
Emission Factor	
Maximum CH ₄ producing capacity (B_o)	± 30%
Fraction treated anaerobically (MCF)	The MCF is technology dependent. See Table 6.3. Thus, the uncertainty range is also technology dependent. The uncertainty range should be determined by expert judgement, bearing in mind that MCF is a fraction and must be between 0 and 1. Suggested ranges are provided below. Untreated systems, ± 50% Lagoons ± 30% Centralised plant, digester, reactor, ± 10%
Activity Data	
Human population (P)	± 5%
Biochemical oxygen demand (BOD)	± 30%
Fraction of population income group (U)	Good data on urbanization are available, however, the distinction between urban high income and urban low income may have to be based on expert judgment. ± 15%
Degree of utilisation of treatment/discharge pathway or system for each income group (T_{ij})	Can be as low as ± 3% for countries that have good records and only one or two systems. Can be ± 50% for an individual method/pathway. Verify that total $T_{ij} = 100\%$
Correction factor for additional industrial BOD discharged into sewers (I)	For uncollected, the uncertainty is zero %. For collected the uncertainty is ± 20%
Amount of sludge removed from waste water treatment (S_{mass})	± 30%
Sludge factor (K_{rem})	± 25%
Fraction of the population managing their septic system complying with the sludge removal instruction (F)	Can be as low as ± 3% for countries that have good records on implementation. Can be ± 50% if based on expert judgement.
Amount of CH ₄ recovered (R)	For systems with measured data, the uncertainty is equal to the uncertainty of the measurement system.
Source: Based on expert judgement by Lead Authors of this section.	

6.2.2.6 QA/QC, COMPLETENESS, REPORTING AND DOCUMENTATION

No refinement

6.2.3 Industrial wastewater

6.2.3.1 CHOICE OF METHOD

An updated decision tree for industrial wastewater is included as updated Figure 6.3 and should be used to determine the tier approach that is applicable to the country.

6.2.3.2 CHOICE OF EMISSION FACTORS

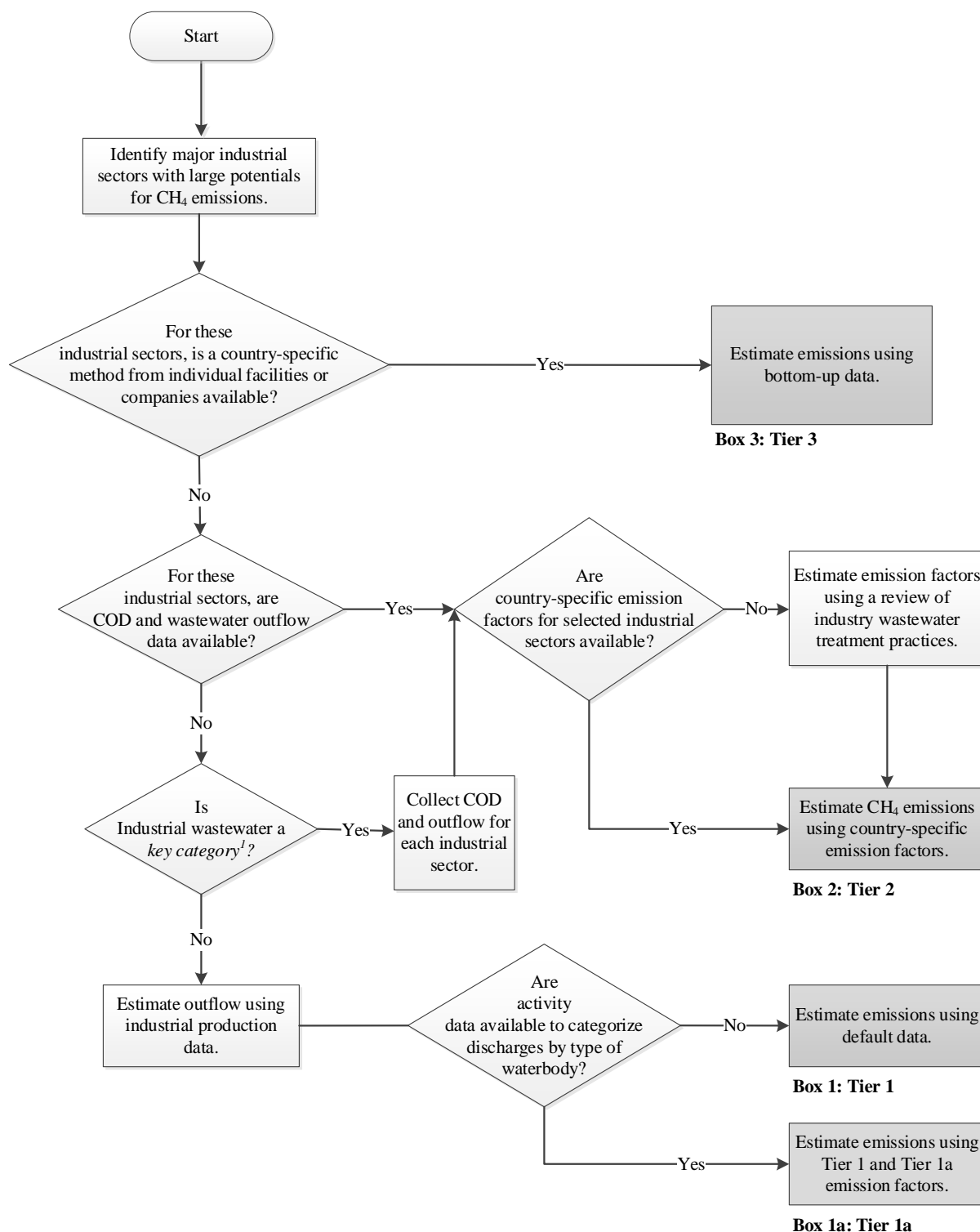
This section represents an update to Section 6.2.3.2 of the *2006 IPCC Guidelines*.

As stated in the *2006 IPCC Guidelines*, there are significant differences in the CH₄ emitting potential of different types of industrial wastewater dependent on the type and form of constituents present in the wastewater. To the extent possible, data should be collected to determine the maximum CH₄ producing capacity (B_o) in each industry. If country-specific data are available to determine the B_o for a particular industry, industry-specific MCFs must be developed for the calculation of CH₄ emissions. However, if country-specific data are not available, Table 6.14 provides default values of B_o for certain industry types.

In addition, the MCFs in Table 6.8 of the *2006 IPCC Guidelines* have been updated to reflect revisions to certain wastewater treatment and discharge pathways and systems, as described in Section 6.2.2.2.

NEW TABLE 6.14 DEFAULT MAXIMUM CH ₄ PRODUCING CAPACITY (B _o) FOR INDUSTRIAL WASTEWATER ¹	
Industry Type	B _o (kg CH ₄ /kg COD)
Brewery	0.25
Food and Beverage	0.22
Meat processing	0.26
Potato Processing	0.163
Paper Production	0.235
Pulp Production	0.196
Wheat Starch Production	0.206
Yeast Wastewater	0.106
Other industries, not elsewhere specified	0.25
Sources: ¹ Doorn et al, 1997. No ranges are provided.	

564 **Updated Figure 6.3 Decision tree for CH₄ emissions from industrial wastewater treatment**



¹ See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of key categories and use of decision trees.

UPDATED TABLE 6.8 DEFAULT MCF VALUES AND RESULTANT EF ² FOR INDUSTRIAL WASTEWATER				
Type of treatment and discharge pathway or system	Comments	MCF ¹ (Range)	EF ² (kg CH ₄ /kg BOD)	EF ² (kg CH ₄ /kg COD)
Discharge from treated or untreated system				
Discharge other than to reservoirs, lakes, and estuaries (Tier 1)	Most freshwater systems including rivers are supersaturated in CH ₄ . Nutrient oversupply will increase CH ₄ emissions.	0.035 ³ (0.004– 0.06)	0.021	0.009
Discharge to reservoirs, lakes, and estuaries (Tier 1a)	Environments where carbon accumulates in sediments have higher potential for methane generation.	0.19 ³ (0.08-0.27)	0.114	0.048
Treated wastewater treatment system				
Centralised, aerobic treatment plant	Some CH ₄ can be emitted from settling basins and other anaerobic pockets. For treatment plants that are receiving wastewater beyond the design capacity, inventory compilers should judge the amount of organic material removed in sludge accordingly.	0 (0-0.1)	0	0
Anaerobic reactor (e.g., upflow anaerobic sludge blanket digestion (UASB))	CH ₄ recovery is not considered here.	0.8 (0.8-1.0)	0.48	0.2
Anaerobic shallow lagoon and facultative lagoons	Depth less than 2 metres, use expert judgment.	0.2 (0-0.3)	0.12	0.05
Anaerobic deep lagoon	Depth more than 2 metres.	0.8 (0.8-1.0)	0.48	0.2
Constructed wetlands	See 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC 2014)			
Onsite sludge treatment system				
Anaerobic digester for sludge	CH ₄ recovery is not considered here. See Chapter 4 for emissions methodology.	See Chapter 4, Table 4.1		
Composting	See Chapter 4 for emissions methodology.	See Chapter 4, Table 4.1		
Incineration and open burning	See Chapter 5 for emissions methodology.	See Chapter 5		
Sources:				
¹ Based on expert judgment by Lead Authors of this section.				
² Emission factors calculated using default B _o and default MCF.				
³ See Annex 6A.4.				

6.2.3.3 CHOICE OF ACTIVITY DATA

No refinement

6.2.3.4 TIME SERIES CONSISTENCY

No refinement

6.2.3.5 UNCERTAINTIES

No refinement

6.2.3.6 QA/QC, COMPLETENESS, REPORTING AND DOCUMENTATION

No refinement

6.3 NITROUS OXIDE EMISSIONS FROM DOMESTIC WASTEWATER

This section refines Section 6.3 of the 2006 IPCC Guidelines by providing elaboration and new guidance for estimating domestic N₂O emissions from WWTPs and provides new guidance on the estimation of N₂O emissions from wastewater after disposal of untreated wastewater or wastewater treatment effluent into aquatic environments by accounting for losses of nitrogen prior to disposal.

6.3.1 Methodological issues

Nitrous oxide (N₂O) emissions can occur as emissions from wastewater treatment plants or as emissions from wastewater after disposal of untreated wastewater or wastewater treatment effluent into aquatic environments. This section describes how to estimate the N₂O produced during wastewater treatment, sludge treatment that occurs within the wastewater treatment system, and disposal of the wastewater. More recent research and field surveys have revealed that emissions in sewer networks and from nitrification or nitrification-denitrification processes at wastewater treatment plants, previously judged to be a minor source, may in fact result in more significant emissions. N₂O is generated as a by-product of nitrification, or as an intermediate product of denitrification. There are many factors affecting N₂O emissions at the treatment system such as the temperature and dissolved oxygen concentration of the wastewater, and the specific operational conditions of the treatment system.

Emissions also result from untreated wastewater or wastewater treatment effluent that is discharged into aquatic environments. It is important to note that emissions are dependent on the oxygenation level of the aquatic environment receiving the discharge. The current methodology in the 2006 IPCC Guidelines appropriately captures discharge to well-oxygenated environments. However, in the case of discharge to hypoxic waters such as eutrophic lakes, estuaries and rivers, or locations where stagnant conditions occur, emissions can be significantly higher.

Three tier methods for N₂O from this category are summarised below:

The Tier 1 method applies default values for the emission factor and activity parameters. This method is considered *good practice* for countries with limited data.

The Tier 2 method follows the same method as Tier 1 but allows for incorporation of a country-specific emission factor and country-specific activity data. For example, a specific emission factor for a prominent treatment system based on field measurements could be incorporated under this method. Use of country-specific EF in the same region or climate area is also *good practice*. The amount of sludge removed for incineration, landfills, and agricultural land should be taken into consideration.

For a country with good data and advanced methodologies, a country-specific method could be applied as a Tier 3 method. A more advanced country-specific method could be based on plant-specific data from large wastewater treatment facilities.

Note that only a few countries may have sludge removal data. The default for sludge removal is zero.

6.3.1.1 CHOICE OF METHOD

A decision tree for domestic wastewater is included in Figure 6.4.

The steps for *good practice* in inventory preparation for N₂O from domestic wastewater are as follows:

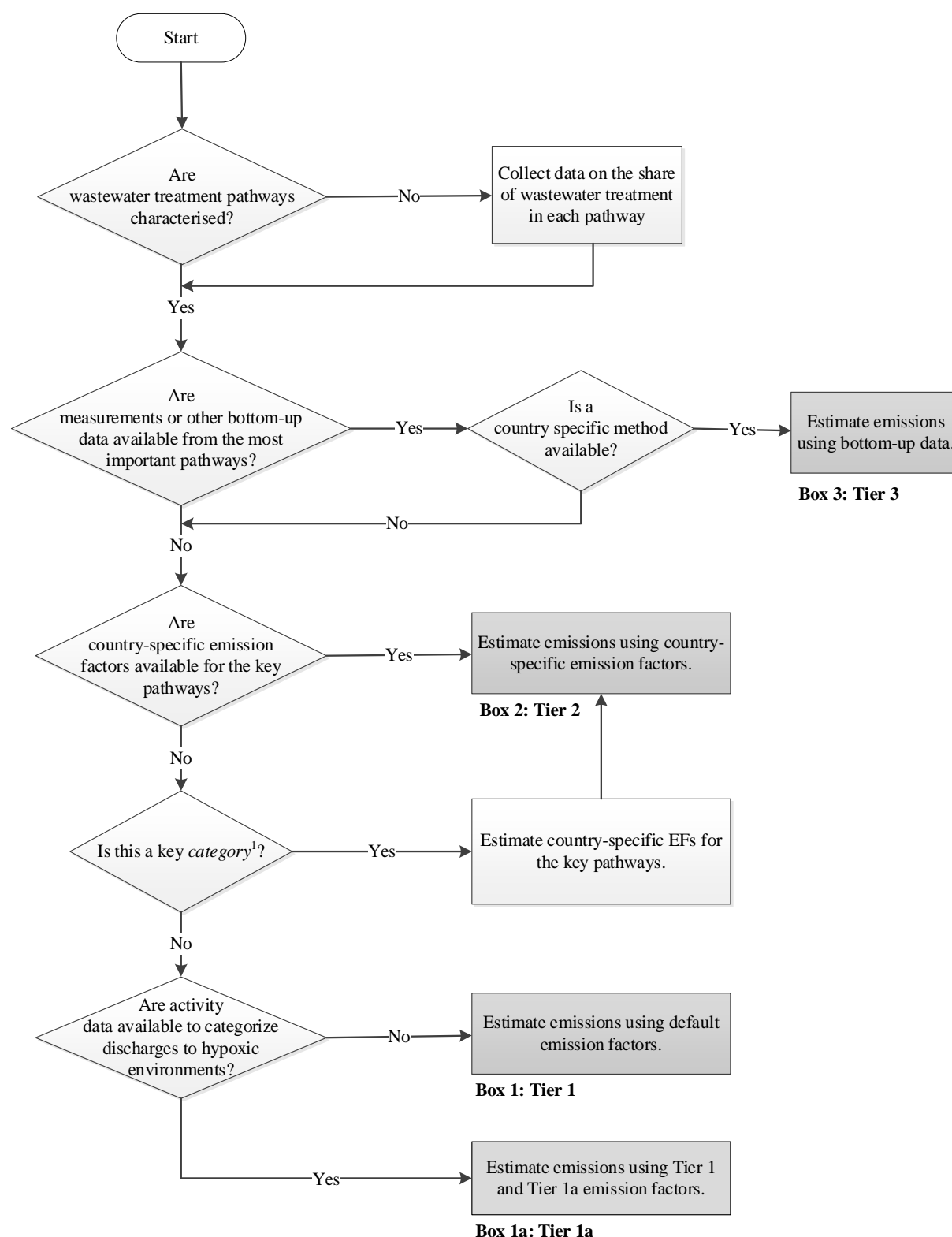
Step 1: Use new Equation 6.10 to estimate total nitrogen in wastewater.

Step 2: Select the pathway and systems (See Updated Figure 6.1) according to country activity data. Select the emission factor for each domestic wastewater treatment/discharge pathway or system.

Step 3: Use updated Equation 6.9 to estimate emissions from wastewater treatment and sum the results for each treatment pathway/system.

Step 4: Use updated Equation 6.7 to estimate emissions from effluent, accounting for losses of nitrogen that occur within the wastewater treatment process including sludge removal and sum the results for each pathway/system. Emissions should also be calculated for nitrogen discharged as untreated wastewater.

623 **New Figure 6.4 Decision tree for N₂O emissions from domestic wastewater**



¹ See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of key categories and use of decision trees.

As described earlier, the wastewater characterisation will determine the fraction of wastewater treated or disposed of by a particular system. To determine the use of each type of treatment or discharge system, it is *good practice* to refer to national statistics (e.g., from regulatory authorities). If these data are not available, wastewater

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associations or international organisations such as the World Health Organization (WHO) may have data on the system usage.

Otherwise, consultation with sanitation experts can help, and expert judgement can also be applied (see Chapter 2, Approaches to Data Collection, in Volume 1). Urbanisation statistics may provide a useful tool, e.g., city sizes and income distribution.

If activity data are available to categorize discharges to hypoxic environments, these refinements introduce a new Tier 1a emission factor for those discharges.

UPDATED EQUATION 6.9
N₂O EMISSIONS FROM DOMESTIC WASTEWATER TREATMENT PLANTS

$$N_2O \text{ Plants}_{DOM} = \left[\sum_{i,j} (U_i \cdot T_{ij} \cdot EF_j) \right] \cdot TN_{DOM} \cdot \frac{44}{28}$$

Where:

$N_2O \text{ Plants}_{DOM}$ = N₂O emissions from domestic wastewater treatment plants in inventory year, kg N₂O/yr

TN_{DOM} = total nitrogen in domestic wastewater in inventory year, kg N/yr. See Equation 6.10.

U_i = fraction of population in income group i in inventory year. See Table 6.5.

T_{ij} = degree of utilisation of treatment/discharge pathway or system j , for each income group fraction i in inventory year. See Table 6.5.

i = income group: rural, urban high income and urban low income

j = each treatment/discharge pathway or system

EF_j = emission factor for treatment/discharge pathway or system j , kg N₂O-N/kg N

The factor 44/28 is the conversion of kg N₂O-N into kg N₂O.

It is also required to estimate N₂O emissions arising from the discharge of wastewater (treated or untreated) into aquatic receiving environments. The methodology for emissions from effluent is similar to that of N₂O emissions explained in Volume 4, Section 11.2.2 in Chapter 11 N₂O Emissions from Managed Soils, and CO₂ Emissions from Lime and Urea Application. The simplified general equation is as follows:

UPDATED EQUATION 6.7
N₂O EMISSIONS FROM DOMESTIC WASTEWATER EFFLUENT

$$N_2O \text{ Effluent}_{DOM} = N_{EFFLUENT,DOM} \cdot EF_{EFFLUENT} \cdot \frac{44}{28}$$

Where:

$N_2O \text{ Effluent}_{DOM}$ = N₂O emissions from domestic wastewater effluent in inventory year, kg N₂O/yr

$N_{EFFLUENT,DOM}$ = nitrogen in the effluent discharged to aquatic environments, kg N/yr. See updated Equation 6.8.

$EF_{EFFLUENT}$ = emission factor for N₂O emissions from wastewater discharged to aquatic systems, kg N₂O-N/kg N

The factor 44/28 is the conversion of kg N₂O-N into kg N₂O.

6.3.1.2 CHOICE OF EMISSION FACTORS

Table 6.15 includes default EF values for N₂O emissions (see Annex 6A.5). These refinements to the emission factors build on the current default value for $EF_{EFFLUENT}$ provided in Table 6.11 of the 2006 IPCC Guidelines. This existing emission factor is adequate for Tier 1 and for discharges to well-oxygenated aquatic environments. However, it is expected to generate an underestimate of N₂O emissions in the case of discharge to hypoxic waters such as eutrophic lakes, estuaries and rivers, or locations where stagnant conditions occur. Harmful algal blooms and hypoxia are the two most common symptoms of waterway nutrient over-enrichment (eutrophication).

Waterway hypoxia is becoming increasingly common globally and is characterised by dissolved oxygen concentrations between 0.1–2.0 mg/L (Naqvi et al., 2010). Research published between 1978 and 2017 provide data indicating that higher N₂O emissions occur when wastewater is discharged to estuarine or hypoxic marine environments, resulting in a new EF_{EFFLUENT} of 0.019 g N₂O-N/g N (95% confidence limits 0.0041-0.091) for use in Tier 2 assessments (see Annex 6A.6 for a discussion of references used to develop this emission factor). This is not necessarily the same as one would expect from agricultural runoff due to the combination of reducing conditions and high organic loading in many wastewaters.

NEW TABLE 6.15 DEFAULT EF VALUES FOR DOMESTIC AND INDUSTRIAL WASTEWATER			
Type of treatment and discharge pathway or system	Comments	EF ¹ (kg N ₂ O-N/kg N)	Range
Discharge from treated or untreated system, EF _{EFFLUENT}			
Freshwater, estuarine, and marine discharge (Tier 1)	Based on limited field data and on specific assumptions regarding the occurrence of nitrification and denitrification in rivers and in estuaries	0.005 ²	0.0005 – 0.075
Hypoxic freshwater, estuarine, and marine environments (Tier 1a)	Higher emissions are associated with hypoxic water such as eutrophic lakes, estuaries and rivers, or locations where stagnant conditions occur	0.019 ²	0.0041 – 0.091
Wastewater treatment system, EF _{plants}			
Centralised, aerobic treatment plant (see next two rows)			
• Conventional activated sludge (non-BNR) processes	Treatment processes designed and operated for BOD removal	0.0083 ¹	0.0016 – 0.023
• Biological nutrient removal (BNR) processes	Anaerobic-aerobic treatment processes designed and operated for BOD and nutrient removal	0.014 ¹	0.00016 – 0.073
Anaerobic reactor	N ₂ O is not significant	0	0 – 0.001
Anaerobic lagoons	N ₂ O is not significant	0	0 – 0.001
Constructed wetlands	See 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC 2014)		
Septic system	N ₂ O is not significant	0	0 – 0.001
Latrine	N ₂ O is not significant	0	0 – 0.001
Sludge treatment system			
Anaerobic digester for sludge	N ₂ O is not significant.	0	0
Composting	See Chapter 4 for emissions methodology.	See Chapter 4, Table 4.1	
Incineration and open burning	See Chapter 5 for emissions methodology.	See Chapter 5	
Sources: Based on scientific literature and expert judgment by Lead Authors of this section. ¹ See Annex 6A.5. ² See Annex 6A.6.			

6.3.1.3 CHOICE OF ACTIVITY DATA

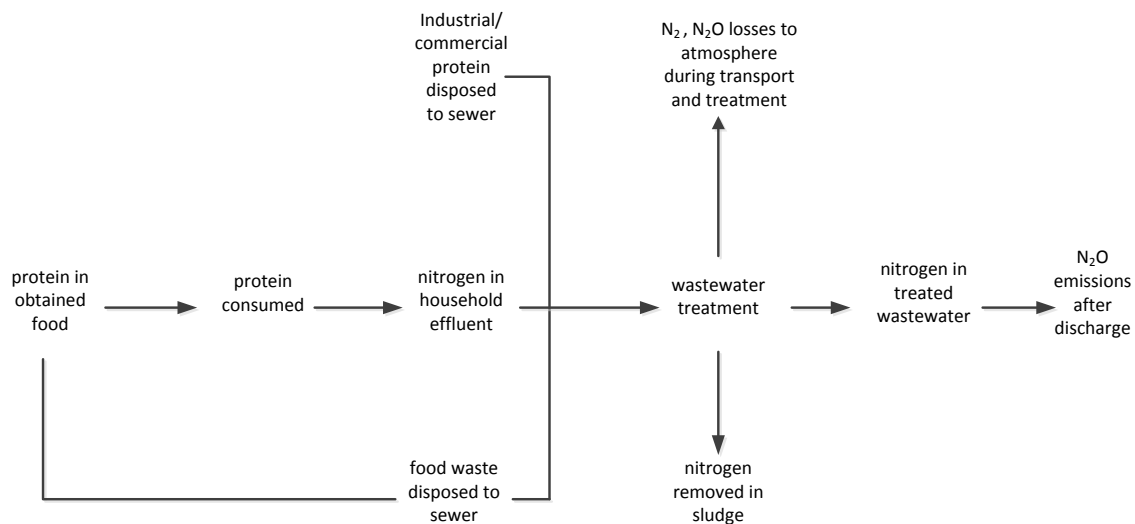
The methodology to calculate the amount of nitrogen content in wastewater effluent (N_{EFFLUENT,DOM}) presented in Equation 6.8 of the 2006 IPCC Guidelines currently does not account for the removal of ammonia-N via nitrification-denitrification processes in the sewer and the WWTP, or the removal of nitrogen in sludge, which can result in a significant overestimate of N discharged to aquatic systems. Typical total nitrogen concentrations in raw urban sewage is about 35 mg/L (range 20–70 mg/L) (Tchobanoglous et al, 2014) whereas effluent treated in

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conventional activated sludge facilities (with nitrification) is about 25 mg/L. Plants with biological nutrient removal (with denitrification) regularly achieve an effluent quality of 5 mg/L. The difference is due both to nitrogen removed in sludge (see Table 2.4A regarding the nitrogen content of sewage sludge) and the remainder to atmosphere (see Figure 6.5).

This section refines the methodology presented in the 2006 IPCC Guidelines to estimate the amount of N content in wastewater entering treatment (TN_{DOM}), the loss or removal of N through the treatment process (either through biological conversion or removal with sludge) (N_{REM}), and the N content in wastewater discharged to aquatic systems ($N_{EFFLUENT,DOM}$).

New Figure 6.5 Nitrogen in domestic wastewater treatment



NITROGEN IN DOMESTIC WASTEWATER (TN_{DOM})

The activity data that are needed for estimating TN_{DOM} in domestic wastewater include the population associated with the wastewater, the average annual per capita protein consumed (kg/person/yr), and factors to account for non-consumed protein entering the wastewater and other nitrogen from industrial and commercial sources co-discharged into the sewer system. The total nitrogen in wastewater for each treatment pathway is estimated as follows:

NEW EQUATION 6.10
TOTAL NITROGEN IN DOMESTIC WASTEWATER BY TREATMENT PATHWAY

$$TN_{DOM_k} = \left(P_{treatment_k} \bullet Protein \bullet F_{NPR} \bullet F_{NON-CON} \bullet F_{IND-COM} \right)$$

Where:

TN_{DOM_k}	=	total annual amount of nitrogen in domestic wastewater for treatment pathway k , kg N/yr
$P_{treatment_k}$	=	human population who are served by the treatment pathway k , person/yr
Protein	=	annual per capita protein consumption, kg protein/person/yr
F_{NPR}	=	fraction of nitrogen in protein, default = 0.16 kg N/kg protein
$F_{NON-CON}$	=	factor for non-consumed protein and additional nitrogen from household products added to the wastewater, kg N/kg N. See new Table 6.13.
$F_{IND-COM}$	=	factor for industrial and commercial co-discharged protein into the sewer system, kg N/kg N

Per capita “protein supply quantity” is published in Food Balance Sheets of FAOSTAT. This information represents the total amount of protein available to the population but must be adjusted to reflect the fraction of protein consumed. FAOSTAT may have country-specific data available on protein consumed in the published Indicators from Household Surveys. A default value based on expert judgement for the fraction of protein consumed is 0.85.

Food (waste) that is not consumed may be washed down the drain (e.g., as result of the use of food waste disposals in some countries). Bath and laundry water can be expected to contribute an additional 10% to nitrogen loadings as well (Henze et al, 2008; Tjandraatmadja et al, 2010). These factors influence the amount of nitrogen in domestic wastewater and are included in the updated values of $F_{\text{NON-CON}}$, as shown in Table 6.16. Two sets of $F_{\text{NON-CON}}$ were prepared, depending if the activity data are based on protein available or protein consumed.

NEW TABLE 6.16 DEFAULT FACTORS FOR DOMESTIC WASTEWATER		
Basis of Protein Activity Data	Disposal of food waste	$F_{\text{NON-CON}}^1$
Protein available	In-sink disposal	1.1
	Waste bin disposal	1
Protein consumed	In-sink disposal	1.25
	Waste bin disposal	1.1
¹ Based on expert judgment by Lead Authors of this section.		

Wastewater from industrial or commercial sources that is discharged into the sewer may contain protein (e.g., from grocery stores and butchers). The default for this fraction is 1.25 for centralised treatment and 0 for decentralised treatment systems (septic system, latrines, discharge).

NITROGEN IN WASTEWATER EFFLUENT ($N_{\text{EFFLUENT,DOM}}$)

The total nitrogen in wastewater effluent is estimated as follows:

UPDATED EQUATION 6.8 TOTAL NITROGEN IN DOMESTIC WASTEWATER EFFLUENT

$$N_{\text{EFFLUENT,DOM}} = \sum_k \left[(TN_{\text{DOM}} \bullet FWT_k) \bullet (1 - N_{\text{REM},k}) \right]$$

Where:

$N_{\text{EFFLUENT,DOM}}$ = total nitrogen in the wastewater effluent discharged to aquatic environments in inventory year, kg N/yr

TN_{DOM} = total nitrogen in domestic wastewater in inventory year, kg N/yr. See Equation 6.10.

FWT_k = fraction of wastewater treated exclusively by each wastewater treatment type k in inventory year. See Table 6.5.

k = each wastewater treatment type used in inventory year

N_{REM} = fraction of total wastewater nitrogen removed during wastewater treatment per treatment type k . See Table 6.17.

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NEW TABLE 6.17 WASTEWATER TREATMENT NITROGEN REMOVAL FRACTIONS (N_{REM}) ACCORDING TO TREATMENT TYPE		
Treatment Type	Default	Range
No treatment	0 ¹⁻³	0 ¹⁻³
Primary (mechanical)	0.10 ¹⁻³	0.05–0.20 ¹⁻³
Secondary (biological)	0.40 ¹⁻³	0.35–0.55 ¹⁻³
Tertiary (advanced biological)	0.80 ¹⁻⁴	0.45–0.85 ¹⁻⁴
Septic tank	0.15 ¹⁻³	0.10–0.25 ¹⁻³
Latrine	0.12 ⁵	0.07–0.21 ⁵
Sources: ¹ Kristensen et al., 2004 ² Van Drecht et al., 2009 ³ Based on expert judgment by Lead Authors of this section. ⁴ Ekama and Wentzel, 2008 ⁵ Harper et al., 1993		

Primary treatment involves mechanical processes such as screening, grit removal and sedimentation. Secondary treatment involves biological processes in which microorganisms convert inorganic and organic nutrients into settleable solids which can be removed by sedimentation and degradation metabolites which are transferred to the atmosphere. Secondary biological treatment processes may be augmented with chemical disinfection. Commonly used secondary treatment processes include: activated sludge; trickling filters; and lagoons. Tertiary treatment involves the use of advanced biological nutrient removal processes (nitrification–denitrification), and other physical and chemical processes. Pathways for nitrogen removal (N_{REM}) include loss to sludge, nitrification–denitrification and concomitant nitrogen loss to the atmosphere as degradation metabolites N₂ and N₂O.

6.3.2 Time series consistency

No refinement

6.3.3 Uncertainties

Large uncertainties are associated with the IPCC default factors for N₂O. Updated Table 6.11 below includes uncertainty ranges based on expert judgment.

<p style="text-align: center;">UPDATED TABLE 6.11 N₂O METHODOLOGY DEFAULT DATA</p>			
	Definition	Default Value	Range
Emission Factor			
EF	N ₂ O emission factor	See Table 6.15	See Table 6.15
Activity Data			
P	Number of people in country	Country-specific	± 10 %
Protein	Annual per capita protein consumption	Country-specific	± 10 %
F _{NPR}	Fraction of nitrogen in protein (kg N/kg protein)	0.16	0.15 – 0.17
T _{plant}	Degree of utilisation of large WWT plants	Country-specific	± 20 %
F _{NON-CON}	Factor to adjust for non-consumed protein, based on available protein	1.0 for countries with no in-sink disposals, 1.1 for countries with in-sink disposals	0.9 – 1.2
	Factor to adjust for non-consumed protein, based on consumed protein	1.1 for countries with no in-sink disposals, 1.25 for countries with in-sink disposals	1.0 – 1.4
F _{IND-COM}	Factor to allow for co-discharge of industrial nitrogen into sewers. For countries with significant fish processing plants, this factor may be higher. Expert judgment is recommended.	1.25	1.0 – 1.5
N _{REM}	Factor to account for losses of nitrogen prior to discharge.	See Table 6.17	See Table 6.17

6.3.4 QA/QC, Completeness, Reporting and Documentation

No refinement

6.4 NITROUS OXIDE EMISSIONS FROM INDUSTRIAL WASTEWATER

6.4.1 Methodological issues

This section refines the *2006 IPCC Guidelines* by adding guidance for estimating N₂O emissions from industrial WWTPs and refines the estimation of N₂O emissions from wastewater after disposal of untreated wastewater or wastewater treatment effluent into aquatic environments by accounting for losses of nitrogen prior to disposal.

6.4.1.1 CHOICE OF METHOD

A decision tree for industrial wastewater is included in Figure 6.6.

The steps for *good practice* in inventory preparation for N₂O from industrial wastewater are as follows:

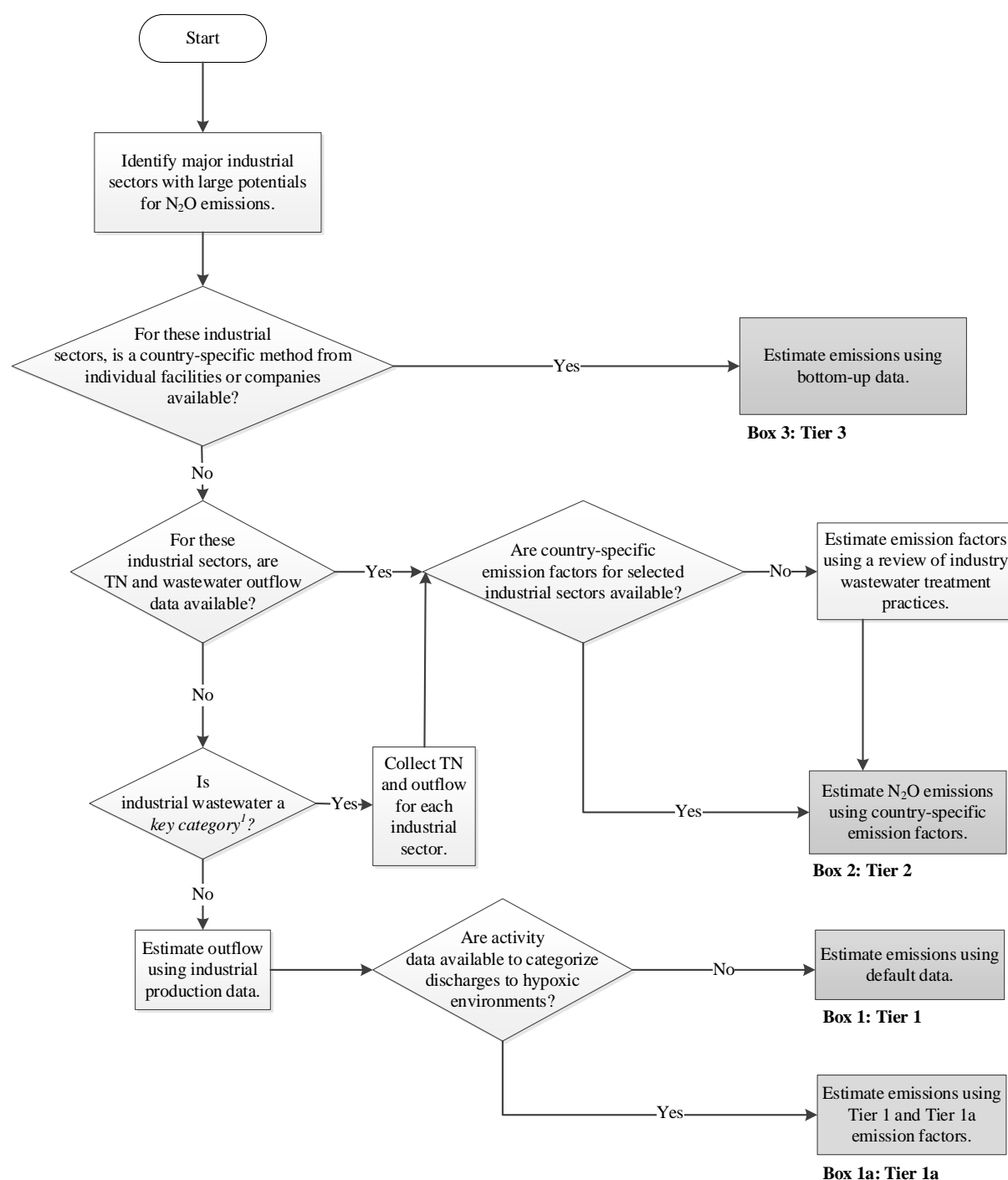
Step 1: Use new Equation 6.13 to estimate total nitrogen in wastewater.

Step 2: Select the pathway and systems (See Updated Figure 6.1) according to country activity data. Select the emission factor for each domestic wastewater treatment/discharge pathway or system.

Step 3: Use new Equation 6.11 to estimate emissions from wastewater treatment and sum the results for each pathway/system.

Step 4: Use new Equation 6.12 to estimate emissions from effluent, accounting for losses of nitrogen that occur within the wastewater treatment process including sludge removal and sum the results for each pathway/system.

780 **New Figure 6.6 Decision tree for N₂O emissions from industrial wastewater**



¹ See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of key categories and use of decision trees.

As described earlier, the wastewater characterisation will determine the fraction of wastewater treated or disposed of by a particular system. To determine the use of each type of treatment or discharge system, it is *good practice* to refer to national statistics (e.g., from regulatory authorities). If these data are not available, industry associations may have data on the system usage. Otherwise, consultation with industry experts can help, and expert judgement can also be applied (see Chapter 2 Approaches to Data Collection, Volume 1).

NEW EQUATION 6.11
N₂O EMISSIONS FROM INDUSTRIAL WASTEWATER TREATMENT PLANTS

$$N_2O\ Plants_{IND} = \left[\sum_i (T_{i,j} \bullet EF_j \bullet TN_{IND_i}) \right] \times \frac{44}{28}$$

Where:

N₂O Plants_{IND} = N₂O emissions from industrial wastewater treatment plants in inventory year, kg N₂O/yr

TN_{INDi} = total nitrogen in wastewater from industry *i* in inventory year, kg N/yr. See Equation 6.13.

T_{ij} = degree of utilisation of treatment/discharge pathway or system *j*, for each industry *i* in inventory year

i = industry

j = each treatment/discharge pathway or system

EF_j = emission factor for treatment/discharge pathway or system *j*, kg N₂O-N/kg N

The factor 44/28 is the conversion of kg N₂O-N into kg N₂O.

It is also required to estimate N₂O emissions from wastewater treatment effluent that is discharged into aquatic environments. The methodology for emissions from effluent is like that of N₂O emissions explained in Volume 4, Section 11.2.2, Chapter 11, N₂O Emissions from Managed Soils, and CO₂ Emissions from Lime and Urea Application. The simplified general equation is as follows:

NEW EQUATION 6.12
N₂O EMISSIONS FROM INDUSTRIAL WASTEWATER EFFLUENT

$$N_2O_{Effluent_{IND}} = N_{EFFLUENT,IND} \times EF_{EFFLUENT} \times \frac{44}{28}$$

Where:

N₂O Effluent_{IND} = N₂O emissions from industrial wastewater effluent in inventory year, kg N₂O/yr

N_{EFFLUENT, IND} = nitrogen in the industrial wastewater effluent discharged to aquatic environments, kg N/yr. See updated Equation 6.14.

EF_{EFFLUENT} = emission factor for N₂O emissions from wastewater discharged to aquatic systems, kg N₂O-N/kg N

The factor 44/28 is the conversion of kg N₂O-N into kg N₂O.

6.4.1.2 CHOICE OF EMISSION FACTORS

Table 6.15 includes default EF values for N₂O emissions.

6.4.1.3 CHOICE OF ACTIVITY DATA

TOTAL NITROGEN IN INDUSTRIAL WASTEWATER (TN_{IND})

The activity data for this source category is the amount of nitrogen in the industrial wastewater entering treatment (TN_{IND}). This parameter is a function of industrial output (product) *P* (tonnes/yr), wastewater generation *W* (m³/ton of product), and total nitrogen concentration in the untreated wastewater (kg TN/m³). See Equation 6.13. The following steps are required for determination of TN_{IND}:

- (i) Identify the industrial sectors that generate wastewater with large quantities of nitrogen, by evaluating total industrial product, nitrogen in the wastewater, and wastewater produced.
- (ii) Identify industrial sectors that use treatment systems with N₂O emissions factors (see Table 6.15). Experience has shown that usually three or four industrial sectors are *key*.

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For each selected sector estimate total nitrogen in the industrial wastewater (TN_{IND}).

NEW EQUATION 6.13
TOTAL NITROGEN IN INDUSTRIAL WASTEWATER

$$TN_{IND_i} = P_i \bullet W_i \bullet TN_i$$

Where:

TN_{IND_i} = total nitrogen in wastewater entering treatment for industry i , kg TN/yr

i = industrial sector

P_i = total industrial product for industrial sector i , t/yr

W_i = wastewater generated for industrial sector i , m³/t_{product}

TN_i = total nitrogen in untreated wastewater for industrial sector i , kg TN/m³

Industrial production data and wastewater generation rates may be obtained from national statistics, regulatory agencies, wastewater treatment associations or industry associations. In some cases, quantification of the nitrogen loading in the wastewater may require expert judgement. In some countries, nitrogen content and total water usage per sector data may be available directly from a regulatory agency. Table 6.18 provides examples that could be used as default values for industries that may be considered key sources of N₂O. These values should be used with caution, because they are industry-, process-, and country-specific.

NEW TABLE 6.18
EXAMPLES OF INDUSTRIAL WASTEWATER DATA

Industry Type	Wastewater Generation W (m ³ /tonne)	Range for W (m ³ /tonne)	Total Nitrogen (TN) (kg/m ³)	TN Range (kg/m ³)
Alcohol Refining	24 ²	16 – 32 ²	2.4 ²	0.94 – 3.86 ²
Beer & Malt	6.3 ²	5.0 – 9.0 ²	0.055 ³	0.025 – 0.08 ³
Fish Processing	5 ²	2 – 8 ²	0.60 ²	0.21 – 0.98 ²
Iron and Steel Manufacturing	5 ¹	0.004 – 10.4 ⁴	0.25 ¹	0.0004-0.524 ⁴
Meat & Poultry	13 ²	8 – 18 ²	0.19 ²	0.17 – 0.20 ²
Nitrogen Fertilizer	2.89 ²	0.46 – 8.3 ²	0.5 ²	0.1 – 0.8 ²
Plastics & Resins	0.6 ⁵	0.3 – 1.2 ⁵	0.25 ⁶	No range provided
Starch Production	9 ²	4 – 18 ²	0.9 ²	0.8 – 1.10 ²

¹ Based on expert judgment by Lead Authors of this section.

² IPCC, 2014

³ Simate, et al, 2011

⁴ EPA, 2002

⁵ Doorn et al, 1997

⁶ Li et al, 2016

NITROGEN REMOVED FROM WASTEWATER (N_{REM})

Nitrogen removal by different treatment facilities can range from 10 – 85 percent. Default values for the fraction of nitrogen removed by type of wastewater treatment system are presented in Table 6.17.

NITROGEN IN WASTEWATER EFFLUENT ($N_{EFFLUENT,IND}$)

The total nitrogen in the industrial wastewater effluent is estimated as follows:

NEW EQUATION 6.14
TOTAL NITROGEN IN INDUSTRIAL WASTEWATER EFFLUENT

$$N_{\text{EFFLUENT,IND}} = \sum_k \left[TN_{\text{IND},i} \times FWT_k \times (1 - N_{\text{REM},k}) \right]$$

Where:

- $N_{\text{EFFLUENT,IND}}$ = total annual amount of nitrogen in the industrial wastewater effluent, kg N/yr
- $TN_{\text{IND},i}$ = total nitrogen in wastewater entering treatment for industry i , kg TN/yr
- FWT_k = fraction of wastewater treated exclusively by each wastewater treatment type k in inventory year. See Table 6.5.
- k = each wastewater treatment type used in inventory year
- $N_{\text{REM},k}$ = fraction of total wastewater nitrogen removed during wastewater treatment per treatment type k . See Table 6.17.

6.4.2 Time series consistency

Once an industrial sector is included in the inventory calculation, it should be included for each subsequent year. If the inventory compiler adds a new industrial sector to the calculation, then he or she should re-calculate the entire time series so that the method is consistent from year to year. General guidance on recalculation of estimates through time series is provided in Volume 1, Chapter 5, Time Series Consistency.

If a country decides to incorporate plant emissions into the estimate, this change must be made for the entire time series. Potential sludge removal should be treated consistently across years in the time series.

6.4.3 Uncertainties

Uncertainty estimates for EF, P, W and TN are provided in Table 6.19. The estimates are based on expert judgement.

NEW TABLE 6.19
DEFAULT UNCERTAINTY RANGES FOR INDUSTRIAL WASTEWATER

Parameter	Uncertainty Range
Emission Factor	
N ₂ O emission factor (EF)	± 30%
Activity Data	
Industrial production (P)	± 25%
Wastewater/unit production (W)	Use expert judgement regarding the quality of data source to assign more accurate uncertainty range.
TN/unit wastewater (TN)	These data can be very uncertain as the same sector might use different waste handling procedures at different plants and in different countries. The product of the parameters (W•TN) is expected to have less uncertainty. An uncertainty value can be attributed directly to TN concentration. –50 %, +100% is suggested (i.e., a factor of 2).
Source: Expert Judgement by Lead Authors of this section.	

6.4.4 QA/QC, Completeness, Reporting and Documentation

QA/QC

It is *good practice* to conduct quality control checks and quality assurance procedures as outlined in Chapter 6, QA/QC and Verification, of Volume 1. Below, some fundamental QA/QC procedures include:

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- For industrial wastewater, inventory compilers may review the secondary data sets (e.g., from national statistics, regulatory agencies, wastewater treatment associations or industry associations), that are used to estimate and rank industrial TN waste output. Some countries may have regulatory control over industrial discharges, in which cases significant QA/QC protocols may already be in place for the development of the wastewater characteristics on an industry basis.
- For industrial wastewater, inventory compilers should cross-check values for EFs against those from other national inventories with similar wastewater characteristics.
- If sludge removal is reported in the wastewater inventory, check for consistency with the estimates for sludge applied to agriculture soils, sludge incinerated, and sludge deposited in solid waste disposal.
- For countries that use country-specific parameters or higher tier methods, inventory compilers should cross-check the national estimates with emissions using the IPCC default method and parameters.

COMPLETENESS

Completeness for estimating emissions from industrial wastewater depends on an accurate characterization of industrial sectors that produce nitrogen laden wastewater. In most countries, approximately 3-4 industrial sectors will account for the majority of the nitrogen wastewater volume, so the inventory compilers should ensure that these sectors are covered. Periodically, the inventory compilers should re-survey industrial sources, particularly if some industries are growing rapidly.

This category should only cover industrial wastewater treated onsite. Emissions from industrial wastewater released into domestic sewer systems should be addressed and included with domestic wastewater.

Some sludge from industrial wastewater treatment may be incinerated or deposited in landfills or on agricultural lands. This constitutes an amount of nitrogen that should be subtracted from effluent nitrogen. It is *good practice* to be consistent across sectors: the amount of nitrogen that is removed as sludge should be equal to the amount of sludge disposed at landfills, applied to agricultural soils, incinerated or treated elsewhere.

REPORTING AND DOCUMENTATION

It is *good practice* to document and report a summary of the methods used, activity data and emission factors. When country-specific methods and/or emission factors are used, the reasoning for the choices as well as references to how the country-specific data (measurements, literature, expert judgement, etc.) have been derived (measurements, literature, expert judgement, etc.) should be documented and included in the reporting.

If sludge is incinerated, landfilled, or spread on agricultural lands, the quantities of sludge and associated emissions should be reported in the waste incineration, solid waste disposal systems, or agricultural categories, respectively.

More information on reporting and documentation can be found in Volume 1, Chapter 6, Section 6.11 Documentation, archiving and reporting.

Annex 6A.1 Abiogenic (fossil) CO₂ emissions from wastewater treatment and discharge

The 2006 IPCC Guidelines assume that organic carbon present in wastewater derives from modern (biogenic) organic matter in human excreta or food waste (IPCC, 2006). Consequently, CO₂ emissions from wastewater treatment are also considered wholly biogenic and are discounted from international greenhouse gas accounting inventories, since they do not represent a transfer of carbon from the lithosphere to the atmosphere. In comparison, fossil organic carbon (that with turnover timescales exceeding 10⁶ years) is considered to have a role in climate change and is accounted for in international greenhouse gas emissions inventories. In the 2006 IPCC Guidelines, it is assumed that emissions from biogas flaring are not significant because the CO₂ emissions are of biogenic origin and the CH₄ and N₂O emissions are very small so *good practice* in the Waste Sector does not require their estimation. If countries wish to report such emissions, they should be reported under the Waste Sector. A discussion of emissions from flares and more detailed information are given in Volume 2, Energy, Chapter 4.2. However, the presence of fossil organic carbon in sewage also implies the emission of additional fossil CO₂ from wastewater treatment facilities, sludge management, and environmental recipients of treated or untreated wastewater.

Data emerging since the 2006 IPCC Guidelines indicate that wastewater contains an appreciable amount of abiogenic (fossil) organic carbon, with this fossil carbon thought to be derived from the use of petroleum-based products (domestically and commercially). These products include: cosmetics; pharmaceuticals; surfactants; detergents and food additives (Law et al., 2013). Additionally, direct dosing of synthetic organic substrates (e.g., methanol) can occur at wastewater treatment plants to enhance denitrification performance (Schneider et al., 2015). Despite early indications of the potential for significant fossil organic carbon fractions in sewage sludge (Turekian and Benoit, 1981), fossil carbon in wastewater was first detailed by Griffith et al. (2009) following the sampling of treated effluent from 12 predominantly domestic wastewater treatment plants within the Hudson and Connecticut River watersheds, USA. Since then, several studies have surveyed fossil organic carbon in wastewater from Japan (Nara et al., 2010; Toyoda et al., 2011), Australia (Law et al., 2013), Denmark (Yoshida et al., 2014) and North America (Schneider et al., 2015).

Research published since the 2006 IPCC Guidelines (Griffith et al., 2009; Law et al., 2013; Yoshida et al., 2014; Schneider et al., 2015; Tseng et al., 2016) gives an emerging consensus figure for the fossil wastewater organic carbon fraction at some 4–14%; although more recent work suggests this can be as high as 28% (Tseng et al., 2016) or 51% (Nara et al., 2010; recalculated by Tseng et al., 2016) in some influents. Schneider et al. (2015) put the fossil content of activated sludge process off-gases at 10–15%. Law et al. (2013) put the subsequent fossil carbon fraction in anaerobic digester biogas CO₂ at 2.1±0.2% due to greater recalcitrance of fossil carbon during anaerobic digestion, and total additional scope 1 wastewater treatment plant emission load from previously unaccounted fossil carbon somewhere between 2–12%. Tseng et al. (2016) put this figure at some 13 to 24% higher without and with energy recovery respectively.

Based on the above data, countries are encouraged to evaluate if such emissions should be reported, particularly those countries that have higher levels of fossil carbon in wastewater. In addition, future improvements to the Guidelines should include a method for estimating these non-biogenic emissions associated with wastewater treatment operations and wastewater discharges.

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NEW TABLE 6A.1
SUMMARY OF LITERATURE INVESTIGATING FOSSIL ORGANIC CARBON IN WASTEWATER

Wastewater treatment system	Detection/measurement approach	Fossil C fraction in various wastewater streams	Reference	Comments
Effluent from 12 WWTPs (using conventional activated sludge) sampled, USA	Effluent grab samples; ¹⁴ C analysed via isotope ratio mass spectrometry	25% of treated wastewater dissolved organic carbon (DOC) and 14% of treated wastewater particulate organic carbon (POC)	Griffith et al. (2009)	WWTPs handle predominantly domestic wastewater. Secondary treated effluent sampled only (i.e. not raw influent), so results may overestimate true fossil carbon fraction in raw sewage, since heterotrophic bacteria are known to preferentially utilize young (¹⁴ C-enriched) carbon for assimilation (Raymond and Bauer, 2001). Average reported effluent DOC concentration was 8.7 mg/L.
Four large activated sludge WWTPs in Brisbane, Australia (two receiving domestic sewage and two receiving 15% industrial load)	Range of sampling locations (influent, primary- and secondary-treated effluent, waste activated sludge (WAS), digested biosolids)	Fossil fraction of total organic carbon (TOC) in domestic WWTP influent 4–7% and 8–14% for WWTPs receiving 15% industrial load (5–14% overall range); ≈29–50% of this influent fossil C is transformed to CO ₂ during secondary activated sludge treatment (1.4–6.3% of influent TOC). Higher fossil C fraction in WAS from WWTPs receiving industrial load (8–14%) versus domestic WWTPs (6–7%). 2.1(±0.2)% of biogas CO ₂ is fossil in origin.	Law et al. (2013)	Higher fossil C fractions in WWTPs receiving industrial wastewater load. Equivalent concentrations of fossil organic carbon in raw wastewater were between 6–35 mg/L. Majority of fossil organic carbon in raw wastewater is present in particulate form (>80%; 5 to 29 mg/L), whereas dissolved fossil carbon levels are relatively small (1–6 mg/L).
Influent to Avedøre WWTP, Denmark	Single 24-hour flow proportionate composite influent sample collected in February 2013. Radiocarbon isotope ratio method (ASTM-D6866-12).	14(±3)% in influent wastewater	Yoshida et al. (2014)	Avedøre WWTP receives 15% industrial load from adjacent pharmaceuticals industry. Figure of 14% is corrected for cellulosic biogenic carbon from toilet paper which may contain elevated levels of ¹⁴ C due to historical atomic bomb detonations and underestimate fossil C fraction.
Modified Ludzack–Ettinger (MLE) activated sludge process with biological nitrification–denitrification, USA	¹⁴ C content of emitted CO ₂ measured twice a day for five days in early spring using floating chambers	11.4–15.1% (mean 12.83%) based on measured CO ₂ emissions from secondary treatment reactor	Schneider et al. (2015)	
Three municipal WWTPs and waste stabilisation ponds, two industrial WWTPs	Raw and partially treated wastewater, gas and sludge samples taken during 2010–2013	2–28% in the primary influent	Tseng et al. (2016)	Article provides a tabulation of results from 6 separate research papers.

Assumed conventional activated sludge-based WWTP with primary gravity sedimentation, Japan	Fresh domestic sewage, primary-treated and secondary-treated wastewater sampled	$\Delta^{14}\text{C}$ values (‰) of sewage DOC was more negative (^{14}C ages in the order of $\approx 1000\text{--}5000$ years) than nearby lake and river water; no fossil C fraction given.	Nara et al. (2010)	No information on relative fossil C fraction given.
A2O WWTP, Japan	13 wastewater samples collected along the treatment train during March, 2008	$\delta^{13}\text{C}$ signature of -50.7‰ (depleted with respect to background air)	Toyoda et al. (2011)	WWTP received municipal wastewater

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Annex 6A.2 Summary data for pit latrine use, no sanitation facility, and groundwater use by country

NEW TABLE 6A.2 SUMMARY DATA FOR PIT LATRINE USE, NO SANITATION FACILITY, AND GROUNDWATER USE BY COUNTRY					
Country	Data Source ¹	Report Year	Pit Latrine Use for Sanitation (%)	No Sanitation Facility (%)	Groundwater Use for Drinking (%)
Afghanistan	MICS	2010-2011	42.5	17.7	62.9
Albania	DHS	2008-2009	24.0	0.0	20.8
Algeria	MICS	2006	2.2	4.9	13.4
Angola	MICS	2001	31.0	38.7	37.5
Armenia	DHS	2010	30.4	0.0	2.5
Azerbaijan	DHS	2006	58.8	0.3	25.7
Bangladesh	DHS	2007	60.1	7.5	90.8
Belarus	MICS	2005	27.5	0.0	12.5
Belize	MICS	2006	40.7	2.1	7.5
Benin	DHS	2006	11.7	69.5	38.6
Bhutan	MICS	2010	52.7	3.4	1.5
Bolivia	DHS	2008	25.7	28.4	7.9
Bosnia and Herzegovina	MICS	2006	2.5	0.1	15.7
Botswana	MICS	2000	57.2	16.2	2.9
Brazil	DHS	1996	42.2		21.3
Burkina Faso	MICS	2006	1.0	62.6	68.9
Burundi	MICS	2005	92.7	3.0	69.0
Cambodia	DHS	2010	5.7	55.3	50.0
Cameroon	MICS	2006	82.6	7.5	49.9
Central African Republic	MICS	2006	75.4	22.3	69.1
Chad	DHS	2004	24.3	74.1	77.2
China	CHS04	2004	49.9	2.3	20.1
Colombia	DHS	2010	0.7	4.8	3.2
Comoros	MICS	2000	95.0	0.7	7.9
Congo	DHS	2005	84.4	10.2	30.6
Côte d'Ivoire	MICS	2006	42.7	34.0	51.8
Cuba	MICS	2010-2011	25.7	1.0	18.2
Democratic People's Republic of Korea	MICS	2009	37.4	0.0	10.8
Democratic Republic of the Congo	MICS	2010	80.0	14.5	59.1
Djibouti	MICS	2006	73.4	3.9	2.7
Dominican Republic	DHS	2007	47.6	36.0	9.7
Egypt	DHS	2008		0.4	4.0
Eritrea	DHS	2002	9.0	74.3	45.2

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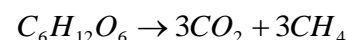
Ethiopia	DHS	2011	56.0	38.2	50.6
Gabon	DHS	2000	92.8	3.0	40.0
Gambia	MICS	2005-2006	80.6	4.4	41.0
Georgia	MICS	2005	57.8	0.0	25.7
Ghana	MICS	2010-2011	56.6	0.5	0.1
Guatemala	DHS	1998-1999	40.9	13.2	14.9
Guinea	DHS	2005	67.2	30.3	60.7
Guinea-Bissau	MICS	2006	4.0	31.1	79.1
Guyana	DHS	2009	43.3	1.0	3.5
Haiti	DHS	2005-2006	32.0	0.0	45.0
Honduras	DHS	2005-2006	39.8	16.7	15.8
India	DHS	2005-2006	12.9	56.2	58.6
Indonesia	DHS	2007	3.8	8.1	52.3
Iraq	MICS	2006	28.9	2.5	3.4
Jamaica	MICS	2005	77.2	0.6	3.3
Jordan	DHS	2009	43.5	0.0	0.0
Kazakhstan	MICS	2006	62.3	0.0	22.5
Kenya	DHS	2008-2009	67.3	14.5	41.4
Kyrgyzstan	MICS	2005-2006	82.0	0.1	10.1
Lao People's Democratic Republic	MICS	2006	31.7	50.1	48.7
Lesotho	DHS	2009	66.8	35.6	36.2
Liberia	DHS	2007	20.1	54.7	76.2
Madagascar	DHS	2008-2009	35.1	43.7	53.3
Malawi	DHS	2010	84.9	9.9	75.3
Maldives	DHS	2009	27.8	1.0	1.3
Mali	DHS	2006	60.2	19.6	69.9
Mauritania	MICS	2007	35.1	45.5	37.7
Mongolia	MICS	2005	67.1	13.4	60.7
Montenegro	MICS	2005-2006	7.7	0.3	9.2
Morocco	DHS	2003-2004	1.7	15.9	16.3
Mozambique	MICS	2008	52.7	41.8	55.9
Myanmar	MICS	2009-2010	74.9	7.0	73.6
Namibia	DHS	2006-2007	11.7	53.4	16.6
Nepal	DHS	2011	21.0	38.4	46.9
Nicaragua	DHS	2001	59.1	13.9	25.3
Niger	DHS	2006	21.5	78.0	74.3
Nigeria	MICS	2007	58.9	27.7	47.6
Pakistan	DHS	2006-2007	13.7	28.4	55.6
Peru	DHS	2011	1.9	12.0	6.6
Philippines	DHS	2008	11.7	9.6	39.0
Republic of Moldova	DHS	2005	62.5	0.0	56.0
Rwanda	DHS	2010	96.6	1.1	59.0

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Samoa	DHS	2009	10.0	0.1	3.8
Sao Tome and Principe	DHS	2008-2009	23.1	57.7	5.9
Senegal	DHS	2010-2011	57.1	16.5	27.6
Serbia	MICS	2010	4.5	0.0	8.5
Sierra Leone	MICS	2010	63.4	28.9	54.1
Somalia	MICS	2006	37.2	53.8	25.6
South Africa	DHS	2003	36.7	8.1	3.8
Sudan	MICS	2000	55.2	32.4	40.7
Suriname	MICS	2006	19.6	6.3	3.1
Swaziland	MICS	2010	69.7	15.4	19.3
Syrian Arab Republic	MICS	2006	18.2	1.0	7.7
Tajikistan	MICS	2005	85.5	0.4	14.2
TFYR Macedonia	MICS	2005	6.9	3.1	7.0
Thailand	MICS	2005-2006	1.4	0.8	12.3
Timor-Leste	DHS	2009-2010	28.0	35.8	48.7
Togo	MICS	2010	31.5	55.7	55.2
Trinidad and Tobago	MICS	2006	15.0	0.1	1.2
Turkey	DHS	2003	22.8	0.5	7.3
Turkmenistan	DHS	2000	71.3	0.6	22.9
Uganda	DHS	2006	66.4	11.8	73.5
Ukraine	DHS	2007	47.2	0.0	28.0
United Republic of Tanzania	DHS	2010	78.8	15.9	48.3
Uzbekistan	MICS	2006	87.4	0.0	20.1
Vanuatu	MICS	2007	77.3	3.2	22.7
Venezuela	MICS	2000	6.7	4.4	2.1
Viet Nam	MICS	2010-2011	18.2	6.4	43.7
Yemen	MICS	2006	42.1	21.4	35.9
Zambia	DHS	2007	57.1	23.5	47.1
Zimbabwe	DHS	2010-2011	42.6	28.3	64.0
Sources:					
¹ MICS: Multiple Indicator Cluster Surveys, UNICEF (http://www.childinfo.org/mics.html); DHS: Demographic and Health Surveys, USAID (http://www.measuredhs.com); CHS04: Economic, Population, Nutrition, and Health Survey, data accessed from WHO/UNICEF Joint Monitoring Program reports (http://wssinfo.org)					

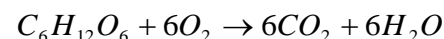
Annex 6A.3 Derivation of the maximum CH₄ producing potential (B_o) for domestic wastewater

The maximum CH₄ producing potential (B_o) for domestic wastewater is calculated theoretically by the anaerobic decomposition of glucose:



One mole of glucose weighs 180 g and produces 3 moles of methane which weighs $3 \times 16 = 48$ g. Therefore, the methane production rate per gram of glucose is $48 \text{ g} / 180 \text{ g} = 0.27 \text{ g methane} / \text{g glucose}$.

The complete oxidation of one mole of glucose (180 g) requires six moles of oxygen ($6 \times 32 \text{ g} = 192 \text{ g}$)



Then, the oxygen demand rate per gram of glucose is $192 \text{ g} / 180 \text{ g} = 1.067 \text{ g oxygen} / \text{g glucose}$

Finally, the maximum CH₄ producing potential (B_o) for domestic wastewater based of COD content is $48 \text{ g CH}_4 / 192 \text{ g oxygen} = 0.25 \text{ kg CH}_4 / \text{kg COD}$.

The BOD/COD ratio of a specific wastewater indicates the amount of organic matter difficult to degrade. For domestic wastewater, a typical BOD/COD ratio is 2.4 based on empirical tests. However, the ratio between the components in any given domestic wastewater stream may vary due to contributions from other sources, particularly wastewater contributions from commercial or industrial sources. The expected range of BOD/COD ratios is between 1.5 and 3.5 (Henze et al, 2008).

Inventory compilers should compare country-specific data on BOD/COD ratio in domestic wastewater to IPCC default values of 2.4. If inventory compilers use country-specific values, they should provide documented justification why their country-specific values are more appropriate for their national circumstances.

Annex 6A.4 Calculation of MCF for methane emissions from sewage discharges

Data were obtained from a recent global review article by Deemer et al. (2016) for CO₂ and CH₄ emissions from different environments. At equilibrium with current atmospheric conditions, CO₂ is relatively soluble (over 500 µg/L) compared with CH₄ (about 40 ng/L) at 25 degrees Celsius. Therefore, a reliance on studies that only measure diffusive flux will underestimate the relative emission of CH₄. Deemer and colleagues raised previous estimates of CH₄ emissions by excluding data from sources that did not include assessment of ebullition. Regarding emissions from all kinds of reservoirs, this exclusion had the effect of increasing the relative CH₄ flux ($\text{CH}_4\text{-C}/(\text{CH}_4\text{-C} + \text{CO}_2\text{-C})$) to 27% (first data row in table) which is higher than previously thought. For an estimate of this effect on the other data, it is noted that about 52% of the data listed by Deemer and colleagues included ebullition, and for this about 40–60% of the total ebullitive and diffusive flux was due to ebullition. To illustrate the potential effect of adding ebullition to the *reservoir* studies a scaling factor of $1.48 = 0.52/1 + 0.48/0.5$ is applied for *reservoirs* and *hydroelectric reservoirs* in the table. Deemer et al. (2016) used Bastviken et al. (2011) for an estimate of methane emissions from *lakes* and the original data (Table 1 in Bastviken) suggests a smaller correction factor for that *lake* data of 1.23. For rivers, Stanley et al. (2016) reports a relationship similar to Deemer et al.'s observation – that of total flux, 46% is ebullitive among those studies reporting both kinds of fluxes (see Table 1 in Stanley *et al.*, 2016). Correcting the average of the larger dataset in Stanley et al. (2016) with this figure, suggests a range of riverine yields of 0.4–6%. Note that the riverine CO₂ figure in Deemer et al. (2016) of 7,954 mg C/m²/day was based on original 1,800 Tg C/y datum in Raymond et al. (2013), which has been reduced using the Lauerwald et al. (2015) updated estimate of 659 Tg C/y figure and is thus 2,872 mg C/m²/day.

Considering the data in the table, the average yield for reservoirs and lakes is 19% (8–27%) while the average for rivers is much lower at 3.5 % (0.4–6%). Data ranges rather than standard deviations are given owing to the potential for overlap between the underlying datasets. These CH₄ yield data are used to estimate the MCF. On the same basis as the B_o calculation, 1.067 kg of O₂ are required to oxidise one kg of glucose. Considering that 40% of glucose is carbon, this implies the COD of glucose on a carbon basis is 2.67 kg COD/kg C. So 0.19 kg CH₄-C/kg (CH₄-C + CO₂-C) corresponds to 0.071 kg CH₄-C/kg COD. Taking a global perspective, Tranvik et al. (2009) state that approximately 1.4 Pg of carbon is emitted from inland waters at CO₂ and a further 0.1 Pg as CH₄, the remainder being sequestered in sediments or lost to the ocean. Thus of 3.0 Pg of carbon inputs, 50% is emitted to the atmosphere. Correcting the previous figure for this yield and converting to kg CH₄ suggests $0.071 [\text{kg CH}_4\text{-C/kg COD}] \times (12.01 + 1.00797 \times 4) / 12.01 [\text{kg CH}_4/\text{kg CH}_4\text{-C}] \times 0.5 = 0.048 \text{ kg CH}_4/\text{kg COD}$. For use in conjunction with B_O then $\text{MCF} = 0.048/0.25 = 0.19$ (0.08–0.27) for lakes and reservoirs. In the same way, $\text{MCF} = 0.035$ (0.004–0.06) for rivers and streams.

NEW TABLE 6A.3
SUMMARY OF LITERATURE INVESTIGATING METHANE EMISSIONS FROM WASTEWATER DISCHARGE

Type of Waterbody	CH ₄ flux (mg C/m ² /day)	<i>n</i> (reservoirs, lakes or rivers)	CH ₄ flux corrected for ebullition (mg C/m ² /day)	CO ₂ flux (mg C/m ² /day)	Yield	Approx. revised yield	Reference
Reservoirs	120	75	120	330	27%	27%	Deemer et al, 2016
Reservoirs	82–96	161	121–142	498	14–16%	20–22%	CH ₄ : Bastviken et al, 2011, St Louis et al, 2000; CO ₂ : St Louis et al, 2000
Hydroelectric reservoirs	24–112	85, 104	48–224	386–660	6–15%	8–20%	Barros et al, 2011; Li & Zhang 2014
Lakes	40	66	80	216	16%	19%	CH ₄ : Bastviken et al, 2011; CO ₂ Raymond et al, 2013
Rivers	6–98	21, 26	11–183	2872	0.21–3.3%	0.39–6.0%	CH ₄ : Bastviken et al, 2011, Stanley et al, 2016; CO ₂ : Lauerwald et al, 2015

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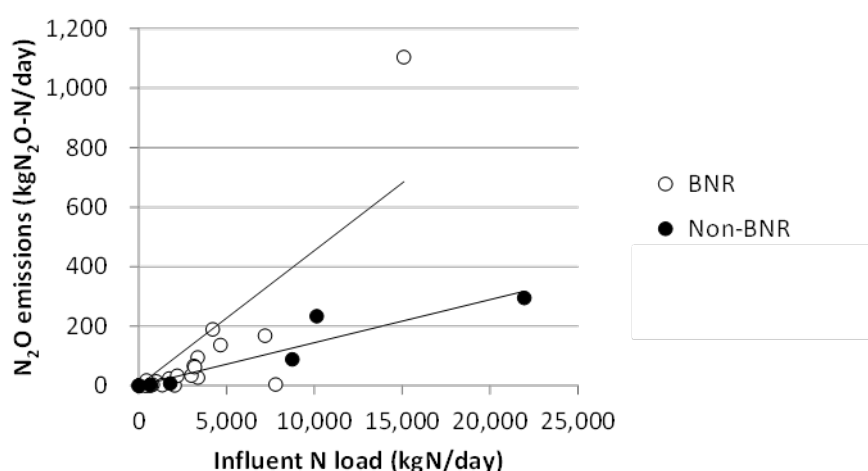
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Annex 6A.5 Estimation of default emission factors for N₂O in domestic wastewater treatment plants

We reviewed scientific literature to find emission factors from full-scale domestic wastewater treatment plants. Although much literature exists regarding N₂O emission from wastewater treatment processes, relatively few studies relate to full-scale treatment plants and provide key information such as influent nitrogen load. Then, we collected and categorized 34 data into two groups; Biological Nutrient Removal (BNR) and non-BNR. Based on these data, N₂O emission correlated with influent N load (Figure 6A.1). Emission factors and references are listed in Table 6A.4A and Table 6A.4B. Specific and relatively new/uncommon treatment processes such as membrane bioreactors were intentionally excluded from this list in order to develop emission factors for the most typical and popular treatment processes.

Figure 6A.1 Correlation between influent N load and N₂O emission



NEW TABLE 6A.4A				
DEFAULT N ₂ O EMISSION FACTORS FOR DOMESTIC WASTEWATER TREATMENT PLANTS				
Categories	N ₂ O emission factor (kg N ₂ O-N/kg N)	STDEV	Max	Min
BNR	0.014	0.017	0.073	0.00016
Non-BNR	0.0083	0.0084	0.0230	0.0016

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NEW TABLE 6A.4B EMISSION FACTORS IN FULL-SCALE DOMESTIC WASTEWATER TREATMENT PLANTS			
Type of treatment process¹	Categories	References	N₂O emission factor (kg N₂O-N/kg N)
AO	BNR	Daelman et al. (2015)	0.028
AO	BNR	Foley et al. (2010)	0.021
AO	BNR	Foley et al. (2010)	0.045
AO	BNR	Foley et al. (2010)	0.073
A2O	BNR	Foley et al. (2010)	0.013
SBR	BNR	Foley et al. (2010)	0.023
OD	BNR	Foley et al. (2010)	0.0080
IA	BNR	Kimochi et al. (1998)	0.0005
EA	BNR	Foley et al. (2010)	0.015
A2O	BNR	Wang et al. (2016)	0.013
CAS	BNR	Aboobakar et al. (2013)	0.00036
AO	BNR	Rodriguez-Caballero et al. (2014)	0.12
OD	BNR	Masuda et al. (2018)	0.00016
AO	BNR	Masuda et al. (2018)	0.0013
AO	BNR	Masuda et al. (2018)	0.0049
Separate-stage BNR	BNR	Ahn et al. (2010)	0.00019
Bardenpho	BNR	Ahn et al. (2010)	0.0036
Step-feed BNR	BNR	Ahn et al. (2010)	0.011
MLE	BNR	Ahn et al. (2010)	0.0007
MLE	BNR	Ahn et al. (2010)	0.0006
OD	BNR	Ahn et al. (2010)	0.0003
Step-feed BNR	BNR	Ahn et al. (2010)	0.015
Step-feed BNR	BNR	Ahn et al. (2010)	0.0005
Step feed, plug flow	BNR	Ni et al. (2015); Pan et al. (2016)	0.019
OD	BNR	Lorenzo-Toja et al. (2016)	0.010 ²
EA	BNR	Lorenzo-Toja et al. (2016)	0.02235 ²
SBR	BNR	Bao et al. (2016)	0.029
SBR	BNR	Rodriguez-Caballero et al. (2015)	0.038
Plug flow	Non-BNR	Ahn et al. (2010)	0.004
Plug flow	Non-BNR	Ahn et al. (2010)	0.0062
Step-feed non-BNR	Non-BNR	Ahn et al. (2010)	0.0018
Plug flow	Non-BNR	Masuda et al. (2015)	0.023
AO	Non-BNR	Bao et al. (2016)	0.013
IA	Non-BNR	de Mello et al. (2013)	0.0016

¹ AO; Anaerobic-oxic activated sludge process, A2O; Anaerobic-anoxic-oxic activated sludge process, SBR; Sequencing batch reactor, OD; Oxidation ditch, IA; Intermittent aeration process, EA; Extended aeration process, CAS; Conventional activated sludge process, MLE; Modified Ludzack Ettinger.

² These are not included in Figure 6A.1 due to lack of information on influent N load.

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Annex 6A.6 Estimation of default emission factors for N₂O in effluent

Table 6.11 in the 2006 IPCC Guidelines was based on expert judgement. For the refinement of these guidelines, literature was reviewed for reported yields of nitrous oxide from environments with known oxygen saturation conditions. A total of 62 data points for well-oxygenated environments and 59 for low-oxygen environments were obtained from Beaulieu et al. (2011), Frame and Casciotti (2010), Goreau et al. (1980), He et al. (2017), Ji et al. (2015), Kaplan et al. (1978), Kaplan and Wofsy (1985), Kester et al. (1997), Mantoura et al. (1993), McCarthy et al. (1984), McElroy et al. (1978), Punshon and Moore (2004), Seitzinger (1988), Seitzinger & Kroeze (1998), Seitzinger et al. (1984), Wang et al. (2015), Yan et al. (2012), Yoshida (1988) and Zhu et al. (2013).

These data suggested a mean yield of 0.019 kg N₂O-N/kg-N for low oxygen environments and 0.005 kg N₂O-N/kg-N for well-oxygenated environments. Calculation of a simple standard deviation is inappropriate for this data, since it is a proportion. Therefore, confidence intervals for these averages were calculated using the adjusted Wald method for small proportions (Bonett and Price, 2012). The resulting 95% (two tailed) limits are 0.0041 – 0.0912 and 0.0 – 0.0753 respectively.

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