2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Volume 5

Waste

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Task Force on National Greenhouse Gas Inventories

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WASTE

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CHAPTER 2

WASTE GENERATION, COMPOSITION AND MANAGEMENT DATA

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2 WASTE GENERATION, COMPOSITION AND MANAGEMENT DATA

Users are expected to go to Mapping Tables in Annex 1, before reading this chapter. This is required to correctly understand both the refinements made and how the elements in this chapter relate to the corresponding chapter in the 2006 IPCC Guidelines.

2.1 INTRODUCTION

The starting point for the estimation of greenhouse gas emissions from solid waste disposal, biological treatment and incineration and open burning of solid waste is the compilation of activity data on waste generation, composition and management. General guidance on the data collection for solid waste disposal, biological treatment and incineration and open burning of waste is given in this chapter in order to ensure consistency across these waste categories. More detailed guidance on choice of activity data, emission factors and other parameters needed to make the emission estimates is given under Chapter 3, Solid Waste Disposal, Chapter 4, Biological Treatment of Solid Waste, and in Chapter 5, Incineration and Open Burning of Waste.

Solid waste generation is the common basis for activity data to estimate emissions from solid waste disposal, biological treatment, and incineration and open burning of waste. Solid waste generation rates and composition vary from country to country depending on the economic situation, industrial structure, waste management regulations and life style. The availability and quality of data on solid waste generation as well as subsequent treatment also vary significantly from country to country. Statistics on waste generation and treatment have been improved substantially in many countries during the last decade, but at present only a small number of countries have comprehensive waste data covering all waste types and treatment techniques. Historical data on waste disposal at solid waste disposal sites (SWDS) are necessary to estimate methane (CH_4) emissions from this category using the First Order Decay method (see Chapter 3 Solid Waste Disposal, Section 3.2.2). Very few countries have data on historical waste disposal going back several decades.

Solid waste is generated from households, offices, shops, markets, restaurants, public institutions, industrial installations, water works and sewage facilities, construction and demolition sites, and agricultural activities (emissions from manure management as well as on-site burning of agricultural residues are treated in the Agriculture, Forestry and Other Land Use (AFOLU) Volume). It is a *good practice* to account for all types of solid waste when estimating waste-related emissions in the greenhouse gas inventory.

Solid waste management practices include: collection, recycling, solid waste disposal on land, biological and other treatments as well as incineration and open burning of waste. Although recycling (material recovery) activities will affect the amounts of waste entering into other management and treatment systems, the impact on emissions due to recycling (e.g., changes in emissions in production processes and transportation) is covered under other sectors and will not be addressed here in more detail

This chapter provides updated data for the year (2010) for waste generation rates and waste composition by region according to UN classification. Waste generation rate and waste composition are key parameters used in the First Order Decay (FOD) model for estimation of CH_4 emissions from SWDS. These two parameters are subject to change over time depending on waste policies such as promotion of waste to energy, recycling and other treatment technologies. The refinement tables provide data which are based on references found during the period 2005 to 2010 which are assumed to be applicable for estimates of the year 2010. Data provided in *Revised 1996 IPCC Guidelines* and *2006 IPCC Guidelines* also help countries construct proper historical time series for waste generation which varies by time. In case data for countries are available beyond 2010, such data can be used to improve estimates of emissions for these years. The update of waste composition by country and region based on city and country level information is provided. Waste composition provided are in line with IPCC FOD model. The refinement provides detailed information per country in the tables in the Annexes. When country values are not available in the annex, default regional values provided in Table 2.1 (Updated) and Table 2.3 (Updated) can be used.

In addition to waste generation rate and waste composition, this refinement provides data on carbon, nitrogen and degradable organic carbon (DOC) contents in sludge which are also used in Chapters 5 and 6, Volume 5 (Waste) and Chapter 11, Volume 4 (AFOLU).

2.2 WASTE GENERATION AND MANAGEMENT DATA

No refinement.

2.2.1 Municipal Solid Waste (MSW)

Default data

Updated default data of region-specific waste generation rate per capita per year are provided in updated Table 2.1. To generate data sets on waste practice at the country level for EU countries, the data were derived from Eurostat, for other countries‑World Bank data based on references. These data are based on weight of wet waste and can be assumed to be applicable for the year 2010. Waste generation per capita for subsequent or earlier years can be estimated using the same guidance indicated in *2006 IPCC Guidelines*. Data from *Revised 1996 IPCC Guidelines* and *2006 IPCC Guidelines* provided in Table 2A.1 (Updated) help countries construct proper historical time series for waste generation which varies by time.

For developing countries using regional waste generation rates provided in the Table 2.1 (Updated) and for developing countries in italics in the Table 2 A.1 (Updated), the generation rates should be multiplied by the urban population only to obtain the total waste generated in the country since these rates assume that the waste is generated by urban population only and not rural population. Hoornweg and Bhada (2012) was the main reference used for data from developing countries. The methodology used for most developing countries in this reference estimated the waste generation rates from the total waste generated in the country divided by the urban population[1]. For other countries (not in italics in the table), the generation rates should be multiplied by the total population to estimate the total waste generated in the country.

TABLE 2.1 (UPDATED)
MSW GENERATION AND TREATMENT DATA – REGIONAL DEFAULTS

Region	MSW Generation Rate[1,2,3] (tonnes/cap/yr)	Fraction of MSW open dumped	Fraction of MSW disposed to landfills	Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified[4]
Asia						
Central Asia	0.34					
Eastern Asia	0.48	0.00	0.23	0.24	0.00	0.52
South-Eastern Asia	0.46					
Southern Asia	0.50					
Western Asia	0.69	0.11	0.68	0.08	0.01	0.12
Africa						
Northern Africa	0.41	0.79	0.17	0.00	0.00	0.04
Eastern Africa	0.29	0.98	0.00	0.00	0.01	0.01
Middle Africa	0.19	0.95	0.00	0.00	0.00	0.05
Southern Africa	0.33					
Western Africa	0.18	0.00	0.64	0.00	0.00	0.36

[1] During the time of finalizing this refinement, a new version of the report was issued in September 2018. Inventory compilers are encouraged to refer to the new version of the report for any updated values taking into account any updates in the methodology of estimating the generation rates.

TABLE 2.1 (UPDATED) (CONTINUED)
MSW GENERATION AND TREATMENT DATA – REGIONAL DEFAULTS

Region	MSW Generation Rate[1,2,3] (tonnes/cap/yr)	Fraction of MSW open dumped	Fraction of MSW disposed to landfills	Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified[4]
Europe						
Eastern Europe	0.37	0.00	0.71	0.06	0.04	0.19
Northern Europe	0.48	0.00	0.47	0.20	0.09	0.24
Southern Europe	0.47	0.00	0.76	0.04	0.03	0.17
Western Europe	0.59	0.00	0.08	0.40	0.21	0.31
America						
Caribbean	0.78	0.03	0.78	0.00	0.01	0.18
Central America	0.58	0.13	0.62	0.00	0.00	0.25
South America	0.43	0.43	0.40	0.00	0.00	0.18
Northern America	0.96	0.00	0.22	0.26	0.13	0.38
Oceania						
Australia and New Zealand	0.60	0.00	0.69	0.04	0.00	0.27
Melanesia	1.18					
Polynesia	1.35					

[1] Data are based on weight of wet waste.

[2] To obtain the total waste generation in the country, the per-capita values should be multiplied with the population whose waste is collected. For developing countries using regional values from the table above, the generation rates should be multiplied by the urban population.

[3] The data are default data for the year 2010, although for some countries the year for which the data are applicable was not given in the reference, or data for the year 2010 were not available. This year for which the data are collected, where available, is given in Annex 2A.1 (Updated)

[4] Other, unspecified, includes data on recycling for some countries.

Country-specific data

It is *good practice* that countries use data on country-specific MSW generation, composition and management practices as the basis for their emission estimation.

Country-specific data on MSW generation and management practices can be obtained from waste statistics, surveys (municipal or other relevant administration, waste management companies, waste association organisations, other) and research projects (World Bank, Organization for Economic Co-operation and Development (OECD), Asian Development Bank (ADB), Japan International Cooperation Agency (JICA), US Environmental Protection Agency (US EPA), International Institute for Applied Systems Analysis (IIASA), European environment Agency (EEA), etc.).

Large countries with differences in waste generation and treatment within the domestic regions are encouraged to use data from these regions to the extent possible. Additional guidance on data collection in general and on waste surveys is given in Chapter 2, Approaches to Data Collection, in Volume 1.

Data from waste stream analyses

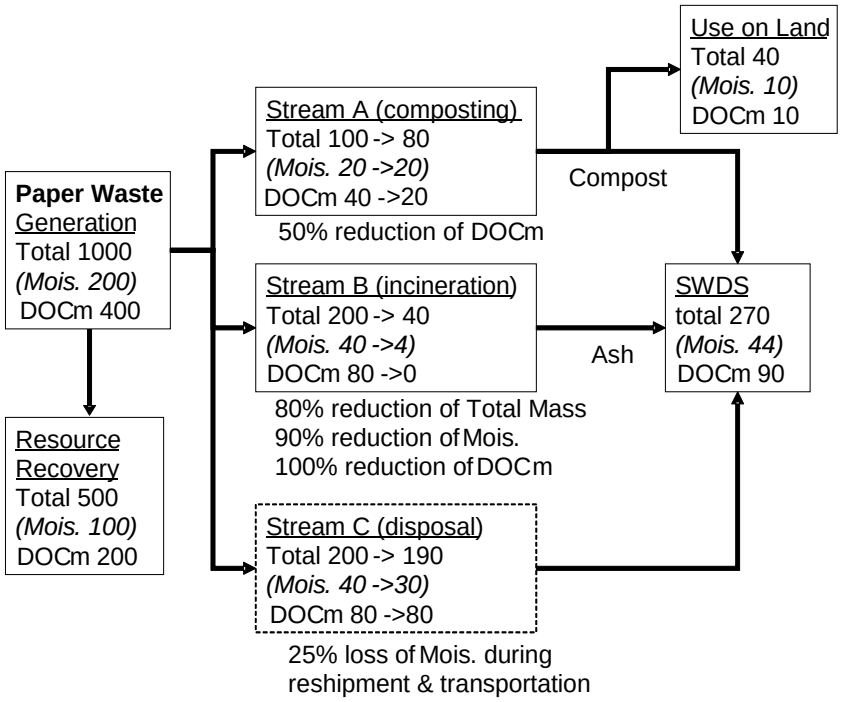
MSW treatment techniques are often applied in a chain or in parallel. A more accurate but data intensive approach to data collection is to follow the streams of waste from one treatment to another taking into account the changes in composition and other parameters that affect emissions. Waste stream analyses should be combined with high quality country-specific data on waste generation and management. The approach is often complemented with modelling. When using this approach, it is *good practice* to verify the data using separately collected data on MSW generation, treatment and disposal, especially in cases where they are based largely on modelling. This method is only more accurate than the approaches given above if countries have good quality, detailed data on each end point and have verified the information.

An example of applying the approach for estimating the amount of paper waste disposed at SWDS is given in Box 2.1, Example of Activity Data Collection for Estimation of Emissions from Solid Waste Treatment Based on Waste Stream Analysis by Waste Type. Using this approach following all waste streams in the country would provide activity data for all solid waste treatment and disposal (including waste incineration and open burning of waste). The data needed for the approach could be estimated based on surveys to industry, households and waste management companies/facilities, complemented with statistical data on MSW generation, treatment and disposal.

BOX 2.1

EXAMPLE OF ACTIVITY DATA COLLECTION FOR ESTIMATION OF EMISSIONS FROM SOLID WASTE TREATMENT BASED ON WASTE STREAM ANALYSIS BY WASTE TYPE

Waste streams begin at the point of generation, flow through collection and transportation, separation for resource recovery, treatment for volume reduction, detoxification, stabilisation, recycling and/or energy recovery and terminate at SWDS. Waste streams are country-specific. Traditionally most solid waste has been disposed at SWDS in many countries. Recent growing recognition of the need for resource conservation and environmental protection has increased solid waste recycling and treatment before disposal in developed countries. In developing countries, recovery of valuable material at collection, during transportation and at SWDSs has been common. Degradable organic carbon (DOC) is one of the main parameters affecting the CH_4 emissions from solid waste disposal. DOC is estimated based on the waste composition, and varies for different waste fractions. Accurate estimates of the amount of waste and amount of DOC in waste (DOCm) disposed at SWDS could be achieved by sampling waste at the gate of SWDS and measuring DOCm in that waste, or specifying the waste stream for each waste type and/or source. Intermediate processes in the waste stream can significantly change physical and chemical properties of waste, including moisture and DOCm. DOCm in waste at SWDS will differ considerably from that at generation, depending on the treatment before the disposal. For those countries that do not have reliable data based on measurements on DOCm disposed at SWDS, the analysis on the change in mass of moisture and DOCm during earlier treatment for each waste type, could provide a method to avoid over-/under-estimating the CH4 emissions at SWDS.



Note 1: 'Mois.' means moisture and DOCm is the mass of degradable organic carbon.
Note 2: Values in each box give the weight of the total mass (Total), moisture (Mois.) and DOCm in mass units (tonnes or kilograms or other).

BOX 2.1 (CONTINUED)
EXAMPLE OF ACTIVITY DATA COLLECTION FOR ESTIMATION OF EMISSIONS FROM SOLID WASTE TREATMENT BASED ON WASTE STREAM ANALYSIS BY WASTE TYPE

The figure above shows an example of a paper waste flow chart for analysis of change in DOCm in waste during the treatment before disposal. Some portion of paper waste would be recovered as material, and be diverted from the waste management flow. The DOCm in paper waste is reduced by intermediate processes, such as composting and incineration before disposal at the SWDS. Mass of total waste, DOCm and moisture at the exit of each process can be given by multiplying mass of these components at the entrance by reduction rates of the process. In this figure the changes of mass are studied for paper waste solely, although the treatment steps would usually include also other waste types. Incineration will remove most of the moisture, but the ash will be re-wetted to avoid the fly loss during transportation and loading into SWDS. Greenhouse gas emissions from other categories than SWDS (i.e., resource recovery, composting, incineration and use on land) should be estimated under guidelines in relevant chapters. The estimates in this figure are based on expert judgement only as an example.

To apply this approach national statistics on municipal waste generation and treatment streams, country-specific parameters on waste composition and fraction moisture as well as DOC estimates for each waste type are needed for precise estimation. It may be difficult to obtain all these data and parameters in many countries. If country-specific reduction rates of moisture and DOCm at each intermediate treatment step before disposal at SWDS can be obtained, estimated DOCm disposed into SWDS will be more precise than when based on data measured at generation.

2.2.2 Sludge

No refinement.

2.2.3 Industrial waste

No refinement.

2.2.4 Other waste

No refinement.

2.3 WASTE COMPOSITION

2.3.1 Municipal Solid Waste (MSW)

Waste composition is one of the main factors influencing emissions from solid waste treatment, and is influenced by factors such as cultural norms, level of economic development, climate, and energy consumption etc. In the municipal solid waste stream, waste can be classified into organic and inorganic component. Food waste, garden (yard) and park waste, and wood are classified as organic waste while paper/cardboard, textiles, nappies, and leather/rubber contain some fossil carbon. The different waste types contain different amount of DOC and fossil carbon. Waste compositions, as well as the classifications used to collect data on waste composition in MSW vary widely in different regions and countries.

In this Volume, default data on waste composition in MSW are provided for the following waste types:

(1) food waste;

(2) garden (yard) and park waste;

(3) paper and cardboard;

(4) wood;

(5) textiles;

(6) nappies (disposable diapers);

(7) rubber and leather;

(8) plastics;

(9) metal;

(10) glass (and pottery and china);

(11) other (e.g., ash, dirt, dust, soil, electronic waste).

Waste types from (1) to (6) contain most of the DOC in MSW. Ash, dust, rubber and leather contain also certain amounts of non-fossil carbon, but this is hardly degradable. Some textiles, plastics (including plastics in disposable nappies), rubber and electronic waste contain the bulk part of fossil carbon in MSW. Paper (with coatings) and leather (synthetic) can also include small amounts of fossil carbon.

Based on data on MSW compositions collected from international literatures, the regional average components were calculated and the regional default data on waste composition in MSW are given in Table 2.3 (Updated). These updated default data are by specific region using UN classification in accordance to the updated default data of waste generation rate.

These data are based on weight of wet waste without industrial waste. Table 2.3 (Updated) and Table 2A.2 (New) provide default data for garden and park waste and nappies. These values are based on limited number of countries which have data on these waste types. In Table 2A.2 (New), when values of nappies and garden and yard waste are not included for a country, the country should subtract the assumed value for nappies and garden and park waste from the “others” category.

This refinement updates waste composition by region with the average from city and country level on wet weight basis. Waste components are in line with IPCC Waste model. Detailed information on waste composition is provided in Annex 2A.2 (New).

TABLE 2.3 (UPDATED)
MSW COMPOSITION DATA BY PERCENT – REGIONAL DEFAULTS

Region	Food waste	Garden waste	Paper /cardboard	Wood	Textiles	Nappies	Rubber /Leather	Plastic	Metal	Glass	Other
Asia											
Central Asia	30.0	1.4	24.7	2.5	3.5	0	0	8.4	0.8	5.9	23.0
Eastern Asia	40.3	0.0	20.4	2.1	1.0	0.0	0.0	6.5	2.7	4.3	22.9
South-Eastern Asia	49.9	1.0	11.2	0.8	0.4	0.0	0.0	10.2	4.2	3.7	18.6
Southern Asia	66.1	0.0	9.2	0.0	1.2	0.0	0.4	7.0	0.9	1.5	13.9
Western Asia	42.2	3.2	15.3	0.8	3.0	0.4	0.3	17.2	2.5	3.4	11.8
Africa											
Northern Africa	50.4	0.0	12.1	0.0	5.8	0.0	0.0	13.8	4.4	3.3	10.5
Eastern Africa	44.4	6.9	10.4	0.5	3.0	0.0	0.4	8.0	2.6	2.1	21.7
Middle Africa	28.4	0	8	0	1.3	0	0	7.1	1.4	1.1	52.7
Southern Africa	24.0	0.0	14.5	0.0	5.5	0.0	0.0	26.5	6.5	9.0	14.0
Western Africa	53.9	0.0	7.5	0.0	1.9	0.0	0.0	6.4	2.7	1.3	26.5

TABLE 2.3 (UPDATED) (CONTINUED)
MSW COMPOSITION DATA BY PERCENT – REGIONAL DEFAULTS

Region	Food waste	Garden waste	Paper/ cardboard	Wood	Textiles	Nappies	Rubber/ Leather	Plastic	Metal	Glass	Other
Europe											
Eastern Europe	31.8	2.4	17.1	2.5	3.1	0.1	0.5	4.6	0.7	1.8	35.3
Northern Europe	30.3	5.2	13.8	1.8	3.2	1.2	0.0	4.9	1.4	4.3	34.0
Southern Europe	35.8	1.4	21.4	1.2	2.8	1.1	0.2	14.1	2.0	3.5	16.7
Western Europe	33.2	2.7	17.2	2.3	5.9	3.0	0.0	20.5	1.5	1.4	12.3
America											
Central America	62.7	0.0	12.6	0.3	2.2	0.0	0.0	10.3	2.7	3.3	6.0
South America	54.1	3.3	12.4	0.0	1.7	1.9	0.6	13.7	2.0	3.0	7.2
Northern America	20.2	6.8	23.3	4.1	3.9	0	1.6	15.8	6.4	4.2	14.0
Oceania											
Australia and New Zealand	25.9	12.2	12.0	6.5	2.9	3.5	0.0	8.3	1.8	2.8	24.1

Note 1: Data are based on weight of wet waste of MSW without industrial waste at generation around year 2010.

Note 2: The region-specific values are calculated from national, partly incomplete composition data. The percentages given may therefore not add up to 100percent. Some regions may not have data for some waste types - blanks in the table represent missing data.

Note 3: Data of rest of Oceania and Caribbean are not refined

2.3.2 Sludge

The *2006 IPCC Guidelines* elaborate sludge as "…Sludge from domestic and industrial wastewater treatment plants is addressed as a separate waste category in this Volume. In some countries, sludge from domestic wastewater treatment is included in MSW and sludge from industrial wastewater treatment in industrial waste. Countries may also include all sludge in industrial waste. When country-specific categorization is used, it should be documented transparently…".

In this refinement, definition of sludge is addressed. Sludge is a mixture of liquid and solid components and can be produced as sewage sludge from wastewater treatment processes or as a settled suspension obtained from conventional drinking water treatment or from numerous other industrial processes. Sludge from industrial processes is usually process-specific and it is *good practice* to obtain sludge composition data from producers.

Data characterizing sludge composition needed for emission estimations include carbon content, nitrogen content and DOC of sludge. Default values are presented percent or fraction of sludge as dry mass in Table 2.4a (New).

The carbon (C) content and nitrogen (N) content are result of ultimate analysis (quantifying C or N disregarding the form or chemical compound in which they are present in sludge).

The DOC content in sludge will vary depending on the wastewater treatment method producing the sludge, and be different for domestic and industrial sludge.

For domestic sludge, the default DOC value (as percentage of wet waste assuming a default dry matter content of 10 percent) is 5 percent (range 4 - 5 percent, which means that the DOC content would be 40-50 percent of dry matter

In this refinement, the DOC in sludge was estimated as multiplication of carbon content and volatile suspended solids fraction of sludge. It is assumed, that volatile suspended solids fraction is equivalent to degradable organics in sludge. This approach is applicable to sludge (mainly from industrial activities), where carbon is evenly distributed in the sludge. In case of sludge from wastewater treatment, which consists from inorganic and organic fractions, majority of carbon is concentrated in organic fraction and therefore DOC of sewage sludge is equivalent to total carbon content. The DOC content 40-50 percent as shown in *2006 IPCC Guidelines* is applicable to untreated sludge. The default DOC value for treated sludge is 30 percent (Werle, 2013; Werle and Dudziak, 2014; He *et al*. 2007; Boutchich *et al*. 2015; Phyllis 2 database).

A rough default value of 9 percent DOC (assuming the dry matter content to be 35 percent) can be used for industrial sludge, when country and/or industry-specific is not available. The default DOC value applies for total industrial sludge in a country. Sewage, food industry, paper industry, textile industry and chemical industry will generate organic sludge. DOC is also found in sludge from water work and dredging. The DOC in sludge can vary much by industry type. Examples of carbon contents in some organic sludge (percentage of dry matter) in Japan are: 27 percent for pulp and paper industry, 30 percent for food industry and 52 percent for chemical industry (Yamada *et al*. 2003).

TABLE 2.4A (NEW)
DEFAULT VALUE AND UNCERTAINTY OF CARBON CONTENT, NITROGEN CONTENT AND DOC OF DOMESTIC AND INDUSTRIAL SLUDGE (PERCENT OF DRY MATTER)

Sludge	Carbon content		Nitrogen content		DOC	
	Default value (percent)	Uncertainty (percent)	Default value (percent)	Uncertainty (percent)	Default value (percent)	Uncertainty (percent)
Domestic Sewage Treated Sludge [2-6]	31	+/- 27	4.2	+/- 56	30	+/- 61
Domestic Sewage Untreated Sludge [1]					50	+/- 30
Food Industry (fruits & vegetables)[2]	44	+/- 33	1.1	+/- 45	36	+/- 69
Paper Industry (process sludge)[2]	28	+/- 49	0.5	+/- 100	12	+/- 25
Paper Industry (Wastewater sludge)[2]	31	+/- 15	0.9	+/- 60		
Chemical Industry[1]	52	+/- 100				
Default for Industrial Sludge[1]					26	

Source:

[1] Derived from *2006 IPCC Guidelines*

2 Derived from Phyllis2 database for biomass and waste, https://www.ecn.nl/phyllis2 Energy research Centre of the Netherlands with uncertainty is estimated as 95 percentile (2*sigma)

3 Werle and Dudziak, 2014

4 Werle, 2013

5 He *et al*. 2007

6 Boutchich *et al.* 2015

In addition to emission estimate and reporting in the 2006 *IPCC Guidelines* Chapter 2, Section 2.2.2 estimation of CH_4 generated from anaerobic sludge stabilization at a wastewater treatment plant should be estimated according to methodology Chapter 4 (Volume 5) and resulting emissions should be included in Chapter 6 (Volume 5).

2.3.3 Industrial waste

No refinement.

2.3.4 Other waste

No refinement.

Annex 2A.1 (Updated) Waste Generation and Management Data – by country and regional averages

TABLE 2A.1 (UPDATED)
MSW GENERATION AND MANAGEMENT DATA – BY COUNTRY AND REGIONAL AVERAGE

Region/country	MSW [1, 2] Generation Rate IPCC-1996 Values [4] (tonnes/cap/yr)	MSW [1, 2, 3] Generation Rate IPCC-2006 Values [5] (tonnes/cap/yr)	MSW Generation Rate Values [1,2,3] (tonnes/cap/yr)	Fraction of MSW disposed to SWDS IPCC-1996 Values [4]	Fraction of MSW disposed to SWDS IPCC-2006 Values [5]	Fraction of MSW disposed to SWDS		Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified [6]	Source
						Open dumped	Disposed to landfills				
Year	1990	2000	2010	1990	2000	2010	2010	2010	2010	2010	
Asia											
Central Asia	**0.12**	**0.21**	**0.34**	**0.60**	**0.74**						
Tajikistan			0.32								1
Turkmenistan			0.36								1
Eastern Asia	**0.41**	**0.37**	**0.48**	**0.38**	**0.55**	**0.00**	**0.23**	**0.24**	**0.00**	**0.52**	
China		0.27	0.37		0.97						2
Hong Kong Special Administrative Region, China			0.93			0.00	0.51	0.00	0.00	0.49	3
Macao Special Administrative Region, China			0.62			0.00	0.23	0.00	0.00	0.77	3
Japan	0.41	0.47	0.35	0.38	0.25	0.00	0.01	0.76	0.00	0.22	4
Mongolia			0.24								1
Republic of Korea		0.38	0.35		0.42	0.00	0.18	0.22	0.00	0.61	5

TABLE 2A.1 (UPDATED) (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA – BY COUNTRY AND REGIONAL AVERAGE

Region/country	MSW [1, 2] Generation Rate IPCC-1996 Values [4] (tonnes/cap/yr)	MSW [1, 2, 3] Generation Rate IPCC-2006 Values [5] (tonnes/cap/yr)	MSW Generation Rate Values [1,2,3] (tonnes/cap/yr)	Fraction of MSW disposed to SWDS IPCC-1996 Values [4]	Fraction of MSW disposed to SWDS IPCC-2006 Values [5]	Fraction of MSW disposed to SWDS		FRACTION OF MSW INCINERATED	Fraction of MSW composted	Fraction of other MSW management, unspecified [6]	Source
						Open dumped	Disposed to landfills				
Year	1990	2000	2010	1990	2000	2010	2010	2010	2010	2010	
South-Eastern Asia		**0.27**	**0.46**		**0.59**						
Brunei Darussalam			0.32								1
Indonesia		0.28	0.19		0.80						1
Lao People's Democratic Republic		0.25	0.26		0.40						1
Malaysia		0.30	0.55		0.70						6
Myanmar		0.16	0.16		0.60						1
Philippines		0.19	0.18		0.62						1
Singapore		0.40	1.28		0.20	0.00	0.03	0.40	0.00	0.57	7, 8
Thailand		0.40	0.64		0.80						1
Viet Nam		0.20	0.53		0.60						1
Southern Asia	**0.12**	**0.21**	**0.50**	**0.60**	**0.74**						
Bangladesh		0.18	0.18		0.95						9
Bhutan			0.53								1
India	0.12	0.17	0.12	0.60	0.70						1
Iran (Islamic Republic of)			0.06								1
Maldives			0.91								10

TABLE 2A.1 (UPDATED) (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA – BY COUNTRY AND REGIONAL AVERAGE

Region/country	MSW [1, 2] Generation Rate IPCC-1996 Values [4] (tonnes/cap/yr)	MSW [1, 2, 3] Generation Rate IPCC-2006 Values [5] (tonnes/cap/yr)	MSW Generation Rate Values [1,2,3] (tonnes/cap/yr)	Fraction of MSW disposed to SWDS IPCC-1996 Values [4]	Fraction of MSW disposed to SWDS IPCC-2006 Values [5]	Fraction of MSW disposed to SWDS		Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified [6]	Source
						Open dumped	Disposed to landfills				
Year	1990	2000	2010	1990	2000	2010	2010	2010	2010	2010	
Nepal		0.18	0.04		0.40						1
Pakistan			0.31								1
Sri Lanka		0.32	1.86		0.90						1
Western Asia			**0.69**			**0.11**	**0.68**	**0.08**	**0.01**	**0.12**	
Armenia			0.25			0.00	1.00	0.00	0.00	0.00	1
Bahrain			0.40								1
Cyprus		0.68	0.69		1.00	0.00	0.86	0.00	0.00	0.14	11
Georgia			0.62								1
Israel			0.62			0.00	0.89	0.00	0.00	0.11	4
Jordan			0.38			0.00	0.85	0.00	0.00	0.15	1
Kuwait			3.05			0.00	0.75	0.00	0.00	0.25	3
Lebanon			0.43			0.37	0.46	0.00	0.08	0.09	1
Oman			0.26								12
Qatar			1.25								3
Saudi Arabia			0.47								12
State of Palestine			0.38			0.00	0.29	0.69	0.00	0.02	3
Syrian Arab Republic			0.50			0.60	0.23	0.00	0.04	0.13	1, 12

TABLE 2A.1 (UPDATED) (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA – BY COUNTRY AND REGIONAL AVERAGE

Region/country	MSW [1, 2] Generation Rate IPCC-1996 Values [4] (tonnes/cap/yr)	MSW [1, 2, 3] Generation Rate IPCC-2006 Values [5] (tonnes/cap/yr)	MSW Generation Rate Values [1,2,3] (tonnes/cap/yr)	Fraction of MSW disposed to SWDS IPCC-1996 Values [4]	Fraction of MSW disposed to SWDS IPCC-2006 Values [5]	Fraction of MSW disposed to SWDS		Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified [6]	Source
						Open dumped	Disposed to landfills				
Year	1990	2000	2010	1990	2000	2010	2010	2010	2010	2010	
Turkey		0.50	0.41		0.99	0.00	0.84	0.00	0.01	0.16	11
United Arab Emirates			0.61								1
Africa											
Northern Africa		**0.29**	**0.41**		**0.69**	**0.79**	**0.17**	**0.00**	**0.00**	**0.04**	
Algeria			0.44			0.97	0.00	0.00	0.01	0.02	1
Egypt			0.50		0.70						1
Morocco			0.53			0.95	0.01	0.00	0.00	0.04	1
Sudan		0.29	0.29		0.82						1
Tunisia			0.30			0.45	0.50	0.00	0.00	0.05	1
Eastern Africa		**0.29**	**0.29**		**0.69**	**0.98**	**0.00**	**0.00**	**0.01**	**0.01**	
Burundi			0.20								1
Comoros			0.81								1
Eritrea			0.18								1
Ethiopia			0.11								13
Kenya			0.11								1
Madagascar			0.29			0.96	0.00	0.00	0.04	0.00	1
Malawi			0.18								1

TABLE 2A.1 (UPDATED) (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA – BY COUNTRY AND REGIONAL AVERAGE

Region/country	MSW [1, 2] Generation Rate IPCC-1996 Values [4] (tonnes/cap/yr)	MSW [1, 2, 3] Generation Rate IPCC-2006 Values [5] (tonnes/cap/yr)	MSW Generation Rate Values [1,2,3] (tonnes/cap/yr)	Fraction of MSW disposed to SWDS IPCC-1996 Values [4]	Fraction of MSW disposed to SWDS IPCC-2006 Values [5]	Fraction of MSW disposed to SWDS		Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified [6]	Source
						Open dumped	Disposed to landfills				
Year	1990	2000	2010	1990	2000	2010	2010	2010	2010	2010	
Mauritius			0.31			0.98	0.00	0.00	0.00	0.02	1, 3
Mozambique			0.05								1
Réunion			0.69								3
Rwanda			0.19								1
Seychelles			1.09								1
Uganda			0.12			1.00	0.00	0.00	0.00	0.00	1
United Republic of Tanzania			0.09								1
Zambia			0.08								1
Zimbabwe			0.19								1
Middle Africa		**0.29**	**0.19**		**0.69**	**0.95**	**0.00**	**0.00**	**0.00**	**0.05**	
Angola			0.18								1
Cameroon			0.28			0.95	0.00	0.00	0.00	0.05	1, 14
Central African Republic			0.18								1
Chad			0.18								1
Congo			0.18								1
Democratic Republic of the Congo			0.18								1

TABLE 2A.1 (UPDATED) (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA – BY COUNTRY AND REGIONAL AVERAGE

Region/country	MSW [1, 2] Generation Rate IPCC-1996 Values [4] (tonnes/cap/yr)	MSW [1, 2, 3] Generation Rate IPCC-2006 Values [5] (tonnes/cap/yr)	MSW Generation Rate Values [1,2,3] (tonnes/cap/yr)	Fraction of MSW disposed to SWDS IPCC-1996 Values [4]	Fraction of MSW disposed to SWDS IPCC-2006 Values [5]	Fraction of MSW disposed to SWDS		Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified [6]	Source
						Open dumped	Disposed to landfills				
Year	1990	2000	2010	1990	2000	2010	2010	2010	2010	2010	
Gabon			0.16								1
Sao Tome and Principe			0.18								1
Southern Africa		**0.29**	**0.33**		**0.69**						
Botswana			0.38								1
Lesotho			0.18								1
Namibia			0.18								1
South Africa			0.73	1.00	0.90						1
Swaziland			0.19								1
Western Africa		**0.29**	**0.18**		**0.69**	**0.00**	**0.64**	**0.00**	**0.00**	**0.36**	
Benin			0.20								1
Burkina Faso			0.19								1
Cabo Verde			0.18								1
Côte d'Ivoire			0.18								1
Gambia			0.19								1
Ghana			0.03								1
Mali			0.24								15
Mauritania			0.18								1

TABLE 2A.1 (UPDATED) (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA – BY COUNTRY AND REGIONAL AVERAGE

Region/country	MSW [1, 2] Generation Rate IPCC-1996 Values [4] (tonnes/cap/yr)	MSW [1, 2, 3] Generation Rate IPCC-2006 Values [5] (tonnes/cap/yr)	MSW Generation Rate Values [1,2,3] (tonnes/cap/yr)	Fraction of MSW disposed to SWDS IPCC-1996 Values [4]	Fraction of MSW disposed to SWDS IPCC-2006 Values [5]	Fraction of MSW disposed to SWDS		Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified [6]	Source
						Open dumped	Disposed to landfills				
Year	1990	2000	2010	1990	2000	2010	2010	2010	2010	2010	
Niger			0.18			0.00	0.64	0.00	0.00	0.36	1
Nigeria			0.20		0.40						16
Senegal			0.19								1
Sierra Leone			0.16								17
Togo			0.19								1
Europe											
Eastern Europe		**0.38**	**0.37**		**0.90**	**0.00**	**0.71**	**0.06**	**0.04**	**0.19**	
Belarus			0.38								3
Bulgaria		0.52	0.55		1.00	0.00	0.74	0.00	0.00	0.26	11
Czechia		0.33	0.32		0.75	0.00	0.65	0.15	0.02	0.18	11
Hungary		0.45	0.40		0.92	0.00	0.70	0.10	0.04	0.16	11
Poland		0.32	0.32		0.98	0.00	0.62	0.00	0.07	0.31	11
Romania		0.36	0.31		1.00	0.00	0.76	0.00	0.10	0.14	11
Russian Federation	0.32	0.34	0.34	0.94	0.71						1
Slovakia		0.32	0.32		1.00	0.00	0.77	0.11	0.03	0.09	11
Northern Europe		**0.64**	**0.48**		**0.47**	**0.00**	**0.47**	**0.20**	**0.09**	**0.24**	
Denmark	0.46	0.67	0.76	0.20	0.10	0.00	0.03	0.48	0.18	0.31	11
Estonia		0.44	0.31		0.98	0.00	0.66	0.00	0.08	0.26	11

TABLE 2A.1 (UPDATED) (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA – BY COUNTRY AND REGIONAL AVERAGE

Region/country	MSW [1, 2] Generation Rate IPCC-1996 Values [4] (tonnes/cap/yr)	MSW [1, 2, 3] Generation Rate IPCC-2006 Values [5] (tonnes/cap/yr)	MSW Generation Rate Values [1,2,3] (tonnes/cap/yr)	Fraction of MSW disposed to SWDS IPCC-1996 Values [4]	Fraction of MSW disposed to SWDS IPCC-2006 Values [5]	Fraction of MSW disposed to SWDS		Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified [6]	Source
						Open dumped	Disposed to landfills				
Year	1990	2000	2010	1990	2000	2010	2010	2010	2010	2010	
Finland	0.62	0.50	0.47	0.77	0.61	0.00	0.45	0.22	0.13	0.20	11
Iceland		1.00	0.48		0.86	0.00	0.72	0.08	0.05	0.15	11
Ireland	0.31	0.60	0.62	1.00	0.89	0.00	0.53	0.04	0.04	0.40	11
Latvia		0.27	0.32		0.92	0.00	0.91	0.00	0.01	0.09	11
Lithuania		0.31	0.40		1.00	0.00	0.86	0.00	0.02	0.12	11
Norway	0.51	0.62	0.47	0.75	0.55	0.00	0.06	0.50	0.16	0.28	11
Sweden	0.37	0.43	0.44	0.44	0.23	0.00	0.01	0.51	0.14	0.34	11
United Kingdom and Northern Ireland	0.69	0.57	0.51	0.90	0.82	0.00	0.46	0.13	0.15	0.26	11
Southern Europe		**0.52**	**0.47**		**0.85**	**0.00**	**0.76**	**0.04**	**0.03**	**0.17**	
Bosnia and Herzegovina			0.33			0.00	0.82	0.00	0.00	0.18	11
Croatia			0.38		1.00	0.00	0.94	0.00	0.01	0.05	11
Greece	0.31	0.41	0.53	0.93	0.91	0.00	0.83	0.00	0.02	0.15	11
Italy	0.34	0.50	0.55	0.88	0.70	0.00	0.46	0.17	0.12	0.25	11
Malta		0.48	0.60		1.00	0.00	0.91	0.00	0.00	0.09	11
Montenegro			0.54			0.00	0.88	0.00	0.00	0.12	11
Portugal	0.33	0.47	0.52	0.86	0.69	0.00	0.62	0.19	0.07	0.11	11

TABLE 2A.1 (UPDATED) (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA – BY COUNTRY AND REGIONAL AVERAGE

Region/country	MSW [1, 2] Generation Rate IPCC-1996 Values [4] (tonnes/cap/yr)	MSW [1, 2, 3] Generation Rate IPCC-2006 Values [5] (tonnes/cap/yr)	MSW Generation Rate Values [1,2,3] (tonnes/cap/yr)	Fraction of MSW disposed to SWDS IPCC-1996 Values [4]	Fraction of MSW disposed to SWDS IPCC-2006 Values [5]	Fraction of MSW disposed to SWDS		Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified [6]	Source
						Open dumped	Disposed to landfills				
Year	1990	2000	2010	1990	2000	2010	2010	2010	2010	2010	
Serbia			0.36			0.00	0.71	0.00	0.00	0.29	11
Slovenia		0.51	0.49		0.90	0.00	0.57	0.01	0.02	0.40	11
Spain	0.36	0.60	0.51	0.85	0.68	0.00	0.62	0.09	0.12	0.18	11
Republic of Macedonia			0.35			0.00	1.00	0.00	0.00	0.00	11
Western Europe	**0.45**	**0.56**	**0.59**	**0.57**	**0.47**	**0.00**	**0.08**	**0.40**	**0.21**	**0.31**	
Austria	0.34	0.58	0.56	0.40	0.30	0.00	0.03	0.35	0.32	0.30	11
Belgium	0.40	0.47	0.46	0.43	0.17	0.00	0.02	0.40	0.21	0.37	11
France	0.47	0.53	0.53	0.46	0.43	0.00	0.31	0.34	0.17	0.18	11
Germany	0.36	0.61	0.60	0.66	0.30	0.00	0.00	0.37	0.17	0.46	11
Luxembourg	0.49	0.66	0.68	0.35	0.27	0.00	0.18	0.36	0.19	0.27	11
Netherlands	0.58	0.62	0.57	0.67	0.11	0.00	0.02	0.49	0.24	0.25	11
Switzerland	0.40	0.40	0.71	0.23	1.00	0.00	0.00	0.50	0.17	0.34	11
America											
Caribbean		**0.49**	**0.78**		**0.83**	**0.03**	**0.78**	**0.00**	**0.01**	**0.18**	
Anguilla			1.10			0.00	1.00	0.00	0.00	0.00	3
Antigua and Barbuda			1.39			0.00	1.00	0.00	0.00	0.00	3
Bahamas		0.95	1.19		0.70						1
Barbados			1.73								1

TABLE 2A.1 (UPDATED) (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA – BY COUNTRY AND REGIONAL AVERAGE

Region/country	MSW [1, 2] Generation Rate IPCC-1996 Values [4] (tonnes/cap/yr)	MSW [1, 2, 3] Generation Rate IPCC-2006 Values [5] (tonnes/cap/yr)	MSW Generation Rate Values [1,2,3] (tonnes/cap/yr)	Fraction of MSW disposed to SWDS IPCC-1996 Values [4]	Fraction of MSW disposed to SWDS IPCC-2006 Values [5]	Fraction of MSW disposed to SWDS		Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified [6]	Source
						Open dumped	Disposed to landfills				
Year	1990	2000	2010	1990	2000	2010	2010	2010	2010	2010	
Cuba		0.21	0.30		0.90	0.00	0.84	0.00	0.11	0.04	1
Dominica			0.32			0.00	1.00	0.00	0.00	0.00	1, 3
Dominican Republic		0.25	0.43		0.90						1
Grenada			0.99			0.00	0.90	0.00	0.00	0.10	1
Guadeloupe			0.60								3
Haiti			0.37			0.24	0.00	0.00	0.00	0.76	1
Jamaica			0.07			0.00	1.00	0.00	0.00	0.00	1
Saint Kitts and Nevis			1.99			0.00	1.00	0.00	0.00	0.00	1
Saint Lucia		0.55	0.25		0.83	0.00	1.00	0.00	0.00	0.00	3
Saint Vincent and the Grenadines			0.35			0.00	0.85	0.00	0.00	0.15	3
Trinidad and Tobago			0.58			0.06	0.00	0.00	0.00	0.94	1
Central America		**0.21**	**0.55**		**0.50**	**0.13**	**0.62**	**0.00**	**0.00**	**0.25**	
Belize			1.05			0.00	1.00	0.00	0.00	0.00	1
Costa Rica		0.17	0.50			0.22	0.72	0.00	0.00	0.06	1

TABLE 2A.1 (UPDATED) (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA – BY COUNTRY AND REGIONAL AVERAGE

Region/country	MSW [1, 2] Generation Rate IPCC-1996 Values [4] (tonnes/cap/yr)	MSW [1, 2, 3] Generation Rate IPCC-2006 Values [5] (tonnes/cap/yr)	MSW Generation Rate Values [1,2,3] (tonnes/cap/yr)	Fraction of MSW disposed to SWDS IPCC-1996 Values [4]	Fraction of MSW disposed to SWDS IPCC-2006 Values [5]	Fraction of MSW disposed to SWDS		Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified [6]	Source
						Open dumped	Disposed to landfills				
Year	1990	2000	2010	1990	2000	2010	2010	2010	2010	2010	
El Salvador			0.41								1
Guatemala		0.22	0.73		0.40	0.00	0.22	0.00	0.00	0.78	1
Honduras		0.15	0.53		0.40						1
Mexico		0.31	0.34			0.00	0.96	0.00	0.00	0.04	4
Nicaragua		0.28	0.40		0.70	0.34	0.28	0.00	0.00	0.38	1
Panama			0.44			0.20	0.56	0.00	0.00	0.24	1
South America		**0.26**	**0.43**		**0.54**	**0.43**	**0.40**	**0.00**	**0.00**	**0.18**	
Argentina		0.28	0.37		0.59						18
Bolivia		0.16	0.12		0.70						1
Brazil		0.18	0.31		0.80						3
Chile			0.35			0.00	1.00	0.00	0.00	0.00	4
Colombia		0.26	0.35		0.31	0.54	0.46	0.00	0.00	0.00	1
Ecuador		0.22	0.41		0.40						1
French Guiana			0.37								3
Guyana			1.95			0.37	0.59	0.00	0.00	0.04	1
Paraguay		0.44	0.08		0.40	0.42	0.44	0.00	0.00	0.14	1
Peru		0.20	0.37		0.53	0.19	0.66	0.00	0.00	0.15	1
Suriname			0.50			1.00	0.00	0.00	0.00	0.00	1

TABLE 2A.1 (UPDATED) (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA – BY COUNTRY AND REGIONAL AVERAGE

Region/country	MSW [1, 2] Generation Rate IPCC-1996 Values [4] (tonnes/cap/yr)	MSW [1, 2, 3] Generation Rate IPCC-2006 Values [5] (tonnes/cap/yr)	MSW Generation Rate Values [1,2,3] (tonnes/cap/yr)	Fraction of MSW disposed to SWDS IPCC-1996 Values [4]	Fraction of MSW disposed to SWDS IPCC-2006 Values [5]	Fraction of MSW disposed to SWDS		Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified [6]	Source
						Open dumped	Disposed to landfills				
Year	1990	2000	2010	1990	2000	2010	2010	2010	2010	2010	
Uruguay		0.26	0.04		0.72	0.32	0.03	0.00	0.00	0.66	1
Venezuela		0.33	0.42		0.50	0.59	0.00	0.00	0.00	0.41	1
Northern America	**0.70**	**0.65**	**0.96**	**0.69**	**0.58**	**0.00**	**0.22**	**0.26**	**0.13**	**0.38**	
Bermuda			1.30			0.00	0.12	0.68	0.18	0.02	3
Canada	0.66	0.49	0.85	0.75	0.71	0.00	0.00	0.00	0.12	0.88	1
United States of America	0.73	1.14	0.74	0.62	0.55	0.00	0.54	0.12	0.08	0.26	4
Oceania											
Australia and New Zealand	**0.47**	**0.69**	**0.60**	**1.00**	**0.85**	**0.00**	**0.69**	**0.04**	**0.00**	**0.27**	
Australia	0.46	0.69	0.61	1.00	1.00	0.00	0.52	0.08	0.00	0.40	4
New Zealand	0.49		0.58	1.00	0.70	0.00	0.85	0.00	0.00	0.15	1, 4
Melanesia			**1.18**								
Fiji			0.77								1
Solomon Islands			1.57								1
Vanuatu			1.20								1
Polynesia			**1.35**								
Tonga			1.35								1

TABLE 2A.1 (UPDATED) (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA – BY COUNTRY AND REGIONAL AVERAGE

[1] Data are based on weight of wet waste. Blank cells mean that no data is available for the country, regional data may be used in this case.

[2] To obtain the total waste generation in the country, the per-capita values should be multiplied with the population whose waste is collected. For developing countries in italics in the table, the waste generation rates should be multiplied by the urban population only.

[3] The data are default data for the year 2010, although for some countries the year for which the data are applicable was not given in the reference, or data for the year 2010 were not available. The year for which the data are collected is given below with source of the data, where available.

[4] Values shown in this column are the ones included in the *Revised 1996 IPCC Guidelines.*

[5]Values shown in this column are the ones included in the *2006 IPCC Guidelines.*

[6] Other, unspecified, includes data on recycling for some countries.

Source: 1. Hoornweg *et al*. 2012; 2. Hoornweg *et al*. 2005; 3. UNSD 2017; 4. OECD 2017; 5. The Ministry of Environment of Korea, 2011; 6. Saeed *et al.* 2009; 7. Singapore Department of Statistics 2017; 8. National Environment Agency of Singapore 2010; 9. SAARC Workshop 2004; 10. UNEP 2002; 11. Eurostat 2017; 12. UNEP 2003; 13. Tadesse *et al.* 2008; 14. Parrot *et al.* 2009; 15. Samake, *et al*. 2009; 16. Solomon 2009; 17. Vanguard 2007; 18. The Ministry of Environment and Sustainable Development of Argentina, 2012.

Annex 2A.2 (New) Waste composition–by country and regional averages

TABLE 2A.2 (NEW)
WASTE COMPOSITION – BY COUNTRY AND REGIONAL AVERAGES

Countries	Food waste	Garden (yard) and park waste	Paper and cardboard	Wood	Textiles	Nappies (disposable diapers)	Rubber and leather	Plastics	Metal	Glass (and pottery and china)	Other	Sources
Asia												
Central Asia	**30.0**	**1.4**	**24.7**	**2.5**	**3.5**	**0**	**0**	**8.4**	**0.8**	**5.9**	**23.0**	
Kazakhstan	21.5	2.8	26.5	0.0	7.0	0.0	0.0	16.8	1.5	11.8	11.9	1, 2
Uzbekistan	38.4	0	22.8	4.9							34.0	3
Eastern Asia	**40.3**	**0.0**	**20.4**	**2.1**	**1.0**	**0.0**	**0.0**	**6.5**	**2.7**	**4.3**	**22.9**	
China	59.1	0.0	8.5	1.6	4.1	0.0	0.0	13.0	1.1	4.1	8.5	4-9
Japan	26.0	0.0	46.0	0.0	0.0	0.0	0.0	9.0	8.0	7.0	4.0	9
Mongolia	70.8	0.0	4.3	0.0	0.0	0.0	0.0	3.8	0.1	3.7	17.3	10, 11
Republic of Korea	5.2	0.0	22.6	6.6	0.0	0.0	0.0	0.0	1.7	2.3	61.7	9, 12
South-Eastern Asia	**49.9**	**1.0**	**11.2**	**0.8**	**0.4**	**0.0**	**0.0**	**10.2**	**4.2**	**3.7**	**18.6**	
Cambodia	65.0		4.0					13.0	1.0	5.0	12.0	9
Indonesia	74.0	0.0	10.0	0.0	2.0	0.0	0.0	8.0	2.0	2.0	2.0	9, 13
Lao People's Democratic Republic	54.3	0.0	3.3	0.0	0.0	0.0	0.0	7.8	3.8	8.5	22.3	9, 13
Malaysia	32.4	0.0	20.0	0.0	0.0	0.0	0.0	9.8	2.5	3.3	32.0	9, 13-18
Myanmar	80.0		4.0					2.0			14.0	9
Philippines	41.6	0.0	19.5	0.0	0.0	0.0	0.0	13.8	4.8	2.5	17.8	9, 13
Singapore	10.1	4.1	15.1	6.8	1.9	0.0	0.4	10.5	18.6	0.9	31.4	19
Thailand	48.6	0.0	14.6	0.0	0.0	0.0	0.0	13.9	3.6	5.1	14.2	9, 13, 20
Viet Nam	42.7	5.0	10.7	0.0	0.0	0.0	0.0	12.9	1.1	5.8	21.9	9, 13, 21

TABLE 2A.2 (NEW) (CONTINUED)
WASTE COMPOSITION – BY COUNTRY AND REGIONAL AVERAGES

Countries	Food waste	Garden (yard) and park waste	Paper and cardboard	Wood	Textiles	Nappies (disposable diapers)	Rubber and leather	Plastics	Metal	Glass (and pottery and china)	Other	Sources
Southern Asia	**66.1**	**0.0**	**9.2**	**0.0**	**1.2**	**0.0**	**0.4**	**7.0**	**0.9**	**1.5**	**13.9**	
Bangladesh	54.9	0.0	12.6	0.0	4.7	0.0	1.5	14.7	1.6	1.1	8.8	4
India	53.0	0.0	6.4	0.0	0.0	0.0	0.0	5.1	0.2	0.4	35.0	4, 23-27
Nepal	80.0	0.0	7.0	0.0	0.0	0.0	0.0	2.5	0.5	3.0	7.0	4, 13, 28
Sri Lanka	76.4	0.0	10.6	0.0	0.0	0.0	0.0	5.7	1.3	1.3	4.7	4, 29, 30
Western Asia	**42.2**	**3.2**	**15.3**	**0.8**	**3.0**	**0.4**	**0.3**	**17.2**	**2.5**	**3.4**	**11.8**	
Cyprus	34.2	13.1	22.5	0	0	0	0	6.7	0.8	5.3	17.4	31
Iraq	54.8	0.0	7.0	2.6	3.5	0.0	0.5	25.2	3.0	2.9	0.4	32
Jordan	52.0	0.0	13.0	0.0	0.0	0.0	0.0	17.0	1.0	3.0	14.0	33
Oman	8.2	6.1	19.4	1.4	14.3	0.0	0.0	31.3	2.6	2.9	13.8	34
Saudi Arabia	48.0	0.0	21.0	1.0	0.0	0.0	0.0	13.0	6.0	4.0	7.0	35
State of Palestine	56.6	0.0	7.3	0.0	0.0	0.0	0.0	14.0	2.4	2.0	17.7	36, 37
Turkey	48.7	6.8	8.1	0.0	2.9	2.9	0.0	5.9	1.4	3.4	19.9	38
United Arab Emirates	35.4	0.0	24.3	1.0	3.2	0.0	1.7	24.2	2.4	3.4	4.4	39
Africa												
Northern Africa	**50.4**	**0.0**	**12.1**	**0.0**	**5.8**	**0.0**	**0.0**	**13.8**	**4.4**	**3.3**	**10.5**	
Libya	36.3	0.0	15.3	0.0	11.5	0.0	0.0	18.6	6.7	3.5	8.0	40
Tunisia	64.4	0.0	8.9	0.0	0.0	0.0	0.0	8.9	2.0	3.0	12.9	40

TABLE 2A.2 (NEW) (CONTINUED)
WASTE COMPOSITION – BY COUNTRY AND REGIONAL AVERAGES

Countries	Food waste	Garden (yard) and park waste	Paper and cardboard	Wood	Textiles	Nappies (disposable diapers)	Rubber and leather	Plastics	Metal	Glass (and pottery and china)	Other	Sources
Eastern Africa	**44.4**	**6.9**	**10.4**	**0.5**	**3.0**	**0.0**	**0.4**	**8.0**	**2.6**	**2.1**	**21.7**	
Kenya	64.4	0.0	5.9	0.0	0.0	0.0	0.0	11.9	1.0	2.0	14.9	4
Mauritius	29.4	34.7	14.1	0.0	2.4	0.0	0.0	11.7	2.0	1.2	4.4	4
United Republic of Tanzania	57.1	0.0	10.9	2.4	6.7	0.0	0.0	9.3	1.9	3.2	8.4	41
Zambia	39.0	0.0	3.0	0.0	0.0	0.0	0.0	7.0	1.0	2.0	48.0	4
Zimbabwe	32.0	0.0	18.0	0.0	6.0	0.0	2.0	0.0	7.0	2.0	33.0	42
Middle Africa	**28.4**	**0**	**8**	**0**	**1.3**	**0**	**0**	**7.1**	**1.4**	**1.1**	**52.7**	
Cameroon	28.4	0.0	8.0	0.0	1.3	0.0	0.0	7.1	1.4	1.1	52.7	43-45, 97
Southern Africa	**24.0**	**0.0**	**14.5**	**0.0**	**5.5**	**0.0**	**0.0**	**26.5**	**6.5**	**9.0**	**14.0**	
South Africa	24	0	14.5	0	5.5	0	0	26.5	6.5	9	14	46
Western Africa	**53.9**	**0.0**	**7.5**	**0.0**	**1.9**	**0.0**	**0.0**	**6.4**	**2.7**	**1.3**	**26.5**	
Ghana	73.0	0.0	8.0	0.0	4.0	0.0	0.0	8.0	0.0	0.0	7.0	21, 47
Mali	25.0	0.0	4.8	0.0	0.0	0.0	0.0	2.4	4.8	1.2	61.9	4，48
Nigeria	63.6	0.0	9.7	0.0	1.6	0.0	0.0	8.7	3.2	2.6	10.6	49, 50-53
Europe												
Eastern Europe	**31.8**	**2.4**	**17.1**	**2.5**	**3.1**	**0.1**	**0.5**	**4.6**	**0.7**	**1.8**	**35.3**	
Bulgaria	18.7	10.0	13.4	1.7	3.6	0.0	1.9	0.0	0.0	0.0	50.8	54
Czechia	35.0	0.0	16.0	13.0	8.0	0.0	0.0	0.0	0.0	0.0	28.0	55
Hungary	29.0	0.0	15.0	0.0	0.0	0.0	0.0	17.0	2.0	2.0	35.0	7
Poland	35.9	0.3	14.7	0.6	3.7	0.0	0.0	0.0	0.0	0.0	44.8	56, 57, 58
Republic of Moldova	29.2	0.0	10.1	0.0	1.6	0.0	0.0	12.8	1.5	5.7	39.0	59

TABLE 2A.2 (NEW) (CONTINUED)
WASTE COMPOSITION – BY COUNTRY AND REGIONAL AVERAGES

Countries	Food waste	Garden (yard) and park waste	Paper and cardboard	Wood	Textiles	Nappies (disposable diapers)	Rubber and leather	Plastics	Metal	Glass (and pottery and china)	Other	Sources
Romania	43.5	5.3	10.3	1.7	0.0	0.0	0.0	0.0	0.0	0.0	39.2	60, 61
Russian Federation	30.2	0	42.5	1.5	4.0	0	0	0	0	0	21.8	62
Ukraine	33.1	3.8	14.6	1.7	4.0	1.1	1.7	6.9	2.0	6.9	24.2	63, 64
Northern Europe	**30.3**	**5.2**	**13.8**	**1.8**	**3.2**	**1.2**	**0.0**	**4.9**	**1.4**	**4.3**	**34.0**	
Denmark	41.0	4.1	23.2	0.0	0.0	0.0	0.0	9.2	3.3	2.9	16.3	65
Estonia	26.0	12.0	20.0	3.0	2.0	0.0	0.0	9.0	4.0	6.0	18.0	66
Finland	35.1	8.8	20.8	2.2	1.7	0.0	0.0	7.9	0.0	0.5	23.0	36
Iceland	41.2	1.4	10.3	3.0	3.5	5.1	0.0	0.0	0.0	0.0	35.4	68
Latvia	0.0	0.0	6.4	2.1	0.0	0.0	0.0	8.5	2.4	20.6	60.0	69
Lithuania	25.5	0.0	5.7	1.2	7.2	0.0	0.0	0.0	0.0	0.0	60.4	70
Sweden	43.0	10.0	10.0	1.0	8.0	3.0	0.0	0.0	0.0	0.0	25.0	71
Southern Europe	**35.8**	**1.4**	**21.4**	**1.2**	**2.8**	**1.1**	**0.2**	**14.1**	**2.0**	**3.5**	**16.7**	
Croatia	30.9	5.7	23.2	1.0	3.7	4.0	0.7	22.9	2.1	3.7	2.3	72
Greece	43.1	0.0	22.6	1.0	3.3	0.0	0.0	11.1	3.2	4.2	11.5	73, 74
Italy	12.6	0.0	39.2	0.0	0.0	0.0	0.0	27.6	2.4	5.9	12.3	75
Portugal	31.8	0.0	10.0	0.7	8.1	0.0	0.0	12.5	1.6	3.2	32.2	7, 76, 77
Serbia	44.3	0.0	13.0	0.0	4.5	4.0	0.4	13.9	1.4	4.2	14.4	78, 79
Slovenia	31.8	2.0	22.6	5.6	0.0	0.0	0.0	0.0	0.0	0.0	38.0	80
Spain	56.2	1.8	19.0	0.0	0.0	0.0	0.0	10.7	3.0	3.3	6.0	81
Western Europe	**33.2**	**2.7**	**17.2**	**2.3**	**5.9**	**3.0**	**0.0**	**20.5**	**1.5**	**1.4**	**12.3**	
United Kingdom of Great Britain and Northern Ireland	21.3	3.5	18.3	5.3	5.6	3.1	0.0	18.0	3.7	3.0	18.2	82-85

TABLE 2A.2 (NEW) (CONTINUED)
WASTE COMPOSITION – BY COUNTRY AND REGIONAL AVERAGES

Countries	Food waste	Garden (yard) and park waste	Paper and cardboard	Wood	Textiles	Nappies (disposable diapers)	Rubber and leather	Plastics	Metal	Glass (and pottery and china)	Other	Sources
Ireland	17.0	4.5	19.8	0.0	23.4	6.3	0.0	0.0	0.0	0.0	29.1	86
France	18.8	4.0	14.9	4.0	3.0	6.9	0.0	21.8	0.0	0.0	26.7	87
Germany	63.2	0.0	15.5	0.0	5.0	0.0	0.0	10.4	2.8	3.1	0.0	88
Luxembourg	45.5	5.0	8.9	5.0	1.0	5.0	0.0	29.7	0.0	0.0	0.0	89
Netherlands	35.0	0.0	26.0	0.0	0.0	0.0	0.0	19.0	4.0	4.0	12.0	90
Switzerland	31.5	1.7	17.2	1.8	3.2	0.0	0.0	44.6	0.0	0.0	0.0	91
America												
Center American	**62.7**	**0.0**	**12.6**	**0.3**	**2.2**	**0.0**	**0.0**	**10.3**	**2.7**	**3.3**	**6.0**	
Jamaica	62.0	0.0	15.0	1.0	5.0	0.0	0.0	12.0	2.0	3.0	0.0	92
Mexico	51.4	0.0	13.6	0.0	1.5	0.0	0.0	10.7	5.1	5.8	12.0	92
Nicaragua	74.8	0.0	9.1	0.0	0.0	0.0	0.0	8.1	1.0	1.0	6.1	4
Southern America	**54.1**	**3.3**	**12.4**	**0.0**	**1.7**	**1.9**	**0.6**	**13.7**	**2.0**	**3.0**	**7.2**	
Brazil	53.5	0.0	17.6	0.0	0.0	0.0	0.0	17.5	2.2	4.0	5.3	4, 93, 94
Argentina	38.8	10.0	13.7		5.0	5.7	1.9	14.6	1.8	3.1	5.3	95
Peru	70.0	0.0	6.0	0.0	0.0	0.0	0.0	9.0	2.0	2.0	11.0	4
Northern America	**20.2**	**6.8**	**23.3**	**4.1**	**3.9**	**0**	**1.6**	**15.8**	**6.4**	**4.2**	**14.0**	
Canada	18.8	5.6	32.3	0.0	0.0	0.0	0.0	13.1	3.4	3.1	23.7	7
United States of America	21.6	7.9	14.3	8.1	7.7	0.0	3.1	18.5	9.4	5.2	4.2	4, 96, 97, 98

TABLE 2A.2 (NEW) (CONTINUED)
WASTE COMPOSITION – BY COUNTRY AND REGIONAL AVERAGES

Countries	Food waste	Garden (yard) and park waste	Paper and cardboard	Wood	Textiles	Nappies (disposable diapers)	Rubber and leather	Plastics	Metal	Glass (and pottery and china)	Other	Sources
Australia and New Zealand	**25.9**	**12.2**	**12.0**	**6.5**	**2.95**	**3.5**	**0.0**	**8.3**	**1.8**	**2.8**	**24.1**	
Australia	35.0	16.5	13.0	1.0	0	4.0	0	16.7	3.6	5.6	4.6	99, 100
New Zealand	16.8	7.9	10.9	11.9	5.9	3.0	0.0	0.0	0.0	0.0	43.6	101

Sources：

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CHAPTER 5

INCINERATION AND OPEN BURNING OF WASTE

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5 INCINERATION AND OPEN BURNING OF WASTE

Users are expected to go to Mapping Tables in Annex 1, before reading this chapter. This is required to correctly understand both the refinements made and how the elements in this chapter relate to the corresponding chapter in the 2006 IPCC Guidelines.

5.1 INTRODUCTION

Thermal treatments of waste are classified into incineration, pyrolysis, gasification, plasma, and open burning of waste. Pyrolysis, gasification, and plasma are regarded as new technologies for treating solid wastes. In Chapter 5, Volume 5 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines*), the new technologies are not included. These new technologies have been applied worldwide and have become important in some countries. The refinement in this chapter provides CH_4 and N_2O emission factors of pyrolysis-melting and gasification-melting plant for treating municipal solid waste (MSW) to be used in their emission estimates. This chapter updates the oxidation factor for open burning of MSW from experiment data including uncertainty.

Waste incineration is defined as the combustion of solid and liquid waste in controlled incineration facilities. Modern refuse combustors have tall stacks and specially designed combustion chambers, which provide high combustion temperatures, long residence times, and efficient waste agitation while introducing air for more complete combustion. Types of waste incinerated include MSW, industrial waste, hazardous waste, clinical waste and sewage sludge1. The practice of MSW incineration is currently more common in developed countries, while it is common for both developed and developing countries to incinerate clinical waste.

Pyrolysis is defined as a reduction process that thermochemically converts organic materials into gas and liquid products mainly containing hydrocarbon components and a solid residue with higher carbon content at elevated temperatures in the absence of oxygen (Box 5.0a New).

Gasification is a process that converts organic materials mainly into carbon monoxide, hydrogen, and carbon dioxide at temperatures above 700℃ with different ratios of gasifying agent such as steam, carbon dioxide, oxygen, and air. The resulting gas mixture is called as synthesis gas (syngas), mainly used as fuel and/or chemical feedstock (Box 5.0b New).

Plasma is defined as a partial oxidation process of reacting organic materials in an oxygen starved environment at high temperature to produce gas and solid products. The highly reactive plasma zone consists largely of electrons, ions, and excited molecules along with high energy radiation. In a plasma zone, organic materials are cracked to high portion of gas products such as carbon dioxide, water, carbon monoxide, hydrogen, and light hydrocarbons along with low quantities of inorganic solid product (slag and metals) (Box 5.0c New).

The new technologies have been mostly applied to produce fuels and chemical feedstocks from waste tires and plastics, and they are also applied to treat MSW to avoid the generations of air pollutants that would arise from conventional MSW incineration. Although many pyrolysis, gasification, and plasma plants have been applied to treat wastes, many plants have been closed due to some technical problems as well as high cost. Rising environmental standards and clean energy demands have recently revived the interest in the new technologies and then new plants are getting installed in developed countries. However, few official data for the emissions of greenhouse gases are available for the new technologies. Especially, greenhouse gas emission data from plasma technology are rarely found.

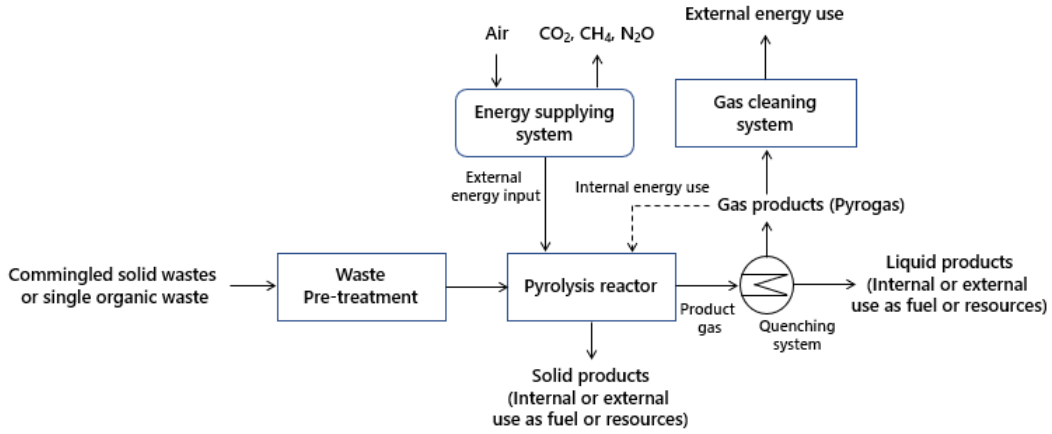
Since gas products generated from the new technologies are usually collected and used mostly as fuel or chemical feedstock, direct emissions of CH_4 and N_2O from the new technologies are expected to be quite low unless gas products containing CH_4 and N_2O are intentionally vented to the atmosphere. If the gas products would be combusted to supply energy to inside processes, the emissions of CH_4 and N_2O are reported under the Energy Sector. On the other hand, the emissions of CH_4 and N_2O in gas products are reported under the Waste Sector provided that the gas products would be released to the atmosphere. If gas, liquid, and solid products generated from the new technologies would be exported outside for their use or disposal, the emissions of

[1] Waste generation, composition and management practices, including waste incineration and open burning, are addressed in detailin Chapter 2 of this volume.

greenhouse gases are not reported as those from the new technologies themselves, but at the point of their use or disposal.

BOX 5.0A (NEW)
PYROLYSIS

Pyrolysis is a reductive and endothermic reaction to convert carbonaceous substances into lower molecular weight compounds by applying external energy. The more energy is applied, the smaller size compounds are produced. CH_4 is one of the smallest compounds generated from pyrolysis process of carbonaceous substances. Pyrolysis of organic wastes is normally operated at temperature ranges between 300 and 700°C. The pyrolysis process can be shown as below:



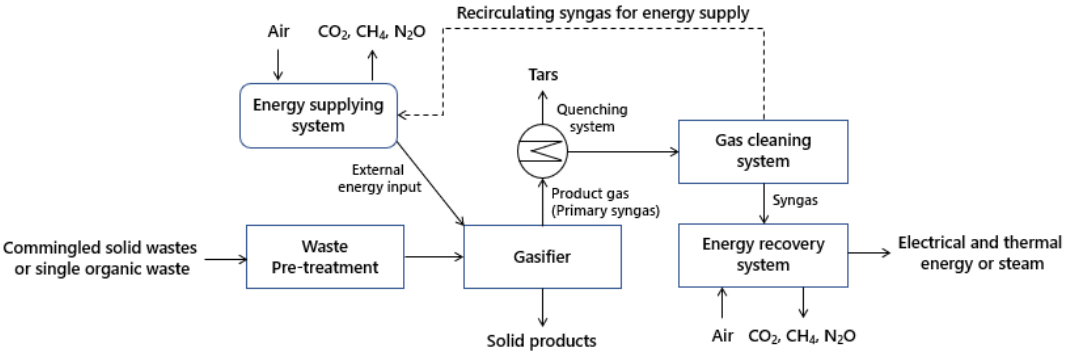
Solid wastes or single organic wastes (e.g., plastic and wood) are pre-treated (e.g., drying and pulverizing, etc.) to satisfy technical requirements for the succeeding pyrolysis reaction. Combustible components of solid wastes are thermally decomposed in pyrolysis reactor to produce gases and solid residues. The product gas is composed of condensable and non-condensable fraction which are separated into gas and liquid products, respectively, by a quenching process. The gas products mainly composed of volatile organic compounds (e.g., CH_4, C_2H_6, etc.), H_2, CO, and CO_2. Liquid products are composed of various aliphatic and aromatic compounds. Solid products include carbon residues (char) and inorganic components. The solid products may be combusted in situ for energy recovery within pyrolysis process or transferred outside for energy and/or chemical feedstock use. The gas products (pyrogases) are combusted in energy supplying system to provide energy to the pyrolysis reactor or transferred outside for energy or chemical feedstock use. The external energy-supplying system to the pyrolysis reactor is considered as the only emission source of greenhouse gases in the pyrolysis plant. The emissions of greenhouse gases from the energy-supplying system within the pyrolysis plant are reported under the Energy Sector. If pyrolysis products would be exported outside for their use or disposal, the emissions of greenhouse gases are not reported as those from the pyrolysis plant, but at the point of their use or disposal.

BOX 5.0B (NEW)
GASIFICATION

Gasification is a conversion process of carbonaceous substances to gas fuel with a high heating value. Depending upon reaction condition, gasification of solid wastes is accounted for by four primary reactions: partial oxidation reaction, Boudouard reaction, water gas reaction, and methanation reaction.

- partial oxidation reaction: $C + 1/2O_2 \rightarrow CO$
- Boudouard reaction: $C + CO_2 \leftrightarrow 2CO$
- water gas shift reaction: $C + H_2O \leftrightarrow CO + H_2$
- methanation reaction: $2C + 2H_2O \rightarrow CH_4 + CO_2$

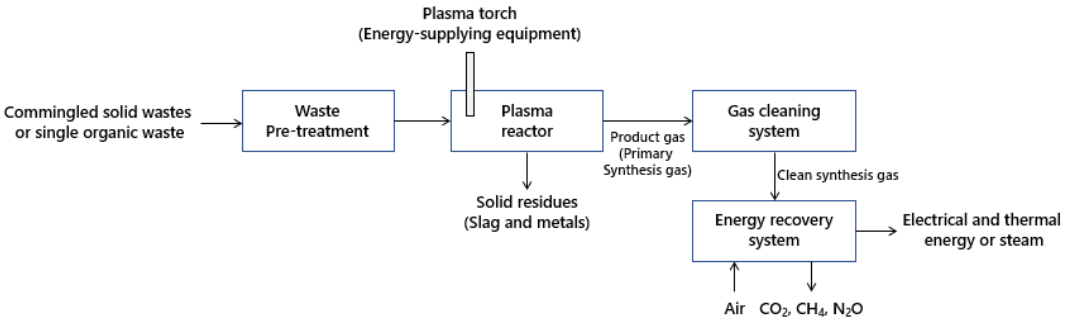
The above gasification reactions reveal that the product gas primarily consists of H_2, CO, and CH_4 and is referred to as synthesis gas (syngas). Solid wastes or single organic wastes (e.g., plastic and wood) are pre-treated (e.g., drying and pulverizing, etc.) to answer technical requirements for the subsequent gasification reaction. The gasification of combustible components of solid wastes produces the primary syngas. The gas cleaning system after the gasifier removes acid gases, fine particulates, heavy metals, and moistures from the primary syngas. The clean syngas may be used as fuel for generating electrical and thermal energy or steam or exported to other processes for energy and/or chemical feedstock use. Some portion of clean syngas can be supplied to energy supplying system within the gasification plant to provide the energy to gasifier. The gasification of combustible components of solid wastes produces syngas together with liquid and solid products. Liquid products separated from product gas by a quenching process are known as tars, which are mainly composed of polyaromatic compounds, while the solid products are represented by inorganic components and a little carbon residue.



Since syngas generated from gasification process is used in situ and/or outside for fuel, CH_4 emissions are rarely expected during the gasification process. It is noted that syngas may be vented directly to atmosphere despite of its rare occurrence. The external energy-supplying system to the gasifier is considered as the only emission source of greenhouse gases in the gasification plant. The emissions of greenhouse gases from the energy-supplying system within the gasification plant are reported under the Energy Sector. If gasification products would be exported outside for their use or disposal, the emissions of greenhouse gases are not reported as those from the gasification plant, but at the point of their use or disposal.

BOX 5.0C (NEW)
PLASMA

Plasma technology is regarded as an advanced and pure gasification process. Since plasma processes are operated at extremely high temperatures in an oxygen deficient condition, combustible components of solid wastes can be nearly completely converted into syngas. Reaction residues of plasma process consist of inorganic components including slag and metals. Primary syngas is produced in plasma rector where one or more plasma arc torches are installed for plasma generation. The primary syngas is treated by gas cleaning system to produce clean syngas.



Since syngas generated from plasma process may be used in situ as fuel or exported to another process for energy and/or chemical feedstock use, CH_4 emissions are rarely expected from the plasma process itself. It is noted that syngas may be vented directly to atmosphere despite of its rare occurrence. The external energy-supplying system to the plasma reactor is considered as the only emission source of greenhouse gases in the plasma plant. The emissions of greenhouse gases from the energy recovery system within the plasma plant are reported under the Energy Sector. If syngas would be exported outside for its use, the emissions of greenhouse gases are not reported as those from the plasma plant, but at the point of its use.

Emissions of greenhouse gases from thermal treatment of waste include incineration, pyrolysis, gasification, plasma and open burning without energy recovery are reported in the Waste Sector, while those with energy recovery are reported in the Energy Sector, both with a distinction between fossil and biogenic carbon dioxide (CO_2) emissions. The methodology described in Chapter 5, Volume 5 of the *2006 IPCC Guidelines* is applicable in general both to incineration with and without energy recovery. In this refinement, emission factors of CH_4 and N_2O emissions from new technologies emitted directly to the atmosphere are provided. Co-firing of specific waste fractions with other fuels is not addressed in this chapter, as co-firing is covered in Volume 2, Energy. Emissions from agricultural residue burning are considered in the AFOLU Sector, Chapter 5 of Volume 4.

Open burning of waste can be defined as the combustion of unwanted combustible materials such as paper, wood, plastics, textiles, rubber, waste oils and other debris in nature (open-air) or in open dumps, where smoke and other emissions are released directly into the air without passing through a chimney or stack. Open burning can also include incineration devices that do not control the combustion air to maintain an adequate temperature and do not provide sufficient residence time for complete combustion. This waste management practice is used in many developing countries while in developed countries open burning of waste may either be strictly regulated, or otherwise occur more frequently in rural areas than in urban areas.

Incineration and open burning of waste are sources of greenhouse gas emissions, like other types of combustion. Relevant gases emitted include CO_2, methane (CH_4) and nitrous oxide (N_2O). Normally, emissions of CO_2 from waste incineration are more significant than CH_4 and N_2O emissions.

Consistent with the *1996 Guidelines* (IPCC, 1997), only CO_2 emissions resulting from oxidation, during incineration and open burning of carbon in waste of fossil origin (e.g., plastics, certain textiles, rubber, liquid solvents, and waste oil) are considered net emissions and should be included in the national CO_2 emissions estimate. The CO_2 emissions from combustion of biomass materials (e.g., paper, food, and wood waste) contained in the waste are biogenic emissions and should not be included in national total emission estimates. However, if incineration of waste is used for energy purposes, both fossil and biogenic CO_2 emissions should be estimated. Only fossil CO_2 should be included in national emissions under Energy Sector while biogenic CO_2 should be reported as an information item also in the Energy Sector. Moreover, if combustion, or any other factor, is causing long term decline in the total carbon embodied in living biomass (e.g., forests), this net release of carbon should be evident in the calculation of CO_2 emissions described in the Agriculture, Forestry and Other Land Use (AFOLU) Volume of the *2006 Guidelines*.

Guidance on methodological choices for estimating and reporting CO_2, CH_4 and N_2O emissions from incineration and open burning reported in Chapter 5, Volume 5 of the *2006 IPCC Guidelines* are valid to estimate CH_4 and N_2O from new technologies. This refinement provides guidance on choice of CH_4 and N_2O emission factors for pyrolysis and gasification for specific type of plant.

Traditional air pollutants from combustion - non-methane volatile organic compounds (NMVOCs), carbon monoxide (CO), nitrogen oxides (NO_x), sulphur oxides (SO_x) - are covered by existing emission inventory systems. Therefore, the IPCC does not provide new methodologies for these gases here, but recommends that national experts or inventory compilers use existing published methods under international agreements. Some key examples of the current literature providing methods include EMEP/CORINAIR Guidebook (EMEP 2004), US EPA's Compilation of Air Pollutant Emissions Factors, AP-42, Fifth Edition (US EPA, 1995), EPA Emission Inventory Improvement Program Technical Report Series, Vol. III Chapter 16: Open Burning (US EPA, 2001).

The estimation of indirect N_2O emissions, resulting from the conversion of nitrogen deposition to soils due to NO_x emissions from waste incineration and open burning, is addressed in Section 5.4.3 of this chapter. General background and information on the reporting of the indirect N_2O emissions is given in Chapter 7, Precursors and Indirect Emissions, of Volume 1, General Guidance and Reporting.

5.2 METHODOLOGICAL ISSUES

The choice of method will depend on national circumstances, including whether incineration and open burning of waste are *key categories* in the country, and to what extent country- and plant-specific information is available or can be gathered.

For waste incineration, the most accurate emission estimates can be developed by determining the emissions on a plant-by-plant basis and/or differentiated for each waste category (e.g., MSW, sewage sludge, industrial waste, and other waste including clinical waste and hazardous waste). The methods for estimating CO_2, CH_4 and N_2O emissions from incineration and open burning of waste vary because of the different factors that influence emission levels. Estimation of the amount of fossil carbon in the waste burned is the most important factor determining the CO_2 emissions. The non-CO_2 emissions are more dependent on the technology and conditions during the incineration process.

Intentional burning of waste on solid waste disposal sites is sometimes used as a management practice in some countries. Emissions from this practice and those from unintentional fires (accidental fires on solid waste disposal sites) should be estimated and reported according to the methodology and guidance provided for open burning of waste.

The general approach to calculate greenhouse gas emissions from incineration and open burning of waste is to obtain the amount of dry weight of waste incinerated or open-burned (preferably differentiated by waste type) and to investigate the related greenhouse gas emission factors (preferably from country-specific information on the carbon content and the fossil carbon fraction). For CO_2 emissions from incineration and open burning of waste, the basic approach is given here as an example of a consecutive approach:

- Identify types of wastes incinerated/open-burned: MSW, sewage sludge, industrial solid waste, and other wastes (especially hazardous waste and clinical waste) incinerated/open-burned.
- Compile data on the amount of waste incinerated/open-burned including documentation on methods used and data sources (e.g., waste statistics, surveys, expert judgement): Regional default data are also provided in Table 2.1 (Updated) in Chapter 2, Waste Generation, Composition and Management Data, and country-specific data for a limited number of countries in Annex 2A.1 (Updated) of this Volume. The default data should be used only when country-specific data are not available. For open burning, the amount of waste can be estimated based on demographic data. This is addressed in Section 5.3.2.
- Use default values provided on dry matter content, total carbon content, fossil carbon fraction and oxidation factor (see Section 5.4.1.3) for different types of wastes: For MSW, preferably identify the waste composition and calculate the respective dry matter content, total carbon content, and fossil carbon fraction using default data provided for each MSW component (plastic, paper, etc) in Section 2.3, Waste composition, of this Volume.
- Calculate the CO_2 emissions from incineration and open burning of solid wastes.
- Provide data in the worksheets given in Annex 1 of this Volume 5 of the *2006 IPCC Guidelines.*

For other waste types and other greenhouse gases, the approach usually does not differentiate as much as for the MSW in terms of waste composition. Detailed guidance on the choice of method, activity data and emission

factors for all major types of waste to estimate the emissions from relevant waste incineration and burning practices is outlined in the following sections.

Methodology from the *2006 IPCC Guidelines* can be used to estimate emission from gasification, pyrolysis and plasma. Emission factors of CH_4 and N_2O from pyrolysis and gasification are provided in new Tables 5.3A and 5.4A.

5.2.1 Choice of method for estimating CO_2 emissions

No refinement.

5.2.1.1 TIER 1

No refinement.

5.2.1.2 TIER 2

No refinement.

5.2.1.3 TIER 3

No refinement.

5.2.1.4 CO_2 EMISSIONS FROM INCINERATION OF FOSSIL LIQUID WASTE

No refinement.

5.2.2 Choice of method for estimating CH_4 emissions

No refinement.

5.2.2.1 TIER 1

No refinement .

5.2.2.2 TIER 2

No refinement.

5.2.2.3 TIER 3

No refinement.

5.2.3 Choice of method for estimating N_2O emissions

No refinement.

5.2.3.1 TIER 1

No refinement.

5.2.3.2 TIER 2

No refinement.

5.2.3.3 TIER 3

No refinement.

5.3 CHOICE OF ACTIVITY DATA

No refinement.

5.3.1 Amount of waste incinerated

No refinement.

5.3.2 Amount of waste open-burned

No refinement.

5.3.3 Dry matter content

No refinement.

5.4 CHOICE OF EMISSION FACTORS

Emission factors in the context of incineration and open burning of waste relate the amount of greenhouse gas emitted to the weight of waste incinerated or open-burned. In the case of CO_2, this applies data on the fractions of carbon and fossil carbon in the waste. For CH_4 and N_2O, this primarily depends on the treatment practice and the combustion technology. For the estimation of CO_2, CH_4 and N_2O emissions from incineration and open burning of waste, guidance on choice of the emission factors is outlined in the following sections.

5.4.1 CO_2 emission factors

It is generally more practical to estimate CO_2 emissions from incineration and open burning of waste using calculations based on the carbon content in the waste, instead of measuring the CO_2 concentration.

Default values for parameters related to emission factors are shown in Table 5.2 (Updated). Each of these factors is discussed in detail in the sections below[2].

TABLE 5.2 (UPDATED)
DEFAULT DATA FOR CO_2 EMISSION FACTORS FOR INCINERATION AND OPEN BURNING OF WASTE

Parameters	Management practice	MSW	Industrial Waste (%)	Clinical Waste (%)	Sewage Sludge (%) Note 4	Fossil liquid waste (%) Note 5
Dry matter content in % of wet weight		see Note 1	NA	NA	NA	NA
Total carbon content in % of dry weight		see Note 1	50	60	30	80
Fossil carbon fraction in % of total carbon content		see Note 2	90	40	0	100
Oxidation factor in % of carbon input	incineration	100	100	100	100	100
	Open- burning (see Note 3,6)	71	NO	NO	NO	NO

NA: Not Available, NO: Not Occurring

Note 1: Use default data from Table 2.4 in Section 2.3 Waste composition and equation 5.8 (for dry matter), Equation 5.9 (for carbon content) and Equation 5.10 (for fossil carbon fraction).

Note 2: Default data by industry type is given in Table 2.5 in Section 2.3 Waste composition. For estimation of emissions, use equations mentioned in Note 1.

Note 3: A default value of 71 percent is provided from the experimental study in Japan. Its uncertainty is +/-8 percent. Reference: Yamada *et al*. (2010)

Note 4: See Section 2.3.2 Sludge in Chapter 2.

Note 5: The total carbon content of fossil liquid waste is provided in percent of wet weight and not in percent of dry weight (GIO, 2005).

References: *GPG2000* (IPCC, 2000), Lead Authors of the *2006 IPCC Guidelines*, Expert judgement.

Note 6: The residue after open-burning contains unburned carbon in the form of ash or other solid residue. The fate of the unburned carbon is to be tracked and the emissions from the disposition of the unburned carbon is to be accounted for in the appropriate category. When open-burning takes place in SWDS, burned fraction of DOC is subtracted from the DOC in SWDS (See Section 3.2.1 of Chapter 3, Volume 5 of the *2006 IPCC Guidelines*). If unburned carbon is placed at the surface of SWDS with aerobic condition, emission is not taken into account. When the condition is regarded as anaerobic by further piling of waste, this fraction is categorised in slowly degrading waste.

5.4.1.1 TOTAL CARBON CONTENT

No refinement.

5.4.1.2 FOSSIL CARBON FRACTION

No refinement.

[2] The parameters total carbon content in percent of dry weight and fossil carbon fraction in percent of total carbon content could be combined to the parameter: fossil carbon content in percent of dry weight.

5.4.1.3 OXIDATION FACTOR

When waste streams are incinerated or open-burned most of the carbon in the combustion product oxidises to CO_2. A minor fraction may oxidise incompletely due to inefficiencies in the combustion process, which leave some of the carbon unburned or partly oxidised as soot or ash. For waste incinerators it is assumed that the combustion efficiencies are close to 100 percent, while the combustion efficiency of open burning is substantially lower. If oxidation factors of waste incineration below 100 percent are applied, these need to be documented in detail with the data source provided. Table 5.2 (Updated) presents updated default oxidation factor for open burning of MSW and total carbon content in percent of dry weight of sewage sludge.

If the CO_2 emissions are determined on a technology- or plant-specific basis in the country, it is *good practice* to use the amount of ash (both bottom ash and fly ash) as well as the carbon content in the ash as a basis for determining the oxidation factor.

The *2006 IPCC Guidelines* provide default oxidation factors for open burning of MSW. This refinement updates the default parameter of oxidation factor from experiment from Japan. The condition of combustion is smouldering with 35 percent of the moisture content. In updated Table 5.2, except the default values of oxidation factor of MSW and total C content in sewage sludge, all values are retrieved from the *2006 IPCC Guidelines*.

5.4.2 CH_4 emission factors

CH_4 emissions from waste incineration are much dependent on the continuity of the incineration process, the incineration technology, and management practices. The most detailed observations have been made in Japan (GIO, 2004), where the following CH_4 emission factors based on technology and operation mode are obtained.

Continuous incineration includes incinerators without daily start-up and shutdown. Batch type and semi-continuous incineration mean that the incinerator is usually started-up and shutdown at least once a day. These differences in operation are at the origin of difference in emission factors. It is sometimes observed that the concentrations of CH_4 in the exhaust gas of the furnace are below the CH_4 concentrations in intake gas of the incinerator (GIO, 2005). Because of the low concentrations and high uncertainties, it is here *good practice* to apply an emission factor of zero (see Section 5.2.2.3).

For continuous incineration of MSW and industrial waste, it is *good practice* to apply the CH_4 emission factors provided in Volume 2, Chapter 2, Stationary Combustion. For other MSW incinerators (semi-continuous and batch type), Table 5.3 shows CH_4 emission factors reported by Greenhouse Gas Inventory Office of Japan (GIO, Japan). The CH_4 emission factors of other industrial waste incinerators are differentiated by waste type, rather than technology (GIO, 2005). In Japan, the CH_4 emission factors of waste oil and of sludge are 0.56 g CH_4/t wet weight and 9.7 g CH_4/t wet weight, respectively.

For open burning of waste, a CH_4 emission factor of 6500 g / t MSW wet weight has been reported (EIIP, 2001). This factor should be applied as a default, unless another CH_4 emission factor seems more appropriate.

If country-specific data are available, these should be applied instead and the method used to derive them as well as the data sources need to be documented in detail.

TABLE 5.3
CH_4 EMISSION FACTORS FOR INCINERATION OF MSW

Type of incineration/technology		CH_4 Emission Factors (kg/Gg waste incinerated on a wet weight basis)
Continuous incineration	stoker	0.2
	fluidised bed [Note1]	~0
Semi-continuous incineration	stoker	6
	fluidised bed	188
Batch type incineration	stoker	60
	fluidised bed	237

Note 1: In the study cited for this emission factor, the measured CH_4 concentration in the exhaust air was lower than the concentration in ambient air.

Source: Greenhouse Gas Inventory Office of Japan, GIO 2004.

This refinement presents the emission factors of CH_4 for new technologies of pyrolysis and gasification. Although a plenty of information on CH_4 emissions from the pyrolysis and gasification of solid wastes are available from scientific research literatures (Box 5.2 (New)), very few data are obtainable for commercial plants of new technologies. Table 5.3a (New) shows the CH_4 emission factors of MSW from a combined system of pyrolysis-melting and gasification-melting processes on a commercial scale (Box 5.3 (New)). In commercially operated pyrolysis-melting and gasification-melting plants, condensable and non-condensable gases including CH_4 generated from the pyrolysis and gasification reactor are mostly oxidized at the subsequent melting furnace, leading to the low CH_4 emissions from the stack. If country-specific data are unavailable for pyrolysis-melting and gasification-melting plants, it is *good practice* to apply the default CH_4 emission factor corresponding to reactor type for both pyrolysis-melting and gasification-melting plants. The emissions of greenhouse gases from the combined system with energy recovery system are reported under the Energy Sector.

TABLE 5.3A (NEW)
CH_4 EMISSION FACTORS FOR PYROLYSIS-MELTING AND GASIFICATION-MELTING PLANT OF MSW

Process	Operating temperature (°C)	CH_4 Emission Factors (g/t waste on a wet basis)	Reactor Type
Pyrolysis-melting and gasification-melting	Pyrolysis: 300 ~ 600°C Gasification: 700~900°C Melting: 1300~1700°C	5.81[1,2] (n=11)	Shaft type
		9.70[1] (n=10)	Fluidized bed type
		5.40[1] (n=5)	Rotary kiln type

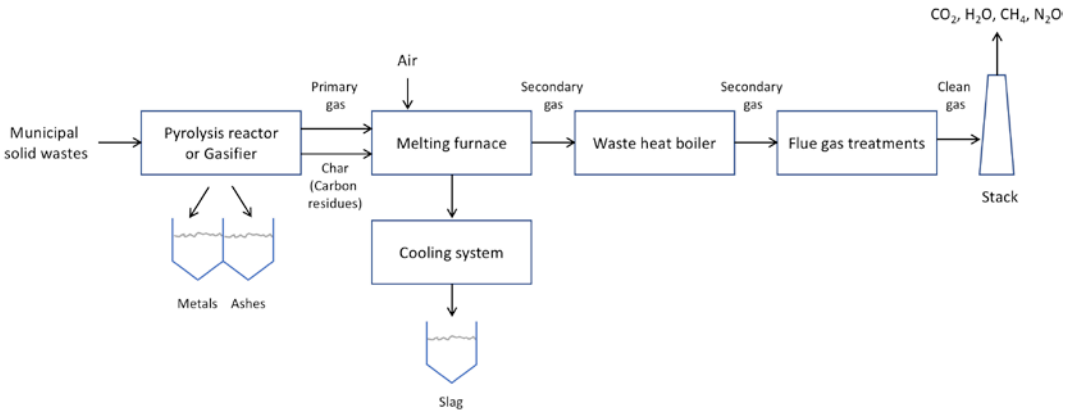
[1]Ministry of the Environment, Japan (2010)
[2]Lee *et al*. (2015)

BOX 5.2 (NEW)
INFORMATION ON CH_4 EMISSION FACTORS IN LABORATORY SCALE

A plenty of information on CH_4 emission from pyrolysis and gasification process in laboratory scale are available for various waste types and reaction conditions. According to the scientific research literatures (Rahman *et al.* 2001, He *et al.* 2010, and Wu *et al*. 2016), CH_4 emission from the pyrolysis and gasification process of solid wastes are dependent on the types of waste and technology as well as the operating conditions. CH_4 emissions from the pyrolysis and gasification process of solid wastes increase with increasing operating temperature. The higher pyrolysis temperature can supply more energy to break down the high-molecular-weight components of solid organic wastes into low-molecular-weight compounds such as CH_4.

BOX 5.3 (NEW)
COMBINED SYSTEM

For MSW treatment, a combined system of two processes was mostly introduced. The first process of the combined system is either pyrolysis or gasification, whereas the second one is represented by melting process.



In the first reactor where pyrolysis or gasification occurs, MSW are thermally decomposed to yield the primary gas with high heating values and carbon residues (char) in the absence of oxygen or oxygen starved environment. The primary gas and char are transported to the melting furnace operating at high temperatures (>1000°C) under oxidation conditions. Primary gas and char are oxidized to produce the secondary gas at the melting furnace. After removing the air pollutants from the secondary gas, the flue gas mainly composed of CO_2 and H_2O is emitted to the air through the stack. Since pyrogas and syngas generated from pyrolysis and gasification, respectively, are mostly oxidized at the melting furnace, the emissions of greenhouse gases from the stack is expected to be negligibly low.

5.4.3 N_2O emission factors

Nitrous oxide emissions from waste incineration are determined by a function of the type of technology and combustion conditions, the technology applied for NOx reduction as well as the contents of the waste stream. As a result, emission factors can vary from site to site.

Several countries have reported N_2O emissions from waste incineration in their national inventory reports. Table 5.4 shows examples of emission factors that have been used for incineration of MSW.

The differences in the emission factors are mainly caused by varying technologies in the context of NO_x removal.

TABLE 5.4 N2O EMISSION FACTORS FOR INCINERATION OF MSW				
Country	**Type of Incineration / Technology**		**Emission factor for MSW (g N_2O/t MSW incinerated)**	**Weight basis**
Japan[1]	Continuous incineration	Stocker	47	wet weight
		Fluidised bed	67	wet weight
	Semi-continuous incineration	Stocker	41	wet weight
		Fluidised bed	68	wet weight
	Batch type incineration	Stocker	56	wet weight
		Fluidised bed	221	wet weight
Germany[2]			8	wet weight
Netherlands[3]			20	wet weight
Austria[4]			12	wet weight

1 GIO, 2005.
2 Johnke 2003.
3 Spakman 2003.
4 Anderl *et al*. 2004.

The emission factors of N_2O for pyrolysis, gasification, and plasma technology of waste vary with types of waste, reactor type, and operating conditions. In this refinement, updated N_2O emissions from pyrolysis-melting and gasification-melting plants for treating MSW are provided.

Since most national regulations for air pollutants rarely require monitoring N_2O emissions from thermal treatment plants of solid wastes, a few official data are available for N_2O emission from pyrolysis, gasification, and plasma plants. Especially, N_2O emission data are unavailable for plasma technology. Table 5.4a (New) indicates the N_2O emissions from pyrolysis-melting and gasification-melting plants of MSW on a commercial-scale basis. The emission factor of N_2O from pyrolysis-melting plant is much lower than that from shaft furnace reactor, indicating that the reactor type plays an important role in N_2O generation. It is also expected that the waste type and operating conditions influence the generation patterns of N_2O. If country-specific data are unavailable for pyrolysis-melting and gasification-melting plants, it is *good practice* to apply the default N_2O emission factor corresponding to reactor type for both pyrolysis-melting and gasification-melting plants.

TABLE 5.4A(NEW) N_2O EMISSION FACTORS FOR PYROLYSIS-MELTING AND GASIFICATION-MELTING PLANT OF MSW			
Process	**Operating temperature (°C)**	**N_2O Emission Factors, (g/t waste on a wet basis)**	**Reactor Type**
Pyrolysis-melting and gasification-melting	Pyrolysis: 300 ~ 600°C Gasification: 700~900°C Melting: 1300~1700°C	17.4[1,2] (n=11)	Shaft type
		5.80[1] (n=10)	Fluidized bed type
		8.38[1,3] (n=6)	Rotary kiln type

[1]Ministry of the Environment, Japan (2010)
[2]Lee *et al*. (2015)
[3]Yoon (2017)

5.5 COMPLETENESS

No refinement.

5.6 DEVELOPING A CONSISTENT TIME SERIES

No refinement.

5.7 UNCERTAINTY ASSESSMENT

No refinement.

5.7.1 Emission factor uncertainties

No refinement.

5.7.2 Activity data uncertainties

No refinement.

5.8 QA/QC, REPORTING AND DOCUMENTATION

5.8.1 Inventory Quality Assurance/Quality Control (QA/QC)

No refinement.

5.8.2 Reporting and Documentation

No refinement.

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CHAPTER 6

WASTEWATER TREATMENT AND DISCHARGE

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6 WASTEWATER TREATMENT AND DISCHARGE

Users are expected to go to Mapping Tables in Annex 1, before reading this chapter. This is required to correctly understand both the refinements made and how the elements in this chapter relate to the corresponding chapter in the 2006 IPCC Guidelines.

6.1 INTRODUCTION

Wastewater can be a source of methane (CH_4) when treated or disposed anaerobically or when dissolved CH_4 enters aerated treatment systems. It can also be a source of nitrous oxide (N_2O) emissions. Carbon dioxide (CO_2) emissions from wastewater are not considered in the IPCC Guidelines because these are generally derived from modern (biogenic) organic matter in human excreta or food waste and should not be included in national total emissions. Appendix 6Ap.1 presents a discussion of non-biogenic (fossil) CO_2 emissions from wastewater treatment and discharge, where fossil organic carbon is present in wastewater or treatment sludge.

Wastewater originates from a variety of domestic, commercial and industrial sources and may be treated on site (uncollected), sewered to a centralised plant (collected) or disposed untreated nearby or via an outfall. Domestic wastewater is defined as wastewater from household water use, while industrial wastewater is from industrial practices only.[1] Treatment and discharge systems can sharply differ between countries and for rural and urban areas. Also, treatment and discharge systems can differ for rural and urban users, and for urban high income and urban low-income users.

Sewer systems may consist of networks of open channels or closed underground pipes. Occasional stagnant conditions and heat provide favourable anaerobic condition for methane generation in closed and open sewers. In urban areas in developing countries and some developed countries, sewer systems may consist of networks of open canals, gutters, and ditches, which are referred to as open sewers. These systems are subject to heating from the sun and the sewers may be stagnant allowing for anaerobic conditions to emit CH_4 (Doorn *et al.* 1997). In most developed countries and in high-income urban areas in other countries, sewers are usually closed and underground. Wastewater in closed underground sewers likely generate CH_4, but there are insufficient data available to quantify the emissions from these collection systems. However, research shows that significant amounts of CH_4 can be formed within closed sewer collection systems and enters centralised wastewater treatment plants (WWTPs) as dissolved CH_4 in the wastewater, where it is then emitted during treatment.

The degree of wastewater treatment varies in most developing countries. In some cases, industrial wastewater is discharged directly into bodies of water, while major industrial facilities may have comprehensive in-plant treatment. Domestic wastewater is treated in centralised plants, pit latrines, septic systems or disposed of in unmanaged lagoons or waterways, via open or closed sewers. In some coastal cities domestic wastewater is discharged directly into the ocean. Pit latrines are lined or unlined holes of up to several metres deep, which may be fitted with a toilet for convenience. The pits are used alternatively, and the contents used as manure after few months' usage.

The most common wastewater treatment methods in developed countries are centralised aerobic wastewater treatment plants and lagoons for both domestic and industrial wastewater. To avoid high discharge fees or to meet regulatory standards, many large industrial facilities pre-treat their wastewater before releasing it into the sewage system. Domestic wastewater may also be treated in on-site septic systems. These are advanced systems that may treat wastewater from one or several households. They consist of an anaerobic underground tank and a drainage field for the treatment of effluent from the tank. Some developed countries continue to dispose of untreated domestic wastewater via an outfall or pipeline into a water body, such as the ocean.

Centralised wastewater treatment methods can be classified as primary, secondary, and tertiary treatment. In primary treatment, physical barriers remove larger solids from the wastewater. Remaining particulates are then allowed to settle. Secondary treatment consists of a combination of biological processes that promote biodegradation of wastewater constituents by microorganisms. Secondary treatment processes include aerobic stabilisation ponds, trickling filters, and activated sludge processes, as well as anaerobic reactors and lagoons. Tertiary treatment processes are used to further purify the wastewater of pathogens, contaminants, and remaining

[1] Because the methodology is on a per person basis, emissions from commercial wastewater are estimated as part of domestic wastewater. To avoid confusion, the term municipal wastewater is not used in this text. Municipal wastewater is a mix of household, commercial and non-hazardous industrial wastewater, treated at wastewater treatment plants.

nutrients such as nitrogen and phosphorus compounds. This is achieved using one or a combination of processes that can include maturation/polishing ponds, biological processes, advanced filtration, carbon adsorption, ion exchange, and disinfection.

Sludge is produced in all of the primary, secondary and tertiary stages of treatment. Sludge that is produced in primary treatment consists of solids that are removed from the wastewater.

Sludge produced in secondary and tertiary treatment results from biological growth in the biomass, as well as the collection of small particles. This sludge must be treated further before it can be safely disposed of. Methods of sludge treatment include aerobic and anaerobic stabilisation (digestion), conditioning, centrifugation, composting, and drying. Some sludge is incinerated before land disposal. Emissions from anaerobic sludge digestion, where the digester's primary use is for treatment of wastewater treatment solids, should be reported under Wastewater Treatment. Land disposal, composting, and incineration of sludge is considered in Volume 5, Section 2.3.2 in Chapter 2, Waste Generation, Composition, and Management Data, Section 3.2 in Chapter 3, Solid Waste Disposal, Section 4.1 in Chapter 4, Biological Treatment and Disposal, and Chapter 5, Incineration and Open Burning of Waste, respectively. N_2O emissions from sludge and wastewater spread on agricultural land are considered in Section 11.2, N_2O emissions from managed soils, in Chapter 11, N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application, in Volume 4 of the Agriculture, Forestry, and Other Land Use (AFOLU) Sector.

Figure 6.1 from the *2006 IPCC Guidelines* has been updated and simplified to show the different pathways for wastewater treatment and discharge, 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 (Updated) 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 CH_4 and N_2O.

Figure 6.1 (Updated) Wastewater treatment systems and discharge pathways

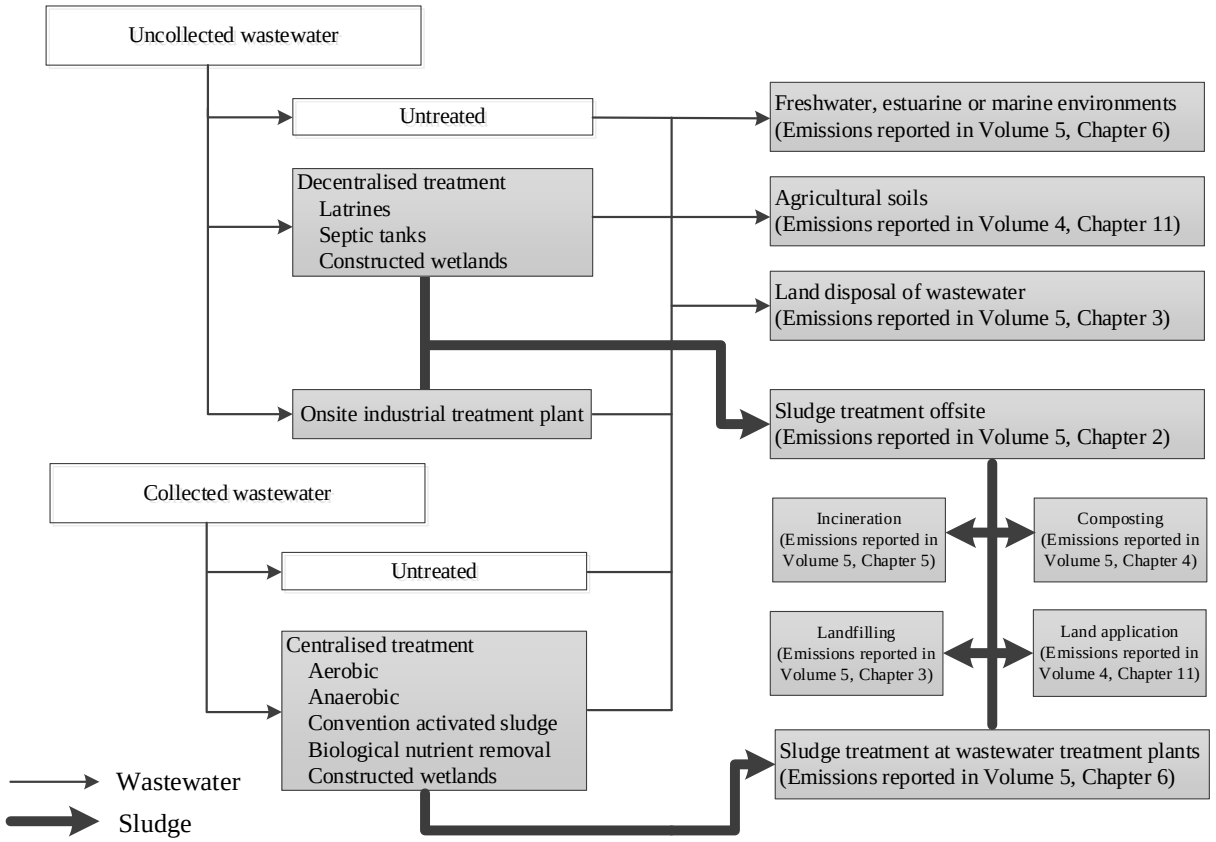


TABLE 6.1 (UPDATED)
CH_4 AND N_2O EMISSION POTENTIALS FOR WASTEWATER AND SLUDGE TREATMENT AND DISCHARGE SYSTEMS

Types of treatment and disposal				CH_4 and N_2O 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_2O.
		Non-aquatic environment (soils)		Emissions are considered in Volume 4 when applied to agricultural land.
Collected	Untreated	Sewers (closed and underground)		Likely source of CH_4/N_2O. However, insufficient data exist to quantify emission factors that address the variation in sewer type and operational conditions.
		Sewers (open)		Stagnant, overloaded open collection sewers or ditches/canals are likely significant sources of CH_4.
	Treated	Aerobic treatment	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_2O.
			Aerobic shallow ponds	Unlikely source of CH_4/N_2O. Poorly designed or managed aerobic systems produce CH_4.
		Anaerobic treatment	Anaerobic lagoons	May be a significant source of CH_4. Insignificant source of N_2O.
			Facultative lagoons[2]	Source of CH_4 from anaerobic layer.
			Constructed wetlands	May be source of CH_4 and N_2O. See *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2014).
			Anaerobic reactors	May be a significant source of CH_4 if emitted CH_4 is not recovered or flared.
		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 or flared. In addition, sludge digestion and handling may be a source of fugitive CH_4 from biogas recovery operations. See Chapter 4 for more details.
			Composting	Emissions are considered in Volume 5, Chapter 4.
			Incineration and open burning	Emissions are considered in Volume 5, Chapter 5.

TABLE 6.1 (UPDATED) (CONTINUED)
CH_4 AND N_2O EMISSION POTENTIALS FOR WASTEWATER AND SLUDGE TREATMENT AND DISCHARGE SYSTEMS

Types of treatment and disposal		CH_4 and N_2O emission potentials
Uncollected	Septic tanks (without dispersion field)	Source of CH_4. Frequent solids removal reduces CH_4 production.
	Septic system (including a septic tank and a soil dispersal system)	Source of CH_4 (tank) and N_2O (soil dispersal system). 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.

[2] 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– the facultative zone–ranges from aerobic near the top to anaerobic at the bottom (US EPA 2002b).

6.1.1 Centralised treatment systems

Centralised wastewater treatment systems may include a variety of treatment processes spanning the hierarchy of treatment levels. 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. In some countries simple disinfection process concludes tertiary treatment; however, elsewhere more advanced tertiary treatment involves the use of enhanced biological nutrient removal processes (nitrification–denitrification), and other advanced physical and chemical processes.

Wastewater treatment processes can range from simple technologies such as lagooning and wetlands, to more technologically advanced treatment technology designed for stringent nutrient removal. Wetlands can be constructed or semi-natural systems and 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 through a combination of biodegradation, volatilisation, sorption and sedimentation process (IPCC 2014).

Sewer collection systems provide an environment conducive to the formation of CH_4, 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 CH_4 formed with the collection system enters the centralised system where it contributes to CH_4 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 receiving environments. Microorganisms can biodegrade soluble organic material in wastewater under aerobic and/or anaerobic conditions, where the latter condition produces CH_4. 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.

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, proteins, and ammonia. Ammonia N is converted to nitrate (NO_3^-) through the aerobic process of nitrification. Denitrification occurs under anoxic/anaerobic conditions, whereby aerobic or facultative organisms reduce oxidized forms of nitrogen (e.g., nitrite, nitrate) in the absence of free oxygen to produce nitrogen gas (N_2). N_2O is an intermediate product of both nitrification and denitrification processes. 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.

CH_4 generated in the sewer system enters the treatment plant as dissolved methane and is emitted during turbulent/aerated treatment steps (Daelman *et al.* 2012). 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 (Willis 2017). In addition, anaerobic conditions can form within the treatment system increasing the potential for CH_4 generation from an otherwise aerobic system. These refinements introduce a new MCF associated with these systems, as well as a revised N_2O emission factor for centralised wastewater treatment systems.

Occasionally wastewater treatment plants could be hydraulically or organically overloaded, resulting in degraded plant performance. In these cases, organic matter and nutrients that would normally be removed by the treatment system instead pass through untreated and are discharged to the aquatic environment. The *2006 IPCC Guidelines* previously 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.

6.1.2 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.

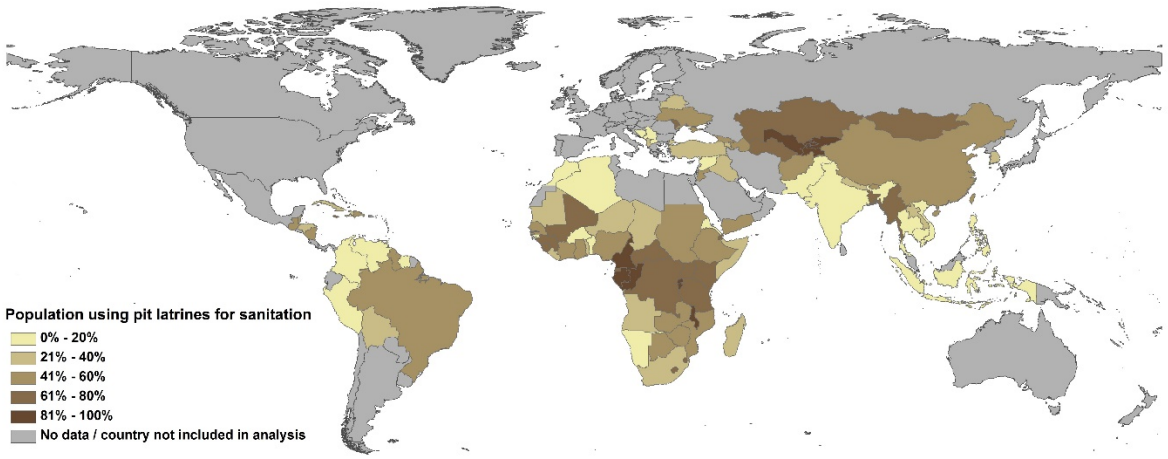
A septic system is usually composed of a septic tank, generally buried in the ground, and a soil dispersal system. Solids and dense materials contained in the incoming wastewater (influent) settle in the septic tanks as sludge. Floatable material (scum) is also retained in the tank. The sludge settled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

A latrine usually consists of a slab over a pit which may be two metres or more in depth. A wide range of configuration options exists for latrines (simple pit latrines, ventilated latrines, composting latrines, etc.) having in common that little (e.g., pour flush latrines) or no water is used to flush excreta into the pit. Pit latrines are utilised by more than 1.5 billion people throughout the world, especially in low-income countries (see new Figure 6.1a and new Annex 6A.1). Pit latrine gaseous emissions depend in part on local groundwater level. Anaerobic conditions favourable to CH_4 emissions occur when the water table is high and the organic waste in the pit is submerged.

In the absence of latrines, people resort to open defecation. Open defecation is not considered as a source of CH_4, as anaerobic conditions are considered unlikely.

In some high-income countries, onsite aerated wastewater treatment systems are used and enable a more advanced level of treatment than septic tanks in reducing the load of organics and nutrients in 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.

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



6.1.3 Emissions from receiving waters

Dissolved CH_4 and N_2O that is generated in sewers, or present in untreated or 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 CH_4 and N_2O has been observed (e.g., Smith *et al.* 2017). Therefore, where wastewater is then discharged to aquatic environments with nutrient-impacted/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 and are subject to eutrophication as a result. Surface marine waters are typically supersaturated (Ward *et al.* 1987; Conrad & Seiler 1988) and freshwaters highly supersaturated (Stanley *et al.* 2016) with CH_4 irrespective of their trophic state, so this refinement does not distinguish between eutrophic and oligotrophic receiving waters, but it does distinguish between default waters (rivers and streams) and lakes and reservoirs where CH_4 emissions are higher.

6.1.4 Changes compared to *1996 Guidelines and Good Practice Guidance*

No refinement.

6.1.5 Changes compared to 2006 IPCC Guidelines

The *2006 IPCC Guidelines* included combined equations to estimate CH_4 emissions from wastewater and from sludge removed from the wastewater. However, in some cases, this combined equation caused confusion among inventory compilers when calculating CH_4 emissions from aerobic systems with anaerobic sludge digestion. In these cases, some compilers estimated zero CH_4 emissions from well operated wastewater treatment systems, and then subtracted emissions associated with sludge digestion operations without first estimating the CH_4 emissions from sludge treatment, resulting in negative emissions. In this refinement, we discuss the proper way to use the equation in such situations, and we present an update to provide guidance on the calculation of the organic component removed in sludge. Countries must estimate the amount (mass) of sludge they generate from wastewater treatment and default data are provided for a number of countries. With this additional guidance, the use of a default value of zero for sludge removal from aerobic treatment systems and septic systems is no longer applicable.

In addition, certain emission factors for CH_4 emissions from domestic and industrial wastewater treatment have been updated to reflect additional measurement data on emissions from septic systems and centralised WWTPs. Furthermore, the CH_4 emission factors for wastewater discharged to aquatic environments have been updated and a new emission factor for discharge to reservoirs, lakes, and estuaries is introduced. The calculation of CH_4 emissions from effluent discharged to aquatic systems has been updated to include the discharge of treated effluent and to reflect the removal of organics that occurs during treatment.

The *2019 Refinement* also includes new guidance on how to estimate N_2O emissions from domestic and industrial wastewater and presents updated guidance to estimate N_2O emissions from centralised WWTPs. Furthermore, the N_2O emission factors for wastewater discharged to aquatic environments have been updated and the calculation of N_2O emissions from effluent discharged to aquatic systems has been updated to reflect the removal of nitrogen that occurs during treatment.

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 CH_4.

Three tier methods for CH_4 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. The amount of sludge removed for incineration, landfills, composting, and agricultural land should be taken into consideration. In addition, countries that are able to categorize wastewater discharge by the type of waterbody should use Tier 2 emission factors for estimating emissions from discharge.

For a country with good data and advanced methodologies, a country specific method could be applied as a Tier 3 method. For example, a more advanced country-specific method could be based on plant-specific data from large wastewater treatment facilities, using country-specific measurements of organics discharged to aquatic environments, or may draw on country-specific water quality data for aquatic environments receiving wastewater inputs.

Wastewater treatment facilities that receive wastewater from collection systems, particularly pressurized sewers and gravity-fed sewers that are closed, can liberate CH_4 in aerobic systems from dissolved CH_4 that enters the treatment system (Daelman *et al.* 2012; Short *et al.* 2017).

Wastewater treatment facilities can include anaerobic process steps. CH_4 generated at such facilities can be recovered and combusted in a flare or energy device. The amount of CH_4 that is flared or recovered for energy use should be subtracted from total emissions through the use of a separate CH_4 recovery parameter. The amount of CH_4 which is recovered or flared is expressed as R in updated Equation 6.1. R refers to CH_4 recovered from wastewater treatment, such as methane captured on filters exhausted from covered (anaerobic) treatment ponds, as well as CH_4 recovered from anaerobic sludge digestion. The approach to estimation of emissions from wastewater treatment in this chapter covers all emission sources and sinks (recovery) at a wastewater treatment plant.

Note that only a few countries may have sludge removal data and CH_4 recovery data. The information on sludge generation has improved and statistical data on sludge can be found in databases of Eurostat and Organization for Economic Co-operation and Development (OECD). The lack of data for CH_4 recovery was taken into account in this refinement by recommending the use of the methodology in Section 4.1, Chapter 4 of Volume 5, *2006 IPCC Guidelines* which estimates emissions on the basis of total sludge anaerobically digested; thus, the information on R is not required in this calculation. Default sludge removal factors are provided in this refinement. The default for CH_4 recovery is zero. If a country selects to report CH_4 recovery, it is *good practice* to distinguish between flaring and CH_4 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 CO_2 emissions are of biogenic origin, and the CH_4 and N_2O 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.

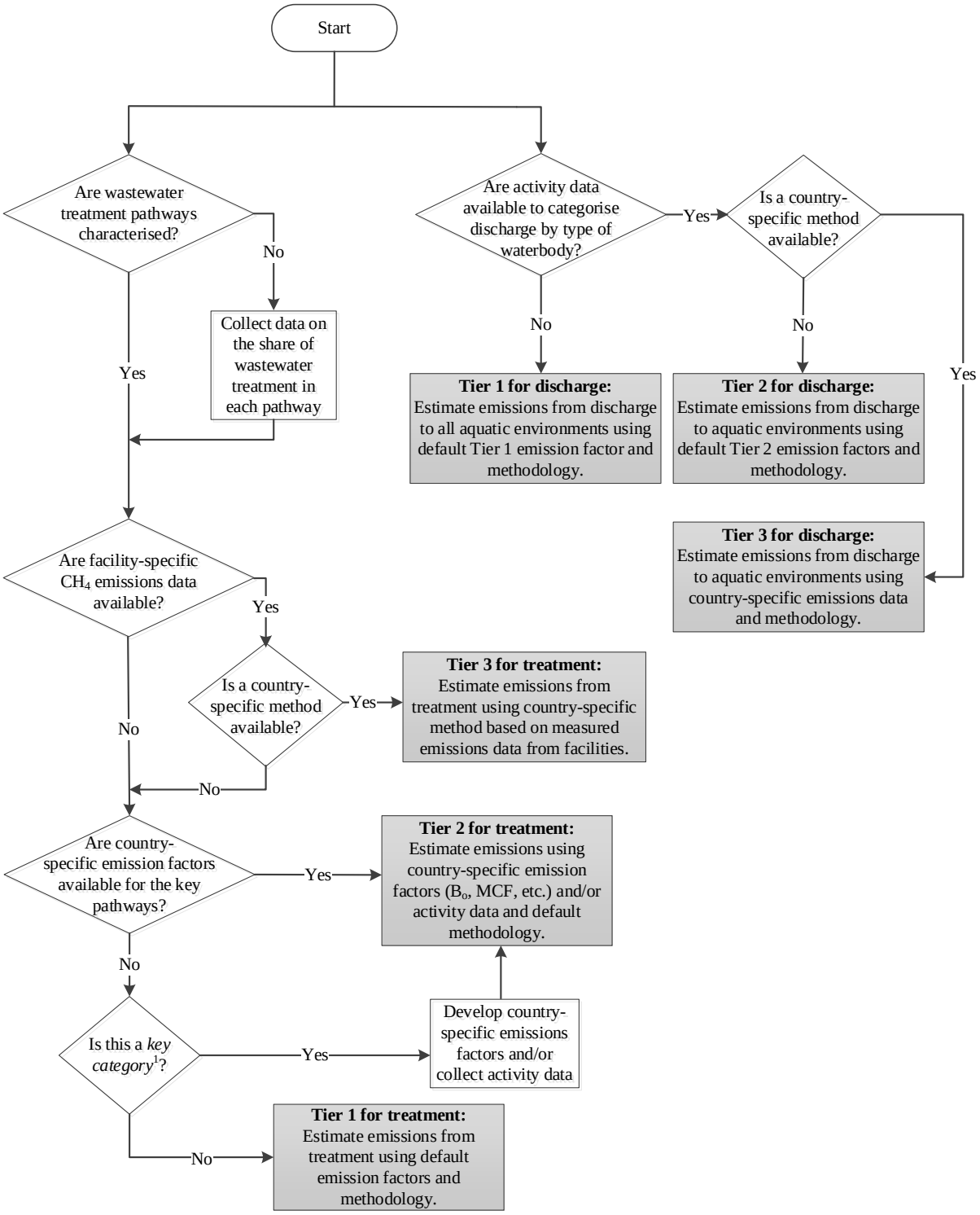
6.2.2 Domestic wastewater

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*. In general, the overall steps for *good practice* in inventory preparation for CH_4 from domestic wastewater have been updated as follows:

Figure 6.2 (Updated) Decision tree for CH_4 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.

Step 1: Use updated Equation 6.3 to estimate organically degradable material TOW in wastewater prior to treatment. Use new Equation 6.3a to estimate total organics in domestic wastewater for each wastewater treatment/discharge pathway or system, *j* (TOW_j). Use new Equation 6.3d to estimate total organics in treated wastewater effluent discharged ($TOW_{EFFtreat}$).

Step 2: Use new Equations 6.3b and 6.3c to estimate the amount of organic component removed in sludge, *S*, from aerobic treatment plants and septic systems.

Step 3: Select the pathway and systems (see updated 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 4: Use updated Equation 6.1 to estimate emissions and adjust for possible sludge removal and/or CH_4 recovery of treatment/discharge pathway or system, *j*, in inventory year. Use new Equation 6.1a to sum the emissions across all treatment/discharge pathways or systems.

Step 5: Use Equation 4.1 and emission factors in Table 4.1 to estimate methane emissions from anaerobic digestion of sludge.

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 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 judgment 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.

These updates are presented because, in some cases, the original Equation 6.1 caused confusion among inventory compilers when calculating CH_4 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.

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 report any CH_4 recovery directly associated with the anaerobic sludge digestion system as a separate pathway using the emissions methodology provided in Table 4.1, Chapter 4 of Volume 5. Net emissions from both systems should be summed together and reported under wastewater treatment and discharge. In no circumstances should a country report negative emissions. As discussed in Chapter 4, the reporting of anaerobic digestion of sludge is under biological treatment only if transferred from the wastewater treatment plant to anaerobic facilities co-digesting sludge with MSW or other waste.

It is important that CH_4 emissions from sludge that is managed using landfills, incineration, composting, biogas production, or used in agriculture are not included in the wastewater treatment and discharge category. The data should be consistent across the sectors, and categories, amount disposed at SWDS, applied to agricultural land, incinerated or used elsewhere should be equal to the amount organic component removed as sludge in updated Equation 6.1. Wastewater and sludge that is applied on agricultural land should be considered in Volume 4 for AFOLU Sector, Section 11.2, N_2O emissions from managed soils, in Chapter 11, N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application.

Wastewater treatment system/pathway usage often differs for rural and urban residents. Also, in developing countries, there are likely to be differences between urban high-income and urban low-income residents. Hence, emissions are calculated by each income group fraction. It is *good practice* to treat the three categories: rural population, urban high-income population, and urban low-income population separately. It is suggested to use a spreadsheet, as shown in Table 6.5.

Equation 6.1 should be used to estimate CH_4 emissions from every treatment system and discharge pathway *j* (hereafter referred to as treatment/discharge pathway or system), presented in Table 6.3 (Updated) that are appropriate for the country, including the discharge of treated or untreated wastewater.

CH_4 emissions from the following discharge pathways must be considered in the inventory for treated and untreated wastewaters (if occurring in the country):

- Discharge to reservoirs, lakes, and estuaries;
- Discharge to aquatic environments other than to reservoirs, lakes, and estuaries;
- Discharge to sewers (with a distinction between stagnant and flowing (open or closed) sewers).

For the discharge of treated wastewater, the TOW should reflect the organics in the wastewater as discharged (see Equation 6.3d (New). As noted in the table, discharges to soil should be reported in Volume 4.

CH_4 emissions from the following wastewater treatment systems must be considered in the inventory (if occurring in the country):

- Centralised, aerobic treatment plant;
- Anaerobic reactor (e.g., upflow anaerobic sludge blanket digestion (UASB));
- Anaerobic lagoons (with a distinction between shallow and facultative lagoons and deep lagoons);
- Constructed wetlands;
- Septic systems (with a distinction between stand-alone septic tanks and septic tanks with land dispersal field);
- Latrines (depending of the climate).

Emissions from anaerobic digestion of wastewater treatment sludge should be estimated using Equation 4.1 and included in the sum of emissions using Equation 6.1A (New). The emission factor used in Equation 4.1 accounts for CH_4 recovery, therefore the amount of methane recovered from anaerobic digestion should not be subtracted.

EQUATION 6.1 (UPDATED)
CH_4 EMISSIONS FROM DOMESTIC WASTEWATER FOR EACH TREATMENT/DISCHARGE PATHWAY OR SYSTEM, *J*

$$CH_4\ Emissions_j = \left[\left(TOW_j - S_j\right) \bullet EF_j - R_j\right]$$

Where:

$CH_4\ Emissions_j$ = CH_4 emissions from treatment/discharge pathway or system, j, in inventory year, kg CH_4/yr

TOW_j = organics in wastewater of treatment/discharge pathway or system, j, in inventory year, kg BOD/yr. See Equation 6.3a.

S_j = organic component removed from wastewater (in the form of sludge) from treatment/discharge pathway or system, j, in inventory year, kg BOD/yr. See Equations 6.3b and 6.3c. For wastewater discharged to aquatic environments, there is no sludge removal ($S_j = 0$) and no CH_4 recovery ($R_j = 0$). For wastewater treatment systems, please see Section 6.2.2.3 for additional guidance on how to estimate S, organic component removed as sludge, if country-specific data are not available.

j = each treatment/discharge pathway or system

EF_j = emission factor for treatment/discharge pathway or system, j, kg CH_4/kg BOD. See Equation 6.2 or updated Table 6.3.

R_j = amount of CH_4 recovered or flared from treatment/discharge pathway or system, j, in inventory year, kg CH_4/yr. Default value is zero.

EQUATION 6.1A (NEW)
TOTAL CH_4 EMISSIONS FROM DOMESTIC WASTEWATER TREATMENT AND DISCHARGE

$$CH_4\ Emissions = \sum_j [CH_4 Emissions_j] \bullet [10^{-6}]$$

Where:

CH_4 Emissions = CH_4 emissions in inventory year, kg CH_4/yr

$CH_4\ Emissions_j$ = CH_4 emissions from treatment/discharge pathway or system, *j*, in inventory year, kg CH_4/yr

j = each treatment/discharge pathway or system

10^{-6} = conversion of kg to Gg

6.2.2.2 CHOICE OF EMISSION FACTORS

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

The emission factor for a wastewater treatment and discharge pathway and system is a function of the maximum CH_4 producing potential (B_o) and the methane correction factor (MCF) for the wastewater treatment and discharge system, as shown in Equation 6.2. The B_o is the maximum amount of CH_4 that can be produced from a given quantity of organics (as expressed in Biochemical Oxygen Demand (BOD) or Chemical Oxygen Demand (COD) in the wastewater and represents the complete conversion of organic C to biogas. The MCF indicates the extent to which the CH_4 producing capacity (B_o) is realised in each type of treatment and discharge pathway and system. Thus, it is an indication of the degree to which the system is anaerobic.

EQUATION 6.2
CH_4 EMISSION FACTOR FOR
EACH DOMESTIC WASTEWATER TREATMENT/DISCHARGE PATHWAY OR SYSTEM

$$EF_j = B_o \bullet MCF_j$$

Where:

EF_j = emission factor, kg CH_4/kg BOD

j = each treatment/discharge pathway or system

B_o = maximum CH_4 producing capacity, kg CH_4/kg BOD

MCF_j = methane correction factor (fraction). See updated Table 6.3.

Table 6.2 includes default maximum CH_4 producing capacity (B_o) for domestic wastewater. 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 based on independent wastewater analyses, they must also update the MCF because the MCFs presented in Table 6.3 were developed using the default B_o values. 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. New Annex 6A.2 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.

TABLE 6.2
DEFAULT MAXIMUM CH_4 PRODUCING CAPACITY (B_o) FOR DOMESTIC WASTEWATER

0.6 kg CH_4/kg BOD
0.25 kg CH_4/kg COD
Based on expert judgment by lead authors and on Doorn *et al*. (1997)

Because the B_o and MCF values must be used together, updated Table 6.3 now also includes the resultant default CH_4 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 (see also new Annex 6A.3).

DISCHARGE FROM TREATED OR UNTREATED SYSTEMS

Updated 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 (Hammer & Hammer Jr. 2012; Tchobanoglous *et al.* 2014), which provides a substrate for the formation of CH_4 in a receiving water body. Furthermore, much of the dissolved CH_4 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 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 CH_4 have been observed (e.g., Smith *et al*. 2017). Despite this relationship, most rivers, estuaries and coastal waters are considerably supersaturated with CH_4, irrespective of their nutrient status (Patra *et al.* 1998; Grunwald *et al.* 2009; Ward *et al.* 2017), while open oceans are slightly supersaturated (Tilbrook & 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 CH_4 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 CH_4 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 CH_4 emissions in freshwater and coastal environments. Recent reviews of measurements of CH_4 generation indicate that a significant proportion of the CH_4 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 new Annex 6A.2), a ratio of 0.938 kg C per kg COD is obtained. Deemer *et al.* (2016) performed an extensive review of measurements of CH_4 and CO_2 originating in aquatic systems, and independent measurements of both CH_4 and CO_2 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 CH_4/kg COD, a Tier 2 MCF of 0.035 is calculated for rivers. Where it is possible to separately identify discharges to slow-flowing systems such as lakes and reservoirs, a Tier 2 MCF of 0.19 is presented (see updated Table 6.3 and new Annex 6A.4).

If countries are not able to collect activity data regarding the distribution of discharge to reservoirs, lakes, and estuaries as compared to discharges to other aquatic environments, they should use the default Tier 1 factors. The default Tier 1 MCF for CH_4 generation for discharges to all aquatic environments is presented as the mean of the two Tier 2 MCFs, or 0.11.

Concerning decentralised treatment systems for domestic wastewater, CH_4 and N_2O emissions from effluent infiltration into soil must be considered.

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 CH_4 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 CH_4 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 CH_4 production becomes unlikely below 12°C. Inside septic tanks, the temperature is uncontrolled and is related to atmospheric temperature as well as volumes of household hot and cold water used and discharged. There may also be a gradient of temperature inside the septic tank, with warmer conditions at the bottom (sludge layer) and colder at the top (Leverenz *et al.* 2010). Therefore, in countries having seasonal temperature variability, when the temperature in septic tanks cools, the rate of digestion slows, the SRT increases, sludge accumulates, and CH_4 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 CH_4 emissions increase. This situation can produce a 'spring boil' phenomenon, wherein warmer weather conditions give rise to increased anaerobic microbial activity, increased gas production, and decreased solids removal efficiency due to the resuspension of settled and incoming solids. Accordingly, there is a seasonal variability of CH_4 emissions (Leverenz *et al.* 2010); however, at this time, insufficient data exist to establish a temperature-dependent emission factor associated with these systems. Countries that experience significant seasonal temperature variations may wish to consider the development of a country-specific emission factor.

TABLE 6.3 (UPDATED)
DEFAULT MCF VALUES AND RESULTANT EFS FOR DOMESTIC WASTEWATER BY TYPE OF TREATMENT SYSTEM AND DISCHARGE PATHWAY, *J*[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 to aquatic environments (Tier 1)	Most aquatic environments including rivers are supersaturated in CH_4. Nutrient oversupply will increase CH_4 emissions. Environments where carbon accumulates in sediments have higher potential for methane generation.	0.11 (0.004 – 0.27)	0.068	0.028
Discharge to aquatic environments other than reservoirs, lakes, and estuaries (Tier 2)	Most aquatic environments 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 2)	Environments where carbon accumulates in sediments have higher potential for methane generation.	0.19[3] (0.08 – 0.27)	0.114	0.048
Discharge to soil	Sludge and/or wastewater discharge to soil may be a source of CH_4 for fertilisation	Emissions reported in Volume 4		
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
Wastewater treatment system				
Centralised, aerobic treatment plant	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.	0.03[4] (0.003 – 0.09)	0.018	0.0075
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 tank	Septic tanks emit CH_4	0.5[5] (0.4 – 0.72)	0.3	0.125
Septic tank + land dispersal field	Septic tanks emit CH_4; negligible emissions come from land dispersal field	0.5[5] (0.4 – 0.72)	0.3	0.125

TABLE 6.3 (UPDATED) (CONTINUED)
DEFAULT MCF VALUES AND RESULTANT EFS FOR DOMESTIC WASTEWATER BY TYPE OF TREATMENT SYSTEM AND DISCHARGE PATHWAY, J[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)
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
Sludge treatment system				
Anaerobic digester for sludge	See Chapter 4 for emissions methodology	See Chapter 4, Table 4.1		
Composting	Emissions reported in Volume 5, Chapter 4	See Chapter 4, Table 4.1		
Incineration and open burning	Emissions reported in Volume 5, Chapter 5	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.

[4] See Annex 6A.3 (Czepiel *et al.* 1993; Kozak *et al.* 2009; Bellucci *et al.* 2010; Wang *et al*. 2011; Daelman *et al.* 2013; Kyung *et al.* 2015; Delre *et al.* 2017).

[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:

EQUATION 6.3 (UPDATED)
TOTAL ORGANICALLY DEGRADABLE MATERIAL IN DOMESTIC WASTEWATER

$$TOW = P \bullet BOD \bullet 0.001 \bullet 365$$

Where:

TOW = total organics in wastewater in inventory year, kg BOD/yr

P = country population in inventory year, (person)

BOD = country-specific per capita BOD_5 in inventory year, g/person/day. See Table 6.4.

0.001 = conversion from grams BOD to kg BOD

Total population statistics should be readily available from national statistics agencies or international agencies (e.g., United Nations Statistics, see https://population.un.org/wpp/). Table 6.4 includes BOD default values for selected countries. It is *good practice* to select a BOD default value from a nearby comparable country when country-specific data are not available. The degree of urbanisation for a country can be retrieved from various sources, (e.g., Global Environment Outlook, United Nations Environment Programme and World Development Indicators, World Health Organization). The urban high-income and urban-low income fractions can be determined by expert judgment when statistical or other comparable information is not available.

TABLE 6.4
ESTIMATED BOD_5 VALUES IN DOMESTIC WASTEWATER FOR SELECTED REGIONS AND COUNTRIES

Country/Region	BOD_5 (g/person/day)	Range	Reference
Africa	37	35 – 45	1
Egypt	34	27 – 41	1
Asia, Middle East, Latin America	40	35 – 45	1
India	34	27 – 41	1
West Bank and Gaza Strip (Palestine)	50	32 – 68	1
Japan	42	40 – 45	1
Brazil	50	45 – 55	2
Canada, Europe, Russia, Oceania	60	50 – 70	1
Denmark	62	55 – 68	1
Germany	62	55 – 68	1
Greece	57	55 – 60	1
Italy	60	49 – 60	3
Sweden	75	68 – 82	1
Turkey	38	27 – 50	1
United States	85	50 – 120	4

Note: These values are based on an assessment of the literature. Please use national values, if available.

Reference:

1. Doorn and Liles (1999).
2. Feachem *et al*. (1983).
3. Masotti (1996).
4. Metcalf and Eddy (2003).

This section is updated to include a new equation for the calculation of total organics in wastewater (TOW_j) by treatment/discharge pathway or system (see new Equation 6.3a).

EQUATION 6.3A (NEW)
TOTAL ORGANICS IN DOMESTIC WASTEWATER BY TREATMENT/DISCHARGE PATHWAY OR SYSTEM

$$TOW_j = \sum_i [TOW \bullet U_i \bullet T_{ij} \bullet I_j]$$

Where:

TOW_j = 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 updated Equation 6.3 for TOW in wastewater prior to treatment or wastewater that is discharged without treatment and new Equation 6.3d for TOW in treated 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

I_j = correction factor for additional industrial BOD discharged into treatment/discharge pathway or system *j* (for collected the default is 1.25, for uncollected the default is 1.00)

The factor *I* values in new Equation 6.3a are from the *2006 IPCC Guidelines.* It expresses the BOD from industries and establishments (e.g., restaurants, butchers or grocery stores) that is co-discharged with

domestic wastewater. In some countries, information from industrial discharge permits may be available to improve *I*. Otherwise, expert judgment is recommended.

Table 6.5 includes default values of U_i and $T_{i,j}$ for selected countries.

TABLE 6.5
SUGGESTED VALUES FOR URBANISATION (U) AND DEGREE OF UTILISATION OF TREATMENT, DISCHARGE PATHWAY OR METHOD ($T_{I,J}$) FOR EACH INCOME GROUP FOR SELECTED COUNTRIES

	Urbanisation(U) [1]			Degree of utilisation of treatment or discharge pathway or method for each income group ($T_{i,j}$)[3]															
	Fraction of Population			U=rural					U= urban high income					U=urban low income					
Country	Rural	urban-high[2]	urban-low[2]	Septic Tank	Latrine	Other	Sewer[4]	None	Septic Tank	Latrine	Other	Sewer[4]	None	Septic Tank	Latrine	Other	Sewer[4]	None
Africa																			
Nigeria	0.52	0.10	0.38	0.02	0.28	0.04	0.10	0.56	0.32	0.31	0.00	0.37	0.00	0.17	0.24	0.05	0.34	0.20
Egypt	0.57	0.09	0.34	0.02	0.28	0.04	0.10	0.56	0.15	0.05	0.10	0.70	0.00	0.17	0.24	0.05	0.34	0.20
Kenya	0.62	0.08	0.30	0.02	0.28	0.04	0.10	0.56	0.32	0.31	0.00	0.37	0.00	0.17	0.24	0.05	0.34	0.20
South Africa	0.39	0.12	0.49	0.10	0.28	0.04	0.10	0.48	0.15	0.15	0.00	0.70	0.00	0.17	0.24	0.05	0.34	0.20
Asia																			
China	0.59	0.12	0.29	0.00	0.47	0.50	0.00	0.3	0.18	0.08	0.07	0.67	0.00	0.14	0.10	0.03	0.68	0.05
India	0.71	0.06	0.23	0.00	0.47	0.10	0.10	0.33	0.18	0.08	0.07	0.67	0.00	0.14	0.10	0.03	0.53	0.20
Indonesia	0.54	0.12	0.34	0.00	0.47	0.00	0.10	0.43	0.18	0.08	0.00	0.74	0.00	0.14	0.10	0.03	0.53	0.20
Pakistan	0.65	0.07	0.28	0.00	0.47	0.00	0.10	0.43	0.18	0.08	0.00	0.74	0.00	0.14	0.10	0.03	0.53	0.20
Bangladesh	0.72	0.06	0.22	0.00	0.47	0.00	0.10	0.43	0.18	0.08	0.00	0.74	0.00	0.14	0.10	0.03	0.53	0.20
Japan	0.20	0.80	0.00	0.20	0.00	0.50	0.30	0.00	0.00	0.00	0.10	0.90	0.00	0.10	0	0	0.90	0
Europe																			
Russia	0.27	0.73	0.00	0.30	0.10	0.00	0.60	0.00	0.10	0.00	0.00	0.90	0.00	NA	NA	NA	NA	NA
Germany[5]	0.06	0.94	0.00	0.20	0.00	0.00	0.80	0.00	0.05	0.00	0.00	0.95	0.00	NA	NA	NA	NA	NA
United Kingdom	0.10	0.90	0.00	0.11	0.00	0.00	0.89	0.00	0.00	0.00	0.00	1.00	0.00	NA	NA	NA	NA	NA
France	0.24	0.76	0.00	0.37	0.00	0.00	0.63	0.00	0.00	0.00	0.00	1.00	0.00	NA	NA	NA	NA	NA
Italy	0.32	0.68	0.00	0.42	0.00	0.00	0.58	0.00	0.04	0.00	0.00	0.96	0.00	NA	NA	NA	NA	NA
North America																			
United States	0.22	0.78	0.00	0.90	0.02	0.00	0.08	0.00	0.05	0.00	0.00	0.95	0.00	NA	NA	NA	NA	NA
Canada	0.20	0.80	0.00	0.90	0.02	0.00	0.08	0.00	0.05	0.00	0.00	0.95	0.00	NA	NA	NA	NA	NA
Latin America and Caribbean																			
Brazil	0.16	0.25	0.59	0.00	0.45	0.00	0.10	0.45	0.00	0.20	0.00	0.80	0.00	0.00	0.40	0.00	0.40	0.20
Mexico	0.25	0.19	0.56	0.00	0.45	0.00	0.10	0.45	0.00	0.20	0.00	0.80	0.00	0.00	0.40	0.00	0.40	0.20
Oceania																			
Australia and New Zealand	0.08	0.92	0.00	0.90	0.02	0.00	0.08	0.00	0.05	0.00	0.00	0.95	0.00	NA	NA	NA	NA	NA

TABLE 6.5 (CONTINUED)
SUGGESTED VALUES FOR URBANISATION (U) AND DEGREE OF UTILISATION OF TREATMENT, DISCHARGE PATHWAY OR METHOD ($T_{I,J}$) FOR EACH INCOME GROUP FOR SELECTED COUNTRIES

Notes:
1. Urbanization projections for 2005 (United Nations, 2002).
2. Suggested urban-high income and urban low income division. Countries are encouraged to use their own data or best judgment.
3. $T_{i,j}$ values based on expert judgment, (Doorn and Liles, 1999).
4. Sewers may be open or closed, which will govern the choice of MCF, see Table 3.3
5. Destatis, 2001.

Note: These values are from the literature or based on expert judgment. Please use national values, if available.

Example

Table 6.6 includes an example. Categories with negligible contributions are not shown. Note that the table can easily be expanded with a column for MCF for each category. The degree of urbanization for this country is 65 percent.

TABLE 6.6
EXAMPLE OF THE APPLICATION OF DEFAULT VALUES FOR DEGREES OF TREATMENT UTILISATION (T) BY INCOME GROUPS

Treatment or discharge system or pathway		T (%)	Notes
Urban high-income	To sea	10	No CH_4
	To aerobic plant[1]	20	Add industrial component
	To septic systems	10	Uncollected
Urban low-income	To sea	10	Collected
	To pit latrines	15	Uncollected
Rural	To rivers, lakes, sea	15	Uncollected
	To pit latrines	15	
	To septic tanks	5	
Total		100%	Must add up to 100%

[1] The degree of treatment utilisation (T) does not take into account emissions associated with the discharge of treated effluent.

Reference: Doorn and Liles (1999)

This section is updated to also include new equations for the calculation of organic components 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. 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 new Equations 6.3b and 6.3c, which provide default calculations of *S* for aerobic treatment plants and septic systems, respectively. The default value of *S* for all other systems is zero. 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 kilogram of sludge produced.

EQUATION 6.3B (NEW)
ORGANIC COMPONENT REMOVED AS SLUDGE FROM AEROBIC TREATMENT PLANTS

$$S_{aerobic} = \left(S_{mass} \bullet K_{rem} \bullet 1000\right)$$

Where:

$S_{aerobic}$ = organic component removed from wastewater (in the form of sludge) in aerobic treatment plants, kg BOD/yr

S_{mass} = amount of raw sludge removed from wastewater treatment as dry mass, tonnes/year

K_{rem} = sludge factor, kg BOD/kg sludge. See Table 6.6a.

1000 = conversion factor for tonnes to kilograms

New Table 6.6a provides factors associated with the amount of organics in wastewater removed in sludge. Aerobic WWTPs with primary treatment only 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 WWTPs with primary sedimentation contains approximately 70 percent of primary sludge and 30percent 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 ratio between BOD removed and sludge generated for each process listed in Table 6.6a. Country-specific K_{rem} should be estimated as a weighted average by individual processes.

TABLE 6.6A (NEW)
REMOVAL OF ORGANIC COMPONENT FROM WASTEWATER AS SLUDGE (K_{REM}) ACCORDING TO TREATMENT TYPE[1,2]

Treatment Type	Default	Range
	(kg BOD/kg dry mass sludge)	
Mechanical treatment plants (primary sedimentation sludge)	0.5	0.4 – 0.6
Aerobic treatment plants with primary treatment (mixed primary and secondary sludge, untreated or treated aerobically)	0.8	0.65 – 0.95
Aerobic treatment plants with primary treatment and anaerobic sludge digestion (mixed primary and secondary sludge, treated anaerobically)	1.0	0.8 – 1.2
Aerobic wastewater treatment plants without separate primary treatment	1.16	1.0 – 1.5

Sources:

[1] BOD, or biochemical oxygen demand, is a proxy indicator of the quality (or organic content) of the waste, but it is not a direct mass measurement of the organic content. Just as the mass of oxygen in carbon dioxide is greater than the mass of carbon, it is feasible for the BOD of a carbon-containing molecule to exceed 1 when the molecule is metabolised to carbon dioxide.

[2] Based on expert judgment by Lead Authors of this section using the following references: Pescod (1992); Davies (2005); Foladori *et al*. (2010); WEF (2010); Wisconsin Department of Natural Resources (2010); Serón *et al*. (2011).

Concerning septic systems, emissions depend on the fraction of the population managing their septic tank in accordance with the sludge removal instructions of their septic tank/system (F in new Equation 6.3c). The default value for *F* is 0.5 and corresponds to the situation where 50percent of the population managing their septic system are complying with the sludge removal instructions. This default value is for countries where there is no effective 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.

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

$$S_{septic} = TOW_{septic} \bullet F \bullet 0.5$$

Where:

S_{septic} = organic component removed from wastewater (in the form of 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 tank in compliance with the sludge removal instruction of their septic system

0.5 = fraction of organics in wastewater removed in sludge when septic tank is managed in accordance with sludge removal instructions

For discharges of treated wastewater, inventory compilers should estimate the amount of TOW in effluent ($TOW_{EFFLUENT}$) as shown in new Equation 6.3d.

EQUATION 6.3D (NEW)
TOTAL ORGANICS IN TREATED DOMESTIC WASTEWATER EFFLUENT

$$TOW_{EFFtreat} = \sum_{j} \left[TOW \bullet T_j \bullet \left(1 - TOW_{REM,j}\right) \right]$$

Where:

$TOW_{EFFtreat}$ = total organics in the treated 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 (Updated).

T_J = degree of utilisation of treatment system *j* in inventory year ($\sum_i T_{ij}$). See Table 6.5.

j = each wastewater treatment type used in inventory year

$TOW_{REM,j}$ = fraction of total wastewater organics removed during wastewater treatment per treatment type *j*. See new Table 6.6b. Pathways for organics removal include loss to sludge and biological decomposition.

TABLE 6.6B (NEW)
WASTEWATER TREATMENT ORGANICS REMOVAL FRACTIONS (TOW_{REM}) ACCORDING TO TREATMENT TYPE

Treatment Type	Default	Range
Untreated systems	0	0 – 0.1
Primary (mechanical treatment plants)	0.40	0.25 – 0.50
Primary + Secondary (biological treatment plants)	0.85	0.80 – 0.90
Primary + Secondary + Tertiary (advanced biological treatment plants)	0.90	0.80 – 0.95
Septic tank/septic system	0.625	0.50 – 0.60
Latrines – Dry climate, groundwater table lower than latrine, small family (3–5 persons)	0.1	0.05 – 0.15
Latrines – Dry climate, groundwater table lower than latrine, communal (many users)	0.5	0.4 – 0.6
Latrines – Wet climate/flush water use, groundwater table higher than latrine	0.7	0.7 – 1.0

TABLE 6.6B (NEW) (CONTINUED)
WASTEWATER TREATMENT ORGANICS REMOVAL FRACTIONS (TOW_{REM}) ACCORDING TO TREATMENT TYPE

Sources:

[1] Based on expert judgment by Lead Authors of this section using the following references: Pescod (1992); WEF (2009); Schaider *et al*. (2017) .

6.2.2.4 TIME SERIES CONSISTENCY

No refinement.

6.2.2.5 UNCERTAINTIES

Chapter 3, Uncertainties, in Volume 1 provides advice on quantifying uncertainties in practice. It includes guidance on eliciting and using expert judgments which in combination with empirical data can provide overall uncertainty estimates. 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. The following parameters are believed to be very uncertain:

- The degrees to which wastewater in developing countries is treated in latrines, septic tanks, or removed by sewer, for urban high, urban low income groups and rural population ($T_{i,j}$).
- The fraction of sewers that are 'open', as well as the degree to which open sewers in developing countries are anaerobic and will emit CH_4. This will depend on retention time and temperature, and on other factors including the presence of a facultative layer and possibly components that are toxic to anaerobic bacteria (e.g., certain industrial wastewater discharges).
- The amount of industrial TOW that is discharged into open or closed domestic sewers for each country is very difficult to quantify.

TABLE 6.7 (UPDATED)
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 judgment, 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 urbanisation 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 ($T_{i,j}$)	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 $T_{i,j}$ = 100%
Correction factor for additional industrial BOD discharged into sewers (I)	For uncollected, the uncertainty is zero %. For collected the uncertainty is ± 20%

TABLE 6.7 (UPDATED) (CONTINUED)
DEFAULT UNCERTAINTY RANGES FOR DOMESTIC WASTEWATER

Parameter	Uncertainty Range
Amount of sludge removed from wastewater 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 judgment.
Amount of CH_4 recovered or flared (R)	For systems with measured data, the uncertainty is equal to the uncertainty of the measurement system.

Source*:*
Based on expert judgment by Lead Authors of this section.

6.2.2.6 QA/QC, COMPLETENESS, REPORTING AND DOCUMENTATION

No refinement.

6.2.3 Industrial wastewater

Industrial wastewater may be treated on site or released into domestic sewer systems. If it is released into the domestic sewer system, the emissions are to be included with the domestic wastewater emissions. This section deals with estimating CH_4 emissions from on-site industrial wastewater treatment. Only industrial wastewater with significant carbon loading that is treated under intended or unintended anaerobic conditions will produce CH_4. Organics in industrial wastewater are often expressed in terms of COD, which is used here.

6.2.3.1 CHOICE OF METHOD

Assessment of CH_4 production potential from industrial wastewater streams is based on the concentration of degradable organic matter in the wastewater, the volume of wastewater, and the propensity of the industrial sector to treat their wastewater in anaerobic systems. Using these criteria, major industrial wastewater sources with high CH_4 gas production potential can be identified as follows:

- pulp and paper manufacture;
- meat and poultry processing (slaughterhouses);
- alcohol, beer, starch production;
- organic chemicals production;
- other food and drink processing (dairy products, vegetable oil, fruits and vegetables, canneries, juice making, etc.).

Both the pulp and paper industry and the meat and poultry processing industries produce large volumes of wastewater that contain high levels of degradable organics. The meat and poultry processing facilities typically employ anaerobic lagoons to treat their wastewater, while the paper and pulp industry also use lagoons and anaerobic reactors. The non-animal food and beverage industries produce considerable amounts of wastewater with significant organic carbon levels and are also known to use anaerobic processes such as lagoons and anaerobic reactors. Anaerobic reactors treating industrial effluents with biogas facilities are usually linked with recovery of the generated CH_4 for energy. Emissions from the combustion process for energy should be reported in the Energy Sector.

The method for estimating emissions from industrial wastewater is similar to the one used for domestic wastewater. 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.

The development of emission factors and activity data is more complex because there are many types of wastewater, and many different industries to track. The most accurate estimates of emissions for this source category would be based on measured data from point sources. Due to the high costs of measurements and the

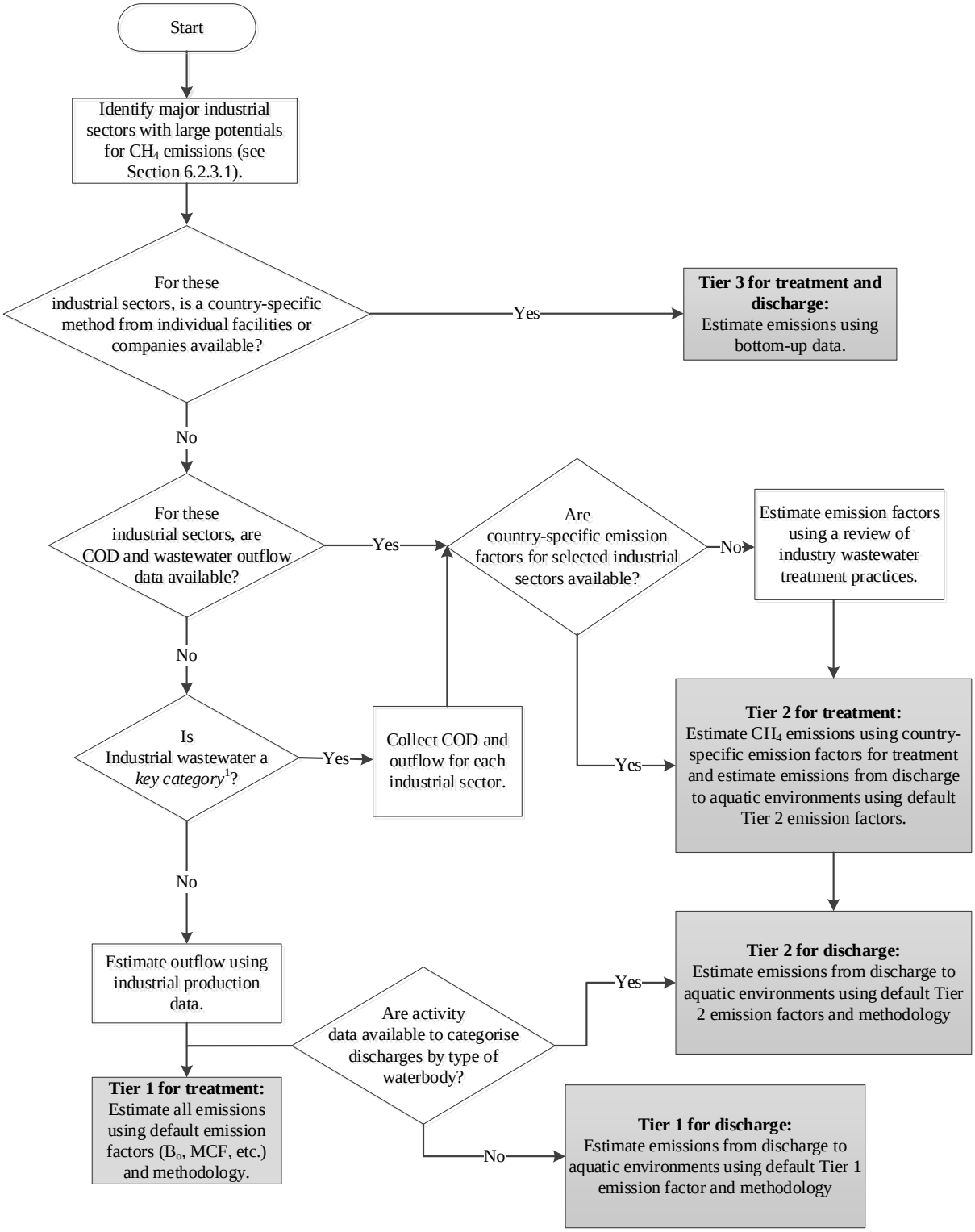
potentially large number of point sources, collecting comprehensive measurement data is very difficult. It is suggested that inventory compilers use a top-down approach that includes the following general steps:

Step 1: Use Equation 6.6 to estimate total organically degradable carbon in wastewater (TOW) for industrial sector *i*

Step 2: Select the pathway and systems (updated Figure 6.1) according to country activity data. Use Equation 6.5 to obtain emission factor. For each industrial sector estimate the emission factor using maximum methane producing capacity and the average industry-specific MCF.

Step 3: Use Equation 6.4 to estimate emissions, adjust for possible sludge removal and or CH_4 recovery and sum the results.

Figure 6.3 (Updated) Decision tree for CH_4 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.

The general equation to estimate CH_4 emissions from industrial wastewater is as follows:

EQUATION 6.4
TOTAL CH_4 EMISSIONS FROM INDUSTRIAL WASTEWATER

$$CH_4\ Emissions = \sum_i \left[\left(TOW_i - S_i \right) \bullet EF_i - R_i \right] \bullet 10^{-6}$$

Where:

CH_4 Emissions = CH_4 emissions in inventory year, Gg CH_4/yr

TOW_i = total organically degradable material in wastewater from industry *i* in inventory year, kg COD/yr

i = industrial sector

S_i = organic component removed from wastewater (in the form of sludge) in inventory year, kg COD/yr

EF_i = emission factor for industry *i*, kg CH_4/kg COD for treatment/discharge pathway or system(s) used in inventory year

If more than one treatment practice is used in an industry this factor would need to be a weighted average.

R_i = amount of CH_4 recovered or flared in inventory year, kg CH_4/yr

10^{-6} = conversion of kg to Gg

The amount of CH_4 which is recovered or flared is expressed as R in Equation 6.4.

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 CH_4 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 CH_4 producing capacity (B_o) in each industry.

As mentioned before, the MCF indicates the extent to which the CH_4 producing potential (B_o) is realised in each type of treatment method. Thus, it is an indication of the degree to which the system is anaerobic. See Equation 6.5.

EQUATION 6.5
CH_4 EMISSION FACTOR FOR INDUSTRIAL WASTEWATER

$$EF_j = B_o \bullet MCF_j$$

Where:

EF_j = emission factor for each treatment/discharge pathway or system, kg CH_4/kg COD, (See Table 6.8.)

j = each treatment/discharge pathway or system

B_o = maximum CH_4 producing capacity, kg CH_4/kg COD

MCF_j = methane correction factor (fraction). See Table 6.8.

Good practice is to use country- and industry-sector specific data that may be available from government authorities, industrial organisations, or industrial experts. 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 CH_4 emissions. However, if country-specific data are not available, it is *good practice* to use the IPCC default factors listed in Table 6.2.

In determining the MCF, which is the fraction of waste treated anaerobically, expert judgment is recommended. A peer-reviewed survey of industry wastewater treatment practices is one useful technique for estimating these data. Surveys should be conducted frequently enough to account for major trends in industry practices (i.e., every 3-5 years). Chapter 2, Approaches to Data Collection, in Volume 1, describes how to elicit expert judgment for

uncertainty ranges. Similar expert elicitation protocols can be used to obtain the necessary information for other types of data if published data and statistics are not available. Table 6.8 includes default MCF values, which are based on expert judgment.

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

TABLE 6.8 (UPDATED)
DEFAULT MCF VALUES AND RESULTANT EFS 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 to aquatic environments (Tier 1)	Most aquatic environments including rivers are supersaturated in CH_4. Nutrient oversupply will increase CH_4 emissions. Environments where carbon accumulates in sediments have higher potential for methane generation.	0.11 (0.004 – 0.27)	0.068	0.028
Discharge to aquatic environments other than reservoirs, lakes, and estuaries (Tier 2)	Most aquatic environments 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 2)	Environments where carbon accumulates in sediments have higher potential for methane generation.	0.19[3] (0.08 – 0.27)	0.114	0.048
Discharge to soil	Sludge and/or wastewater discharge to soil may be a source of CH_4 for fertilisation	Emissions reported in Volume 4		
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)			

TABLE 6.8 (UPDATED) (CONTINUED)
DEFAULT MCF VALUES AND RESULTANT EFS 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)
Sludge treatment system				
Anaerobic digester for sludge	See Chapter 4 for emissions methodology	See Chapter 4, Table 4.1		
Composting	Emissions reported in Volume 5, Chapter 4	See Chapter 4, Table 4.1		
Incineration and open burning	Emissions reported in Volume 5, Chapter 5	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 update and new guidance for estimating domestic N_2O emissions from WWTPs and provides new guidance on the estimation of N_2O emissions from wastewater after disposal of untreated wastewater or treated wastewater effluent into aquatic environments by accounting for losses of nitrogen prior to disposal.

6.3.1 Methodological issues

Nitrous oxide emissions can occur as emissions from WWTPs or as emissions from receiving aquatic environments following the disposal of untreated or treated wastewater effluent. This section describes how to estimate the N_2O 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 WWTPs, previously judged to be a minor source, may in fact result in more substantial emissions. N_2O is generated as a by-product of nitrification, or as an intermediate product of denitrification. There are many factors affecting N_2O

emissions from wastewater treatment systems such as the temperature and dissolved oxygen concentration of the wastewater, and the specific operational conditions.

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 nutrient-impacted status and oxygenation level of the aquatic environment receiving the wastewater discharge. The current methodology in the *2006 IPCC Guidelines* appropriately captures discharge to relatively clean and/or well-oxygenated environments. However, in the case of discharge to nutrient-impacted waters such as eutrophic lakes, estuaries and rivers, or locations where stagnant conditions occur, emissions can be significantly higher.

Three tiers of methods for estimating N_2O emissions 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 emission factor 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. For example, a more advanced country-specific method could be based on plant-specific emissions data from large wastewater treatment facilities or using country-specific measurements of nitrogen discharged to aquatic environments of varying nutrient-impacted status. Direct measurement methods would provide a more accurate measurement of N_2O production from each treatment plant.

6.3.1.1 CHOICE OF METHOD

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

The steps for *good practice* in inventory preparation for N_2O from domestic wastewater are as follows:

Step 1: Use new Equation 6.10 to estimate total nitrogen in wastewater and updated Equation 6.8 to estimate total nitrogen in wastewater effluent.

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.

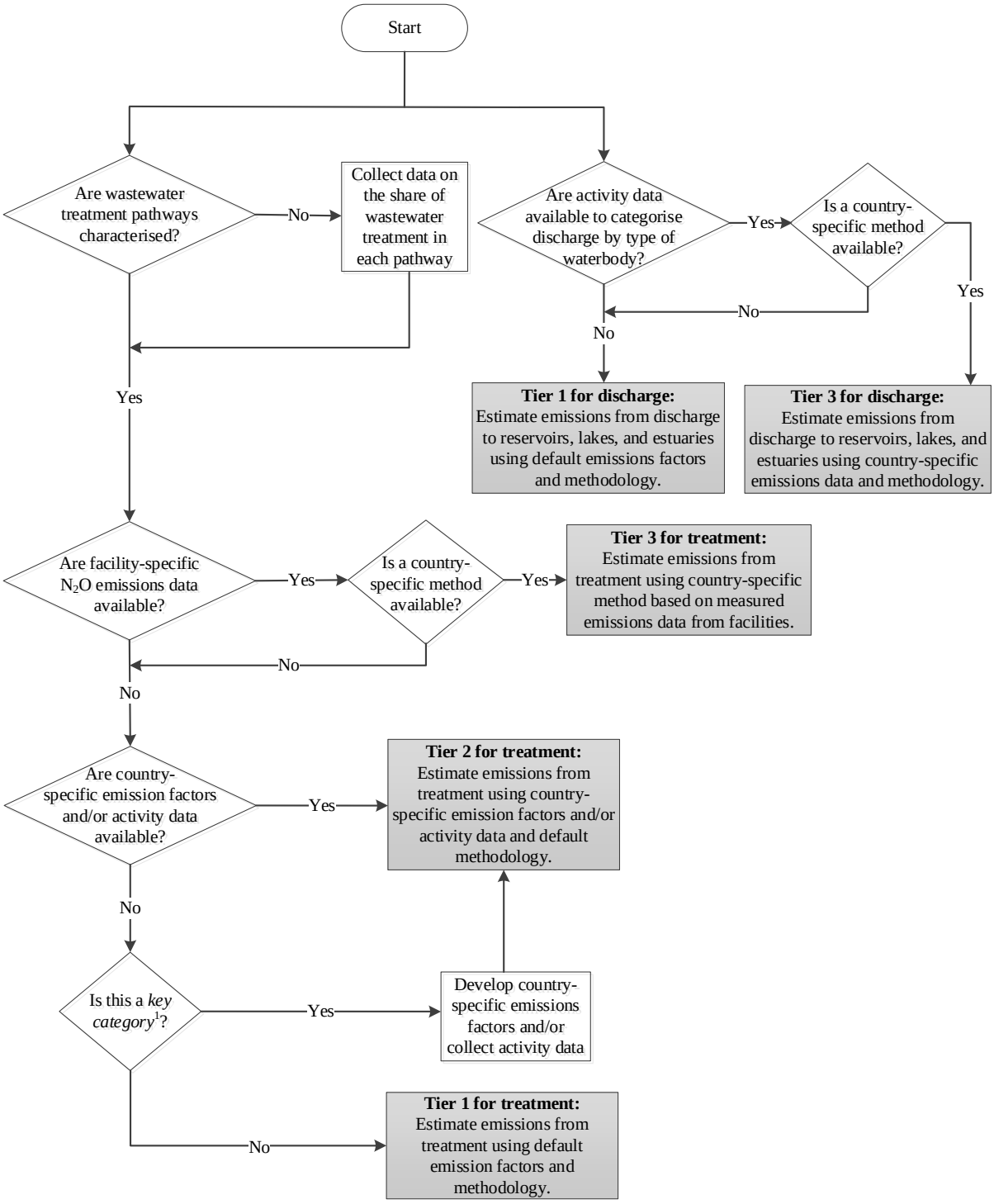
Step 4: Use updated Equation 6.7 to estimate emissions from effluent, accounting for losses of nitrogen that occur within the wastewater treatment process including sludge removal and sum the results for each pathway/system. Emissions should also be calculated for nitrogen discharged as untreated wastewater.

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 associations or international organisations such as the WHO may have data on the system usage.

Otherwise, consultation with sanitation experts can help, and expert judgment 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 nutrient-impacted environments, these refinements introduce a new Tier 3 emission factor for those discharges.

Figure 6.4 (New) Decision tree for N_2O 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.

EQUATION 6.9 (UPDATED)
N_2O EMISSIONS FROM DOMESTIC WASTEWATER TREATMENT PLANTS

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

Where:

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

TN_{DOM} = total nitrogen in domestic wastewater in inventory year, kg N/yr. See new 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 N_2O-N/kg N

The factor 44/28 is for the conversion of kg N_2O-N into kg N_2O.

It is also required to estimate direct N_2O 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 N_2O emissions explained in Volume 4, Section 11.2.2 in Chapter 11 N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application. The simplified general equation is as follows:

EQUATION 6.7 (UPDATED)
N_2O EMISSIONS FROM DOMESTIC WASTEWATER EFFLUENT

$$N_2O_{EFFLUENT,DOM} = N_{EFFLUENT,DOM} \bullet EF_{EFFLUENT} \bullet \frac{44}{28}$$

Where:

$N_2O_{EFFLUENT,DOM}$ = N_2O emissions from domestic wastewater effluent in inventory year, kg N_2O/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 N_2O emissions from wastewater discharged to aquatic systems, kg N_2O-N/kg N

The factor 44/28 is the conversion of kg N_2O-N into kg N_2O.

6.3.1.2 CHOICE OF EMISSION FACTORS

New Table 6.8a includes default Tier 1 EF values for use in estimation of N_2O emissions from waters receiving treated or untreated effluent (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 all discharges when using the Tier 1 methodology. However, it is expected to generate an underestimate of N_2O emissions in the case of discharge to nutrient-impacted waters such as eutrophic lakes, estuaries and rivers, or locations where stagnant conditions occur. Research published between 1978 and 2017 provide data indicating that higher N_2O emissions occur when wastewater is discharged to nutrient-impacted (eutrophic) or hypoxic aquatic receiving environments. Accordingly, Table 6.8a provides a new $EF_{EFFLUENT}$ of 0.019 g N_2O-N/g N (95percent confidence limits 0.0041–0.091) for use with a Tier 3 method (see Annex 6A.6 for a discussion of information used to develop this new emission factor). The compiler can make use of many different indications of whether this higher EF value should be employed. Harmful algal blooms and hypoxia are the two most common symptoms of waterway nutrient over-enrichment (eutrophication). One possibility is to consider the dissolved oxygen status of the receiving waters. Waterway hypoxia is becoming increasingly common globally and definitions of hypoxia can vary depending on temperature, salinity, and the particular biota of interest. Dissolved oxygen concentrations of between 0.1–3.0 mg/L (or <30percent of the oxygen saturation concentration) are typically classified as hypoxic (Vaquer-Sunyer & Duarte 2008; Naqvi *et al.* 2010; Rabalais *et al.* 2010) and are likely to result in increased N_2O yields from microbial metabolism of discharged wastewater nitrogen.

Oxygen status can be a highly dynamic indicator in practice, and compilers may have better access to information regarding the nutrient (trophic) status of receiving waters. Various thresholds for the boundary between mesotrophic and eutrophic conditions have been proposed, such as Secchi depth (suggestions range from 2 to 3.6 m), total phosphorus (20–75 µg/L), total nitrogen (0.3–5 mg/L), benthic chlorophyll (70 mg/m^2) and suspended chlorophyll concentration (5–30 µg/L) (Dodds *et al.* 1998; Burns *et al.* 2009; Mateo-Sagasta & Burke 2010). Compilers may also consider whether there have been reports of algal blooms, sulphurous odours,

fish kills or other indications of eutrophic and/or hypoxic conditions in the discharge environment. Global datasets exist which may assist compilers in assessing the risk of nutrient impacts in different regions (Diaz *et al.* 2011; Xie & Ringler 2017). It is important to note that the context for application of this new Tier 3 $EF_{EFFLUENT}$ factor is not necessarily the same as for nitrogen runoff from agriculture, due to the combination of reducing conditions and high organic loading in many wastewaters which are unlikely to exist in agricultural runoff systems.

TABLE 6.8A (NEW)
DEFAULT EF VALUES FOR DOMESTIC AND INDUSTRIAL WASTEWATER

Type of treatment and discharge pathway or system	Comments	EF[1] (kg N_2O-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
Nutrient-impacted and/or hypoxic freshwater, estuarine, and marine environments (Tier 3, if needed)	Higher emissions are associated with nutrient-impacted/hypoxic water such as eutrophic lakes, estuaries and rivers, or locations where stagnant conditions occur. See section 6.3.1.2 for more information.	0.019[2]	0.0041 – 0.091
Discharge to soil	Emissions reported in Volume 4		
Wastewater treatment system, EF_{plants}			
Centralised, aerobic treatment plant	N_2O is variable and can be significant	0.016[1]	0.00016 – 0.045
Anaerobic reactor	N_2O is not significant	0	0 – 0.001
Anaerobic lagoons	N_2O 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 tank	N_2O is not significant	0	0 – 0.001
Septic tank + land dispersal field	N_2O is emitted by the soil dispersal system	0.0045	0 – 0.001
Latrine	N_2O is not significant	0	0 – 0.001
Sludge treatment system			
Anaerobic digester for sludge	N_2O 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.

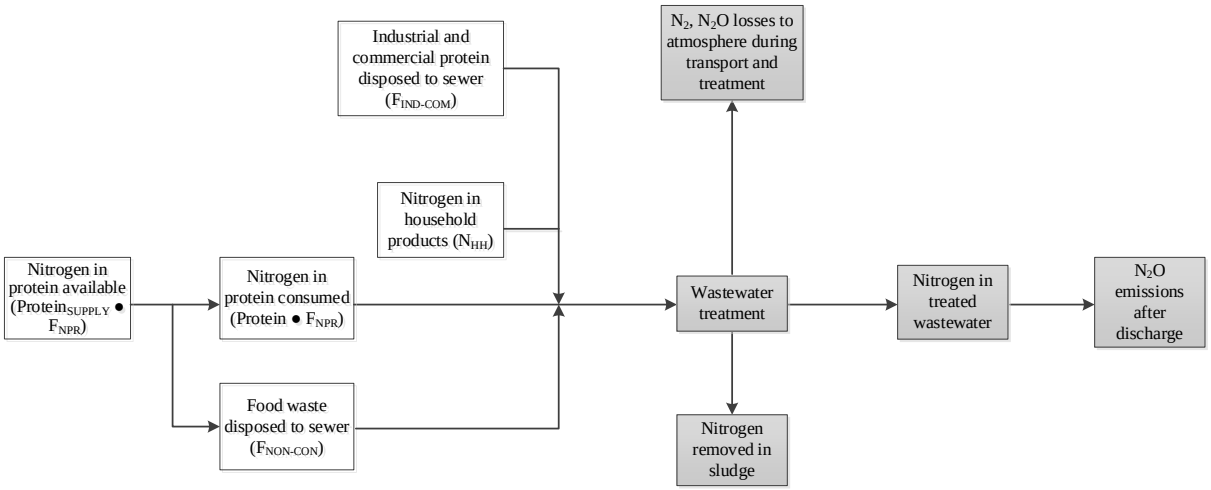
[2] See Annex 6A.6.

6.3.1.3 CHOICE OF ACTIVITY DATA

The methodology to calculate the amount of N 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 N in sludge, which can result in a significant overestimate of N discharged to aquatic receiving environments. Typical total N concentration in raw urban sewage is about 40 mg/L (range 20–70 mg/L) (Tchobanoglous *et al.* 2014), whereas effluent treated in conventional activated sludge facilities (with nitrification) has a total of about 25 mg/L. Plants with biological nutrient removal (with denitrification) regularly achieve an effluent total N of 5 mg/L or less. The difference is due both to N removed in sludge (see Table 2.4A (New), Chapter 2 of Volume 5 regarding the N content of sewage sludge) versus N loss to the atmosphere (see new Figure 6.5).

This section updates 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 ($N_{EFFLUENT,DOM}$).

Figure 6.5 (New) 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 N in non-consumed protein entering the wastewater and other N from household, industrial, and commercial sources co-discharged into the sewer system. The total N in wastewater for each treatment pathway is estimated as follows:

EQUATION 6.10 (NEW)
TOTAL NITROGEN IN DOMESTIC WASTEWATER BY TREATMENT PATHWAY

$$TN_{DOM\_j} = \left(P_{treatment\_j} \bullet Protein \bullet F_{NPR} \bullet N_{HH} \bullet F_{NON-CON} \bullet F_{IND-COM} \right)$$

Where:

TN_{DOM_j} = total annual amount of nitrogen in domestic wastewater for treatment pathway j, kg N/yr

$P_{treatment\_j}$ = human population who are served by the treatment pathway j, 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 nitrogen in non-consumed protein disposed in sewer system, kg N/kg N. See new Table 6.10a.

$F_{IND-COM}$ = factor for industrial and commercial co-discharged protein into the sewer system, kg N/kg N

N_{HH} = additional nitrogen from household products added to the wastewater, default is 1.1 (some country data are in new Table 6.10a).

If national statistics on protein consumed or protein supply are not available, Food Balance Sheets of FAOSTAT can be used as activity data on per capita "protein supply quantity." This information represents the total amount of protein available to the population but must be adjusted to reflect the fraction of protein consumed (FPC), according to the new Equation 6.10a.

EQUATION 6.10A (NEW)
ESTIMATION OF PROTEIN CONSUMED

$$Protein = Protein_{SUPPLY} \bullet FPC$$

Where:

$Protein_{SUPPLY}$ = annual per capita protein supply, kg protein/person/yr

FPC = Fraction of protein consumed. Default regional values are listed in the new Table 6.10a

Food that is not consumed may be disposed to the sewer (e.g., as result of the use of food waste disposals in some countries) and a factor for non-consumed protein ($F_{NON-CON}$) should be used to reflect this additional N entering wastewater (see new Table 6.10a). If food waste is disposed with solid waste, it is assumed that no additional N is entering wastewater and $F_{NON-CON} = 1$.

Bath and laundry water may contain household chemicals (detergents, shampoos, softeners, dishwashing agents, WC fresheners, cosmetics, etc.) and a factor for N from household products (N_{HH}) should be used. The default factor for N_{HH} is 1.1 (Henze *et al.* 2008; Tjandraatmadja *et al.* 2008), but additional regional factors are provided in Table 6.10a.

TABLE 6.10A (NEW)
DEFAULT FACTORS FOR DOMESTIC WASTEWATER

Region[1]	Protein consumed[2] as fraction of protein supply	$F_{NON-CON}$[2] in case food waste is disposed in sewer	Additional N from households' chemicals
Europe	0.85	1.09	1.08
North America and Oceania	0.80	1.13	1.17 (USA) 1.07 (Australia)
Industrialised Asia	0.86	1.08	No data
Sub-Saharan Africa	0.98	1.01	No data
North Africa, West and central Asia	0.90	1.06	No data
South and Southeast Asia	0.96	1.02	1.13 (India)
Latin America	0.92	1.04	No data

[1] See Annex 6A.7 for a list of countries by region

[2] Based on FAO (2011)

TABLE 6.10B (NEW)
ESTIMATE ON USE OF FOOD WASTE DISPOSAL IN SEWER[1]

Country	Share of households disposing food waste in sewer
USA	50%
Canada	10%
Australia	12%
New Zealand	30%
UK	5%
Ireland	1 – 2%
Italy	Supported
Czech Republic	<1% / not allowed
Denmark	Rare
Belgium	Restricted / not allowed
The Netherlands	Not allowed
Germany	Not allowed

[1] Based on EPA (2008) and expert judgment by Lead Authors

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 ($N_{EFFLUENT,DOM}$)

The total nitrogen in wastewater effluent is estimated as follows:

EQUATION 6.8 (UPDATED)
TOTAL NITROGEN IN DOMESTIC WASTEWATER EFFLUENT

$$N_{EFFLUENT,DOM} = \sum_{j}\left[(TN_{DOM} \bullet T_j) \bullet \left(1 - N_{REM,j}\right)\right]$$

Where:

$N_{EFFLUENT,DOM}$ = 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 new Equation 6.10.

T_j = degree of utilisation of treatment system *j* in inventory year ($\sum_i T_{ij}$). See Table 6.5

j = each wastewater treatment type used in inventory year

N_{REM} = fraction of total wastewater nitrogen removed during wastewater treatment per treatment type j. See new Table 6.10c. Pathways for N removal include transfer to sludge and nitrification–denitrification with concomitant N loss to the atmosphere.

TABLE 6.10C (NEW)
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]
Septic tank + land dispersal field	0.68[5]	0.62 – 0.73[5]
Latrine	0.12[6]	0.07 – 0.21[6]

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] Andreoli *et al.* (1979)
[6] EMEP/EAA (2016)

6.3.2 Time series consistency

No refinement.

6.3.3 Uncertainties

Large uncertainties are associated with the IPCC default factors for N_2O. Updated Table 6.11 below includes uncertainty ranges based on expert judgment.

TABLE 6.11 (UPDATED)
N_2O METHODOLOGY DEFAULT DATA

	Definition	Default Value	Range
Emission Factor			
EF	N_2O emission factor	See Table 6.8a	See Table 6.8a
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

TABLE 6.11 (UPDATED) (CONTINUED) N2O METHODOLOGY DEFAULT DATA			
	Definition	**Default Value**	**Range**
N_{REM}	Factor to account for losses of nitrogen prior to discharge	See Table 6.10c	See Table 6.10c

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 new guidance for estimating N_2O emissions from industrial WWTPs and refines the estimation of N_2O 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 new Figure 6.6.

The steps for *good practice* in inventory preparation for N_2O 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 industrial 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.

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 judgment can also be applied (see Chapter 2 Approaches to Data Collection, Volume 1).

EQUATION 6.11 (NEW)
N_2O EMISSIONS FROM INDUSTRIAL WASTEWATER TREATMENT PLANTS

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

Where:

$N_2O\ Plants_{IND}$ = N_2O emissions from industrial wastewater treatment plants in inventory year, kg N_2O/yr

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

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

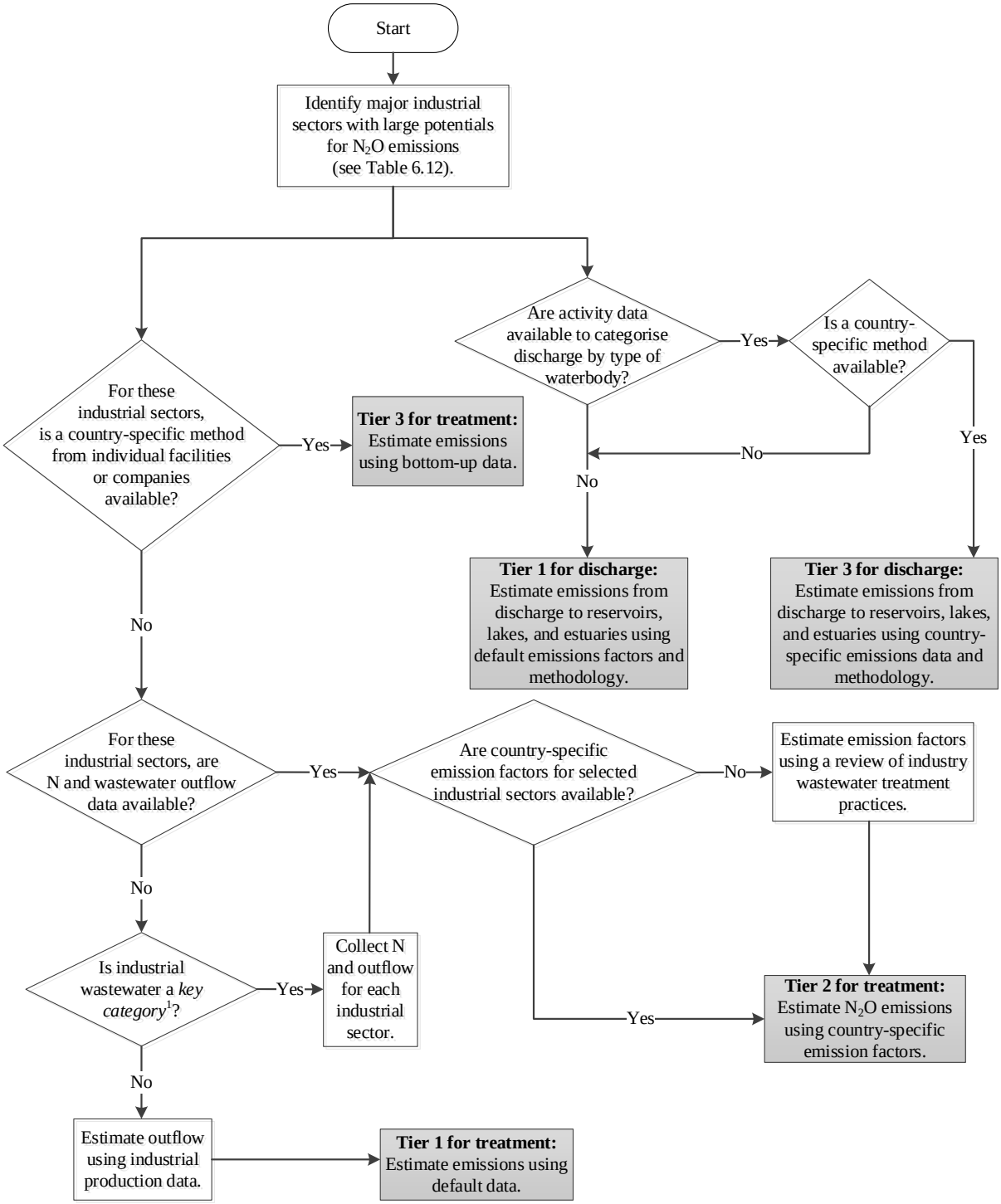
i = industry

j = each treatment/discharge pathway or system

EF_j = emission factor for treatment/discharge pathway or system *j*, kg N_2O-N/kg N. See Table 6.8a (New).

The factor 44/28 is for the conversion of kg N_2O-N into kg N_2O.

Figure 6.6 (New) Decision tree for N_2O 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.

It is also required to estimate N_2O emissions from wastewater treatment effluent that is discharged into aquatic environments. The methodology for emissions from effluent is like that of N_2O emissions explained in Volume 4, Section 11.2.2, Chapter 11, N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application. The simplified general equation is as follows:

EQUATION 6.12 (NEW)
N_2O EMISSIONS FROM INDUSTRIAL WASTEWATER EFFLUENT

$$N_2OEffluent_{IND} = N_{EFFLUENT,IND} \bullet EF_{EFFLUENT} \bullet \frac{44}{28}$$

Where:

$N_2OEffluent_{IND}$ = N_2O emissions from industrial wastewater effluent in inventory year, kg N_2O/yr

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

$EF_{EFFLUENT}$ = emission factor for N_2O emissions from wastewater discharged to aquatic systems, kg N_2O-N/kg N

The factor 44/28 is for the conversion of kg N_2O-N into kg N_2O.

6.4.1.2 CHOICE OF EMISSION FACTORS

New Table 6.8a includes default EF values for N_2O 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 total nitrogen (TN) in the industrial wastewater entering treatment (TN_{IND}). This parameter is a function of industrial output (product) P (tonnes/yr), wastewater generation W (m^3/ton of product), and total N concentration in the untreated wastewater (kg TN/m^3). See new 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 N, by evaluating total industrial product, N in the wastewater, and wastewater produced.

(ii) Identify industrial sectors that use treatment systems with N_2O emissions factors (see new Table 6.8a). Experience has shown that usually three or four industrial sectors are *key*.

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

EQUATION 6.13 (NEW)
TOTAL NITROGEN IN INDUSTRIAL WASTEWATER

$$TN_{IND,i} = P_i \bullet W_i \bullet TN_i$$

Where:

TN_{INDi} = 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*, $m^3/t_{product}$

TN_i = total nitrogen in untreated wastewater for industrial sector *i*, kg TN/m^3

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 N loading in the wastewater may require expert judgment. In some countries, N content and total water usage per sector data may be available directly from a regulatory agency. New Table 6.12 provides examples that could be used as default values for industries that may be considered key sources of N_2O. These values should be used with caution, because they are industry-, process-, and country-specific.

TABLE 6.12 (NEW)
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 fertiliser	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] US EPA (2002a)
[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 6.10c.

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

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

EQUATION 6.14 (NEW)
TOTAL NITROGEN IN INDUSTRIAL WASTEWATER EFFLUENT

$$N_{EFFLUENT,IND} = \sum_{j}\left[TN_{IND_i} \bullet T_j \bullet \left(1 - N_{REM,j}\right)\right]$$

Where:

$N_{EFFLUENT, IND}$ = total annual amount of nitrogen in the industrial wastewater effluent, kg N/yr

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

T_j = degree of utilisation of treatment system *j* in inventory year ($\sum_i T_{ij}$). See Table 6.5.

j = each wastewater treatment type used in inventory year

$N_{REM,j}$ = fraction of total wastewater nitrogen removed during wastewater treatment per treatment type j. See new Table 6.10c.

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 new Table 6.13. The estimates are based on expert judgment.

TABLE 6.13 (NEW)
DEFAULT UNCERTAINTY RANGES FOR INDUSTRIAL WASTEWATER

Parameter	Uncertainty Range
Emission Factor	
N_2O emission factor	± 30%
Activity Data	
Industrial production (P)	± 25% Use expert judgment regarding the quality of data source to assign more accurate uncertainty range.
Wastewater/unit production (W)	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).
TN/unit wastewater (TN)	

Source*:* Expert Judgment by Lead Authors of this section.

6.4.4 QA/QC, Completeness, Reporting and Documentation

QUALITY ASSURANCE / QUALITY CONTROL (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:

- 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 characterisation of industrial sectors that produce nitrogen-laden wastewater. In most countries, approximately 3–4 industrial sectors will account for the majority of the nitrogenous 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 N that should be subtracted from effluent N. It is *good practice* to be consistent across sectors: the amount of N 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 judgment, etc.) have been derived (measurements, literature, expert judgment, 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.

Appendix 6A.1 Non-biogenic (fossil) CO_2 emissions from wastewater treatment and discharge: Basis for Future Methodological Development

The *2006 IPCC Guidelines* assume that organic carbon present in wastewater derives from modern (biogenic) organic matter in human excreta or food waste (Doorn *et al.* 2006). Consequently, CO_2 emissions from wastewater treatment according to those Guidelines 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 10^6 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 CO_2 emissions are of biogenic origin and the CH_4 and N_2O 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 CO_2 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 non-biogenic (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, fossil-derived 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 & 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 4–14percent; although more recent work suggests this can be as high as 28percent (Tseng et al., 2016) or 51percent (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 10–15percent. Law *et al*. (2013) put the subsequent fossil carbon fraction in anaerobic digester biogas CO_2 at 2.1±0.2percent 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 2–12percent. Tseng *et al.* (2016) put this figure at some 13 to 24percent 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 *IPCC Guidelines* should include a method for estimating these non-biogenic emissions associated with wastewater treatment operations and wastewater discharges.

TABLE 6AP.1 (NEW)
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 & 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.

TABLE 6AP.1 (NEW) (CONTINUED)
SUMMARY OF LITERATURE INVESTIGATING FOSSIL ORGANIC CARBON IN WASTEWATER

Wastewater treatment system	Detection/measurement approach	Fossil C fraction in various wastewater streams	Reference	Comments
Assumed conventional activated sludge-based WWTP with primary gravity sedimentation, Japan	Fresh domestic sewage, primary-treated and secondary-treated wastewater sampled	$\Delta^{14}C$ values (‰) of sewage DOC was more negative (14C ages in the order of ≈1000–5000 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	$\delta^{13}C$ signature of −50.7‰ (depleted with respect to background air)	Toyoda *et al*. (2011)	WWTP received municipal wastewater

Annex 6A.1 Summary data for pit latrine use, no sanitation facility, and groundwater use by country

TABLE 6A.1 (NEW)
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

TABLE 6A.1 (NEW) (CONTINUED)
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 (%)
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

TABLE 6A.1 (NEW) (CONTINUED)
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 (%)
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
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 Programme reports (http://wssinfo.org)

Annex 6A.2 Derivation of the maximum CH_4 producing potential (B_o) for domestic wastewater

The maximum CH_4 producing potential (B_o) for domestic wastewater is calculated theoretically by the anaerobic decomposition of glucose considering the total degradation of organic matter:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

One mole of glucose weighs 180 g and produces 3 moles of methane which weighs 3 × 16 = 48 g. Therefore, the methane production rate per gram of glucose is 48 g /180 g = 0.27 g methane / g glucose.

The complete oxidation of one mole of glucose (180 g) requires six moles of oxygen (6 × 32 g = 192 g)

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Then, the oxygen demand rate per gram of glucose is 192 g / 180 g = 1.067 g oxygen / g glucose

Finally, the maximum CH_4 producing potential (B_o) for domestic wastewater based of COD content is 48 g CH_4 / 192 g oxygen = 0.25 kg CH_4 / kg COD.

The COD/BOD ratio of a specific wastewater indicates the amount of organic matter difficult to degrade. For domestic wastewater, a typical COD/BOD 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 COD/BOD ratios is between 1.5 and 3.5 (Henze *et al.* 2008).

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

It should be noted that the emission factors are made up of a) the maximum CH_4 producing capacity (B_o) and b) MCF which indicates the extent to which the B_o is released in each wastewater treatment/discharge pathways or systems. If a country chooses to introduce country-specific data for B_o based on measured composition of wastewater, they must also update the MCF because the MCFs were developed using the default B_o values.

Annex 6A.3 Estimation of default methane conversion factors for CH_4 in centralised wastewater treatment plants treating domestic wastewater

We reviewed scientific literature to find measured CH_4 emissions from full-scale domestic wastewater treatment plants (excluding anaerobic sludge digestion). Although much literature exists, relatively few studies relate to full-scale treatment plants and provide key information such as influent organics in wastewater or organics removed in sludge. We reviewed and accepted data from 14 wastewater treatment plants. MCFs were calculated from data presented in studies, including measured CH_4 emissions from wastewater treatment plant (not including sludge digesters), influent organics in wastewater, estimates of organics removed in sludge, and the IPCC default B_o value. Some data were not accepted for use because the treatment system co-treated a significant percentage of non-domestic wastewater, such as food waste. The references used, along with the type of treatment system studied and the resulting MCF, are listed in Table 6A.2. Although CH_4 emissions vary by the type of wastewater treatment system used, more on-site exhaustive monitoring data are required to develop different MCFs for different treatment processes. Overall, an MCF of 0.03 was calculated for aerobic wastewater treatment systems with a standard deviation of 0.024 and a range of 0.003–0.09.

TABLE 6A.2 (NEW)
MCFS BASED ON MEASURED CH_4 IN FULL-SCALE DOMESTIC WASTEWATER TREATMENT PLANTS

Type of treatment process (Name of plant)	Reference	MCF[1]
Activated sludge (Stickney)	Bellucci *et al.* (2010)	0.017
Activated sludge (Northside)	Bellucci *et al.* (2010)	0.004
Activated sludge (Egan)	Bellucci *et al.* (2010)	0.014
Activated sludge	Czepiel *et al.* (1993)	0.013
Biological nutrient removal (Kralingseveer)	Daelman *et al.* (2013)	0.03
Biological nutrient removal (Kortenoord)	Daelman *et al.* (2013)	0.02
Biological nutrient removal (Papendrecht)	Daelman *et al.* (2013)	0.04
Sequencing batch reactor (Holbæk)	Delre *et al.* (2017)	0.038
Activated sludge (Källby)	Delre *et al.* (2017)	0.048
Biological nutrient removal (Lundtofte)	Delre *et al.* (2017)	0.014
Biological nutrient removal (Lynetten)	Delre *et al.* (2017)	0.015
Activated sludge	Kozak *et al.* (2009)	0.09
5-stage Bardenpho	Kyung *et al.* (2015)	0.07
Anaerobic/anoxic/oxic (A2O) process	Wang *et al.* (2011)	0.003

[1] MCF shown was calculated from data presented in studies, including measured CH_4 emissions from wastewater treatment plant (not including sludge digesters), influent organics in wastewater, estimates of organics removed in sludge, and the IPCC default B_o value.

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 CO_2 and CH_4 emissions from different environments. At equilibrium with current atmospheric conditions, CO_2 is relatively soluble (over 500 μg/L) compared with CH_4 (about 40 ng/L) at 25 degrees Celsius. Therefore, a reliance on studies that only measure diffusive flux will underestimate the relative emission of CH_4. Deemer *et al.* (2016) raised previous estimates of CH_4 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 CH_4 flux (CH_4-C/(CH_4-C + CO_2-C)) to 27 percent (first data row in Table 6A.3) which is higher than previously thought. For an estimate of this effect on the other data, it is noted that about 52 percent of the data listed by Deemer and colleagues included ebullition, and for this about 40–60 percent 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 and colleauges) 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 percent 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 percent. Note that the riverine CO_2 figure in Deemer *et al.* (2016) of 7,954 mg C/m^2/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/m^2/day.

Considering the data in Table 6A.3, the average yield for reservoirs and lakes is 19percent (8–27 percent) while the average for rivers is much lower at 3.5 percent (0.4–6 percent). Data ranges rather than standard deviations are given owing to the potential for overlap between the underlying datasets. These CH_4 yield data are used to estimate the MCF. On the same basis as the B_o calculation, 1.067 kg of O_2 are required to oxidise one kg of glucose. Considering that 40 percent 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 CH_4-C/kg (CH_4-C + CO_2-C) corresponds to 0.071 kg CH_4-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 CO_2 and a further 0.1 Pg as CH_4, the remainder being sequestered in sediments or lost to the ocean. Thus of 3.0 Pg of carbon inputs, 50 percent is emitted to the atmosphere. Correcting the previous figure for this yield and converting to kg CH_4 suggests 0.071 [kg CH_4-C/kg COD] × (12.01 + 1.00797×4)/12.01 [kg CH_4/kg CH_4-C] × 0.5 = 0.048 kg CH_4/kg COD. For use in conjunction with B_o then MCF = 0.048/0.25 = 0.19 (0.08–0.27) for lakes and reservoirs. In the same way, MCF = 0.035 (0.004–0.06) for rivers and streams.

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

Type of Waterbody	CH_4 flux (mg C/m^2/day)	*n* (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 and 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)

Annex 6A.5 Estimation of default emission factors for N_2O 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 N_2O emission from wastewater treatment processes, relatively few studies relate to full-scale treatment plants and provide key information such as influent nitrogen load. We collected 30 data and found that N_2O emission correlated with influent nitrogen load (Figure 6A.1). Emission factors and references are listed in Table 6A.4 and Table 6A.5. 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 widely used treatment processes globally. Although N_2O emissions vary by the type of nitrogen removal process used, more on-site exhaustive monitoring data are required to develop different N_2O emission factors for different treatment processes.

Figure 6A.1 (New) Correlation between influent total nitrogen (TN) loading and N_2O emissions

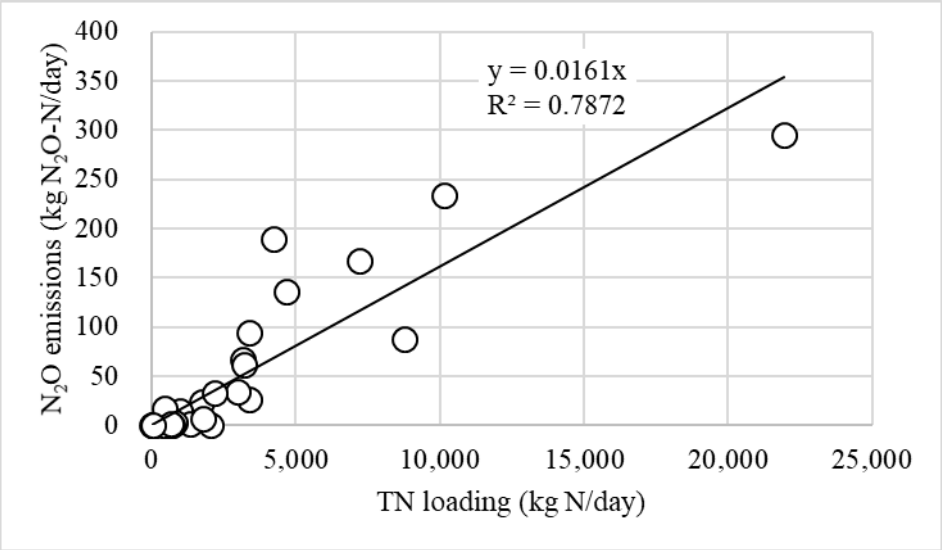


TABLE 6A.4 (NEW)
DEFAULT N_2O EMISSION FACTORS FOR DOMESTIC WASTEWATER TREATMENT PLANTS

N_2O emission factor (kg N_2O-N/kg N)	SD	Maximum	Minimum
0.016	0.012	0.045	0.00016

TABLE 6A.5 (NEW)
N_2O EMISSION FACTORS IN FULL-SCALE DOMESTIC WASTEWATER TREATMENT PLANTS

Type of treatment process[1]	Categories	References	N_2O emission factor (kg N_2O-N/kg N)
AO	Biological Nitrogen Removal (BNR)	Daelman *et al.* (2015)	0.028
AO	BNR	Foley *et al.* (2010)	0.021
AO	BNR	Foley *et al.* (2010)	0.045
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, plug flow	BNR	Ni *et al.* (2015); Pan *et al.* (2016)	0.019
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.

Annex 6A.6 Estimation of default emission factors for N_2O in effluent

Table 6.11 in the *2006 IPCC Guidelines* was based on expert judgment. For the refinement of these guidelines, literature was reviewed for reported yields of N_2O 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 the following literature: Kaplan *et al.* (1978); McElroy *et al.* (1978); Goreau *et al.* (1980); McCarthy *et al.* (1984); Seitzinger *et al.* (1984); Kaplan and Wofsy (1985); Seitzinger (1988); Yoshida (1988); Mantoura *et al.* (1993); Kester *et al.* (1997); Seitzinger and Kroeze (1998); Punshon and Moore (2004); Frame and Casciotti (2010); Beaulieu *et al.* (2011); Yan *et al.* (2012); Zhu *et al.* (2013); Ji *et al.* (2015); Wang *et al.* (2015); He *et al.* (2017).

These data suggested a mean yield of 0.019 kg N_2O-N/kg-N for low oxygen environments (for use in Tier 3 methodologies, if needed) and 0.005 kg N_2O-N/kg-N for well-oxygenated environments (default Tier 1 factor). 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 & Price 2012). The resulting 95percent (two tailed) limits are 0.0041–0.0912 and 0.0–0.0753 respectively.

Annex 6A.7 List of countries by region included in Table 6.10a

Table 6.10a in Section 6.3.1.3 presents default factors for protein consumed as a fraction of protein supplied, fraction of food not consumed and disposed in sewer, and a fraction to represent additional nitrogen introduced to the sewer from household chemicals. The information is provided be geographic region. The list of countries by region can be found in Table 6A.6.

TABLE 6A.6 (NEW)
LIST OF COUNTRIES BY REGION INCLUDED IN TABLE 6.10A

Region	Country
Europe	Albania, Armenia, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxemburg, Macedonia, Moldova, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom
North America and Oceania	Australia, Canada, New Zealand, United States of America
Industrialized Asia	Japan, China, South Korea
Sub-Saharan Africa	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Rep., Chad, Congo-Brazzaville, Congo-Kinshasa, Cote d'Ivoire, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Malawi, Mali, Mauritania, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe
North Africa, West and Central Asia	Algeria, Egypt, Iraq, Israel, Jordan, Kazakhstan, Kuwait, Kyrgyzstan, Lebanon, Libya, Mongolia, Morocco, Oman, Saudi Arabia, Syria, Tajikistan, Tunisia, Turkey, Turkmenistan, Utd Arab Emirates, Uzbekistan, Yemen
South and Southeast Asia	Afghanistan, Bangladesh, Bhutan, Cambodia, India, Indonesia, Iran, Laos, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, Vietnam
Latin America	Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Rep., Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, Uruguay, Venezuela

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ANNEX 1

MAPPING TABLES

Contents

Annex 1 Relating 2019 Refinement to the 2006 IPCC Guidelines

This annex provides a road map for relating sections, equations, tables, figures and boxes in the 2*019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

Type of Refinement: U – Update, NG – New Guidance, NR – No Refinement, R – Removed

CHAPTER 2 WASTE GENERATION, COMPOSITION AND MANAGEMENT DATA

This chapter presents an update of waste generation, composition and management data chapter of the *2006 IPCC Guidelines*. These refinements provide updated default waste generation and treatment data for the year 2010 using UN Classification at country and regional level. The updated waste composition in line with the *2006 IPCC Guidelines* are presented with the additional components of garden waste and nappies. Definition of sludge and estimation of degradable organic carbon (DOC) values are clarified. Default values of carbon content, nitrogen content and DOC of domestic and industrial sludge are presented. Guidance on DOC of sludge is also provided. New Annex 2A.2 with default values of waste composition by country and regional average is provided.

Sections

- Additional introduction has been provided in the introduction part to explain the refinement of this chapter.
- Updated regional default values of waste generation rate and their treatment presented in Section 2.2.1. Guidance on estimation of waste generation rate is clarified.
- Section 2.3.1 provides updated waste composition (in percentage) data. Guidance for countries without data for nappies and garden and yard waste is provided.
- Updated definition of sludge and default values of carbon content, nitrogen content and DOC of sludge from specific industry and domestic sludge and their uncertainties are provided. Clarification on domestic sludge in terms of treated sludge and untreated sludge including their default values are presented.
- New Annex 2A.2 has been added to provide waste composition default values by country and regional averages.

Section Title	Type of Refinement	2006 IPCC Guidelines Section Number	2019 Refinement Section Number
Introduction	U	2.1	2.1
Municipal Solid Waste (MSW): Default data	U	2.2.1	2.2.1
Municipal Solid Waste (MSW): Country specific data	NR	2.2.1	2.2.1
Municipal Solid Waste (MSW): Data from waste stream analysis	NR	2.2.1	2.2.1
Municipal Solid Waste (MSW)	U	2.3.1	2.3.1
Sludge	U/NG	2.3.2	2.3.2
Annex 2A.1 (Updated) MSW Generation and Management Data – by country and regional averages	U	2A.1	2A.1
Annex 2A.2 (New) Waste Composition – by country and regional averages	NG	-	2A.2

Tables

- Table 2.1 has been updated to present waste generation rate and treatment data by regional defaults to the most comparative year of 2010. New column of "Fraction of MSW open dumped" is added in the table to reflect available data on MSW open dumped in some regions.
- Table 2.3 (Updated) presents the update of waste composition by regional defaults with new components of garden waste and nappies.
- Table 2.4a (New) has been added to present default values and uncertainties of carbon content, nitrogen content and DOC of domestic and industrial sludge and provides new default value for domestic sewage treated sludge.
- Table 2A.1 (Updated) presents waste generation and management data for some countries for which data were available to update applicable data for the year 2010. List of countries are according to UN classification by region. Table 2A.1 (Updated) also provides default values of regional averages derived from countries in the region presented in Table 2A.1 (Updated).
- Table 2A.2 (New) presents waste composition by country and region. Data on nappies, and garden and yard waste are provided to reflect the up-to-date waste composition.

Table Title	Type of Refinement	2006 IPCC Guidelines Table Number	2019 Refinement Table Number
MSW generation and treatment data – regional defaults	U	2.1	2.1
MSW composition data by percentage –regional defaults	U	2.3	2.3
Default value and uncertainty of carbon content, nitrogen content and DOC of domestic and industrial sludge (percent of dry matter)	NG	-	2.4a
MSW generation and management data – by country and regional averages	U	2A.1	2A.1
Waste composition by country and regional averages	NG	-	2A.2

Boxes

- Box in this chapter is not refined.

Box Title	Type of Refinement	2006 IPCC Guidelines Box Number	2019 Refinement Box Number
Example of activity data collection for estimation of emissions from solid waste treatment based on waste stream analysis by waste type	NR	2.1	2.1

CHAPTER 3 SOLID WASTE DISPOSAL

This chapter presents an update of the Solid Waste Disposal chapter of the *2006 IPCC Guidelines*. These refinements provide, to the extent of current knowledge, new categories of SWDS including semi-aerobic (managed poorly) and active aeration (well managed and poorly managed). MCF values for these new categories are provided. Default data on fraction of DOC_f by types of waste are updated. Guidance on estimation of DOC lost with leachate from SWDS is provided. The refinement also provides the information on N_2O from SWDS as well as information on the estimation of CH_4 emissions using measured data in the appendices. The IPCC Waste Model has been updated accordingly to the refinement.

Sections

- Section 3.2.1.1 provides information on aerobic management of SWDS including information on calculation of MCF for new categories of aerobic management.
- Section 3.2.3 provides additional information on DOC_f including updated default values and their uncertainties by different type waste (less, moderately and highly decomposable). Information on MCF including default MCF values and definition for new categories of aerobic management as well as information on effect of DOC leaching from SWDS are also provided.
- Additional information of N_2O emission from SWDS is provided in the Appendix 3A.1.
- Information of estimation of CH_4 emission from active aeration SWDS using locally available measured data are provided in the Appendix 3A.2.

Section Title	Type of Refinement	2006 IPCC Guidelines Section Number	2019 Refinement Section Number
First Order Decay	NG	3.2.1.1	3.2.1.1
Methane emissions	NR	3.2.1.1	3.2.1.1
Methane generation	NR	3.2.1.1	3.2.1.1
First order decay basics	NR	3.2.1.1	3.2.1.1
Simple FOD spreadsheet model	NR	3.2.1.1	3.2.1.1
CH_4 generated from decomposable DDOCm	NR	3.2.1.1	3.2.1.1
Simple FOD Spreadsheet Model	NR	3.2.1.1	3.2.1.1
Modelling different geographical or climate regions	NR	3.2.1.1	3.2.1.1
Dealing with different waste categories	NR	3.2.1.1	3.2.1.1
Adjusting waste composition at generation to waste composition at SWDS	NR	3.2.1.1	3.2.1.1
Open burning of Waste at SWDS	NR	3.2.1.1	3.2.1.1
Choice of emission factors and parameters: Degradable organic carbon (DOC)	NR	3.2.3	3.2.3
Choice of emission factors and parameters: Fraction of degradable organic carbon which decomposes (DOC_f)	U/NG	3.2.3	3.2.3
Choice of emission factors and parameters: Methane correction factor (MCF)	U/NG	3.2.3	3.2.3
Choice of emission factors and parameters: Fraction of CH_4 in generated landfill gas (F)	NR	3.2.3	3.2.3
Choice of emission factors and parameters: Oxidation factor (OX)	NR	3.2.3	3.2.3
Choice of emission factors and parameters: Half-life	NR	3.2.3	3.2.3
Choice of emission factors and parameters: Methane recovery	NR	3.2.3	3.2.3
Choice of emission factors and parameters: Delay time	NR	3.2.3	3.2.3

Section Title	Type of Refinement	2006 IPCC Guidelines Section Number	2019 Refinement Section Number
Uncertainties associated with parameters	U	3.7.2.2.	3.7.2.2
Appendix 3A.1 Information on Nitrous Oxide Emission from Solid Waste Disposal Site	NG	-	3A.1
Appendix 3A.2 Information on Estimation of CH_4 Emission from Solid Waste Disposal Site Managed by Active Aeration Using Locally Available Measured Data	NG	-	3A.2

Equations

- Equation 3Ap.1 was introduced to inform the estimation of CH_4 emission from active aeration SWDS using locally measured data.

Equation Title	Type of Refinement	2006 IPCC Guidelines Equation Number	2019 Refinement Equation Number
CH_4 emission from SWDS	NR	3.1	3.1
Decomposable DOC from waste disposal data	NR	3.2	3.2
Transformation from DDOCm to Lo	NR	3.3	3.3
DDOCm accumulated in SWDS at the end of year T	NR	3.4	3.4
DDOCm decomposed at the end of year T	NR	3.5	3.5
CH_4 generated from decayed DDOCm	NR	3.6	3.6
Estimates DOC using default carbon content values	NR	3.7	3.7
MCF for managed SWDS (active aeration)	NG	-	3Ap.1

Tables

- Table 3.0 (New) provides DOC_f for waste types with different degree of decomposition (less, moderately and highly decomposable).
- Table 3.1 (Updated) was introduced to update MCF by SWDS classification. New MCF values for managed poorly semi-aerobic as well as managed well and managed poorly active aeration landfills are presented.
- Table 3.5 (Updated) updates uncertainties associated with the default DOC_f and MCF values.

Table Title	Type of Refinement	2006 IPCC Guidelines Table Number	2019 Refinement Table Number
Fraction of degradable organic carbon which decomposes (DOC_f) for different waste types	NG	-	3.0
SWDS classification and Methane Correction Factors (MCF)	U/NG	3.1	3.1
Oxidation factor (OX) for SWDS	NR	3.2	3.2
Recommended default methane generation rate (k) values under Tier 1	NR	3.3	3.3
Recommended default half-life ($t_{1/2}$) values (yr) under Tier 1	NR	3.4	3.4
Estimates of uncertainties associated with the default activity data and parameters in the FOD method for CH_4 emissions from SWDS	U	3.5	3.5

Boxes

- Box 3.0a (New)provides definition of aerobic active management of SWDS and information on calculation of MCF for different types of aerobic SWDS including managed poorly semi-aerobic, managed well active aeration and managed poorly active aeration.
- Box 3.0b (New) presents information on effect of DOC leachate from SWDS.

Box Title	Type of Refinement	2006 IPCC Guidelines Box Number	2019 Refinement Box Number
Information on calculation of MCF for new category of aerobic management of SWDS (Managed poorly-semi-aerobic, Managed well-active aeration, Managed poorly-active aeration)	NG	-	3.0a
Information on effect of DOC leaching from SWDS	NG	-	3.0b

CHAPTER 5 INCINERATION AND OPEN BURNING OF WASTE

This chapter presents an update of Incineration and Open Burning of Waste chapter of the *2006 IPCC Guidelines*. These refinements present updated information on definition of thermal technology including pyrolysis, gasification and plasma to guide understanding of thermal technology. The refinements provide, to the current knowledge, CH_4 and N_2O emission factors by operation condition and technologies of specific plant. Guidance on reporting of emission is also provided. The default value of oxidation factor in percent of carbon input of MSW open burning is updated. To be consistent with updated information on sludge in Chapter 2, carbon content of sewage sludge was also updated.

Sections

- Section 5.1 provides definition of and information on pyrolysis, gasification and plasma technology.
- Section 5.4.1.3 presents an updated oxidation factor of MSW open burning
- Sections 5.4.2 and 5.4.3 provide default emission factors of CH_4 and N_2O for pyrolysis-melting and gasification-melting for specific plant types.

Section Title	Type of Refinement	2006 IPCC Guidelines Section Number	2019 Refinement Section Number
Introduction	U/NG	5.1	5.1
Methodological issues	U	5.2	5.2
Choice of emission factor	NR	5.4	5.4
CO_2 emission factors	U	5.4.1	5.4.1
Oxidation factor	U	5.4.1.3.	5.4.1.3
CH_4 emission factor	U/NG	5.4.2	5.4.2
N_2O emission factor	U/NG	5.4.3	5.4.3

Tables

- Table 5.2 was updated to provide updated oxidation factor of MSW open burning and carbon content of domestic sludge.
- Table 5.3a (New) presents new default CH_4 emission factor by wet weight of specific pyrolysis and gasification plant.
- Table 5.4a (New) presents new default N_2O emission factor by wet weight of specific pyrolysis and gasification plant.
-

Table Title	Type of Refinement	2006 IPCC Guidelines Table Number	2019 Refinement Table Number
Default data for CO_2 emission factors for incineration and open burning of waste	U	5.2	5.2
CH_4 emission factors for incineration of MSW	NR	5.3	5.3
CH_4 emission factors for pyrolysis-melting and gasification-melting plant of MSW	NG	-	5.3a
N_2O emission factors for incineration of MSW	NR	5.4	5.4
N_2O emission factor for pyrolysis-melting and gasification-melting plant of MSW	NG	-	5.4a

Boxes

- Box 5.0a (New) was introduced to present the basic information on pyrolysis including process and emission.
- Box 5.0b (New) was introduced to present the basic information on gasification including process and emission.
- Box 5.0c (New) was introduced to present the basic information on plasma technology including process and emission
- Box 5.2 (New) presents the information on CH_4 emission from pyrolysis and gasification at laboratory scale to inform dependency on some process factors including types of technology and operation condition related to emission.
- Box 5.3 (New) was introduced to guide the understanding of combined process.

Box Title	Type of Refinement	2006 IPCC Guidelines Box Number	2019 Refinement Box Number
Pyrolysis	NG	-	5.0a
Gasification	NG	-	5.0b
Plasma	NG	-	5.0c
Information of CH_4 emission factors in laboratory scale	NG	-	5.2
Combined system	NG	-	5.3

CHAPTER 6 WASTEWATER TREATMENT AND DISCHARGE

This chapter presents an update of the Wastewater Treatment and Discharge chapter of the *2006 IPCC Guidelines*. 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 GHG emissions from wastewater treatment (including sludge treatment that occurs within the WWTP). In addition, these refinements present an updated section on N_2O emissions to better address emissions from domestic wastewater, including centralised treatment plants, and to include emissions from industrial wastewater.

Sections

- New subsections have been added to the Introduction to provide a discussion of technical topics related to new guidance presented in the chapter.
- Sections that discuss CH_4 emissions from domestic and industrial wastewater, as well as N_2O emissions from domestic wastewater have been updated to reflect the refinements presented throughout the chapter.
- A new section, Section 6.4, has been added to provide new guidance on estimating N_2O emissions from industrial wastewater.
- A series of annexes have been included to provide additional details related to new or revised emission factors and default activity data.
- An appendix has been added to provide a discussion of non-biogemic CO_2 emissions from wastewater treatment and discharge.

Section Title	Type of Refinement	2006 IPCC Guidelines Section Number	2019 Refinement Section Number
Introduction	U	6.1	6.1
Centralised treatment systems	NG	-	6.1.1
Decentralised treatment systems of domestic wastewater (onsite sanitation)	NG	-	6.1.2
Emissions from receiving waters	NG	-	6.1.3
Changes compared to 1996 Guidelines and *Good Practice* Guidance	U (only Section number)	6.1.1	6.1.4
Changes compared to *2006 IPCC Guidelines*	NG	-	6.1.5
Methodological issues	U	6.2.1	6.2.1
Choice of method (CH_4 emissions from domestic wastewater)	U, NG	6.2.2.1	6.2.2.1
Choice of emission factors (CH_4 emissions from domestic wastewater)	U	6.2.2.2	6.2.2.2
Choice of activity data (CH_4 emissions from domestic wastewater)	U, NG	6.2.2.3	6.2.2.3
Uncertainties (CH_4 emissions from domestic wastewater)	U	6.2.2.5	6.2.2.5
Choice of method (CH_4 emissions from industrial wastewater)	U	6.2.3.1	6.2.3.1
Choice of emission factors (CH_4 emissions from industrial wastewater)	U	6.2.3.2	6.2.3.2
Nitrous oxide emissions from domestic wastewater	U, NG	6.3	6.3
Methodological issues (N_2O emissions from domestic wastewater)	U, NG	6.3.1	6.3.1
Choice of method (N_2O emissions from domestic wastewater)	U, NG	6.3.1.1	6.3.1.1

Section Title	Type of Refinement	2006 IPCC Guidelines Section Number	2019 Refinement Section Number
Choice of emission factors (N_2O emissions from domestic wastewater)	U, NG	6.3.1.2	6.3.1.2
Choice of activity data (N_2O emissions from domestic wastewater)	U, NG	6.3.1.3	6.3.1.3
Uncertainties (N_2O emissions from domestic wastewater)	U	6.3.3	6.3.3
Nitrous oxide emissions from industrial wastewater	NG	-	6.4 (and all subsections)
Appendix 6A.1 Non-biogenic (fossil) CO_2 emissions from wastewater treatment and discharge	NG	-	6A.1
Annex 6A.1 Summary data for pit latrine use, no sanitation facility, and groundwater use by country	U, NG	-	6A.1
Annex 6A.2 Derivation of the maximum CH_4 producing potential (B_O) for domestic wastewater	U	-	6A.2
Annex 6A.3 Estimation of default methane conversion factors for CH_4 in centralised wastewater treatment plants treating domestic wastewater	U	-	6A.3
Annex 6A.4 Calculation of MCF for methane emissions from sewage discharges	U, NG	-	6A.4
Annex 6A.5 Estimation of default emission factors for N_2O in domestic wastewater treatment plants	U, NG	-	6A.5
Annex 6A.6 Estimation of default emission factors for N_2O in effluent	U, NG	-	6A.6
Annex 6A.7 List of countries by region included in Table 6.10a	NG	-	6A.7

Equations

- Equation 6.1 in *2006 IPCC Guidelines* was divided to Equations 6.1 (Updated), 6.1a (New), and 6.3a (New) to emphasize calculation by individual pathways.
- Equation 6.3 was updated to remove the correction factor for additional industrial BOD, as it was added to Equation 6.3a (New).
- Equations 6.3b (New) was introduced to allow conversion on sludge (t/yr) to organic component removed as sludge (S in updated Equation 6.1).
- Equation 6.3c (New) was introduced to estimate the organic component removed from wastewater (in the form ofsludge) from septic systems (S in updated Equation 6.1).
- Equation 6.3d (New) was introduced to estimate the organic component discharged to aquatic environments in treated domestic wastewater effluent.
- Equation 6.9 was updated to reflect the calculation of N_2O emissions from domestic wastewater treatment and expanded to cover all wastewater treatment plants.
- Equation 6.7 was updated to reflect the calculation of N_2O emissions from the domestic wastewater effluent discharged to aquatic environments.
- Equation 6.10 (New) was introduced to better reflect the calculation of total nitrogen in domestic wastewater.
- Equation 6.10a (New) was introduced to estimate the amount of protein consumed when national statistics on protein consumed are not available.
- Equation 6.8 was updated to reflect the calculation of nitrogen in effluent from domestic wastewater treatment.

- Equations 6.11 (New) through 6.14 (New) were introduced to allow for calculation of N_2O emissions from industrial wastewater treatment.

Equation Title	Type of Refinement	2006 IPCC Guidelines Equation Number	2019 Refinement Equation Number
Total CH_4 emissions from domestic wastewater for each treatment/discharge pathway or system	U	6.1	6.1
Total CH_4 emissions from domestic wastewater treatment and discharge	U	6.1	6.1a
CH_4 emission factor for each domestic wastewater treatment/discharge pathway or system	NR	6.2	6.2
Total organically degradable material in domestic wastewater	U	6.3	6.3
Total organics in domestic wastewater by treatment/discharge pathway or system	NG	6.1	6.3a
Organic component removed as sludge from aerobic treatment plants	NG	-	6.3b
Organic component removed as sludge from septic systems	NG	-	6.3c
Total organics in treated domestic wastewater effluent	NG	-	6.3d
Total CH_4 emissions from industrial wastewater	NR	6.4	6.4
CH_4 emission factor for industrial wastewater	NR	6.5	6.5
N_2O emissions from domestic wastewater treatment plants	U	6.9	6.9
N_2O emissions from domestic wastewater effluent	U	6.7	6.7
Total nitrogen in domestic wastewater by treatment pathway	NG	-	6.10
Protein consumed	NG	-	6.10a
Total nitrogen in domestic wastewater effluent	U	6.8	6.8
N_2O emissions from industrial wastewater treatment plants	NG	-	6.11
N_2O emissions from industrial wastewater effluent	NG	-	6.12
Total nitrogen in industrial wastewater	NG	-	6.13
Total nitrogen in industrial wastewater effluent	NG	-	6.14

Tables

- Table 6.1 was updated to reflect refinements to the overall wastewater treatment systems and discharge pathways covered in this chapter.
- Tables 6.3, 6.7, 6.8, and 6.11 have been updated, and Tables 6.8a (New) and 6.13 (New) introduced, to reflect updated or new emissions factors for CH_4 and N_2O emissions and the resulting uncertainty ranges. An alternate set of emission factors is provided for CH_4 and N_2O emissions from wastewater after disposal of untreated wastewater or wastewater treatment effluent into aquatic environments when the country has activity data to differentiate the conditions of the waterbody receiving the discharge.
- Tables 6.6a (New) and 6.6b (New) have been introduced to provide default values for the removal of organic component from wastewater as sludge (K_{REM}) and wastewater treatment organics removal fractions (TOW_{REM}), according to treatment type.
- Table 6.10a (New) provides regional default factors for sources of nitrogen in domestic wastewater.

- Table 6.10b (New) has been added to provide additional country-specific information on the use of food waste disposals if needing to calculate a country-specific value for the fraction of protein not consumed.
- Table 6.10c (New) has been introduced to provide default values for the removal of nitrogen from wastewater (N_{REM}).
- Table 6.12 (New) has been added to provide default values for use in estimating N_2O emissions from industrial wastewater.

Table Title	Type of Refinement	2006 IPCC Guidelines Table Number	2019 Refinement Table Number
CH_4 and N_2O emission potentials for wastewater and sludge treatment and discharge systems	U	6.1	6.1
Default maximum CH_4 producing capacity (B_o) for domestic wastewater	NR	6.2	6.2
Default MCF values and resultant EFs for domestic wastewater by type of treatment system and discharge pathway, j	U	6.3	6.3
Estimated BOD_5 values in domestic wastewater for selected regions and countries	NR	6.4	6.4
Suggested values for urbanisation (U) and degree of utilisation of treatment, discharge pathway or method (Ti,j) for each income group for selected countries	NR	6.5	6.5
Example of the application of default values for degrees of treatment utilization (T) by income groups	NR	6.6	6.6
Removal of organic component from wastewater as sludge (K_{REM}) according to treatment type	NG	-	6.6a
Wastewater treatment organics removal fractions (TOW_{REM}) according to treatment type	NG	-	6.6b
Default uncertainty ranges for domestic wastewater	U	6.7	6.7
Default MCF values and resultant EFs for industrial wastewater	U	6.8	6.8
Default EF values for domestic and industrial wastewater	NG	6.11	6.8a
Default factors for domestic wastewater	NG	-	6.10a
Estimate on use of food waste disposal in sewer	NG	-	6.10b
Wastewater treatment nitrogen removal fractions (N_{REM}) according to treatment type	NG	-	6.10c
N_2O methodology default data	U	6.11	6.11
Examples of industrial wastewater data	NG	-	6.12
Default uncertainty ranges for industrial wastewater	NG	-	6.13
Summary of literature investigating fossil organic carbon in wastewater	NG	-	6Ap.1
Summary data for pit latrine use, no sanitation facility, and groundwater use by country	NG	-	6A.1
MCFs based on measured CH_4 in full-scale domestic wastewater treatment plants	NG		6A.2
Summary of literature investigating CH_4 emissions from wastewater discharge	NG	-	6A.3
Default N_2O emission factors for domestic wastewater treatment plants	NG	-	6A.4

Table Title	Type of Refinement	2006 IPCC Guidelines Table Number	2019 Refinement Table Number
N_2O emission factors in full-scale domestic wastewater treatment plants	NG	-	6A.5
List of countries by region included in Table 6.10a (New)	NG	-	6A.6

Figures

- Figure 6.1 was updated to reflect refinements to the overall wastewater treatment systems and discharge pathways covered in this chapter.
- Figure 6.1a (New) was introduced to present information on the use of pit latrines by low-income country populations.
- Figures 6.2 and 6.3 were updated to reflect refinements to the tier methodologies for CH_4 emissions, particularly related to emissions from discharge.
- Figures 6.4 (New) and 6.6 (New) were introduced to reflect refinements to the tier methodologies for N_2O emissions.
- Figure 6.5 (New) was introduced to show the sources of nitrogen in domestic wastewater.
- Figure 6A.1 (New) presents information on the correlation of influent nitrogen load entering wastewater treatment plants to N_2O emissions.

Figure Title	Type of Refinement	2006 IPCC Guidelines Figure Number	2019 Refinement Figure Number
Wastewater treatment systems and discharge pathways	U	6.1	6.1
Percentage of low-income country populations using pit latrines as a primary sanitation facility	NG	-	6.1a
Decision tree for CH_4 emissions from domestic wastewater	U	6.2	6.2
Decision tree for CH_4 emissions from industrial wastewater	U	6.3	6.3
Decision tree for N_2O emissions from domestic wastewater	NG	-	6.4
Nitrogen in domestic wastewater treatment	NG	-	6.5
Decision tree for N_2O emissions from industrial wastewater	NG	-	6.6
Correlation between influent N load and N_2O emission	NG	-	6A.1

ANNEX 2

WORKSHEETS

Contents

Sector	**Waste**		
Category	**Domestic Wastewater Treatment and Discharge**		
Category Code	**4D1**		
Sheet	**1 of 8 Estimation of Total Organically Degradable Material in Domestic Wastewater (Updated)**		
STEP 1			
Region or City	A	B	C
	Population (P) cap	Degradable organic component (BOD) (kg BOD/cap/yr) [1]	Organically degradable material in wastewater (TOW) (kg BOD/yr)
			C = A x B
		Total	

[1] g BOD/cap/day x 0.001 x 365 = kg BOD/cap/yr

Sector		**Waste**				
Category		**Domestic Wastewater Treatment and Discharge**				
Category Code		**4D1**				
Sheet		**2 of 8 Estimation of Total Organics in Domestic Wastewater by Treatment Discharge Pathway or System (New)**				
STEP 1						
Type of treatment or discharge pathway	**Income group**	A Organically degradable material in wastewater (TOW) (kg BOD/yr)	B Fraction of population income group *i* in inventory year (U_i) (fraction)	C Degree of utilization of treatment/ discharge pathway or system, *j*, for each income group *i* (T_{ij}) (fraction)	D Correction factor for industrial BOD discharged in sewers (I_j)[1]	E Total organics in wastewater by income group and pathway (TOW_{ij}) (kg BOD/yr)
		Sheet 1 of 8				E = A x B x C x D
	Rural					
	Urban high income					
	Urban low income					
	Rural					
	Urban high income					
	Urban low income					
	Rural					
	Urban high income					
	Urban low income					
Add as needed						
					Total	

[1] Correction factor for additional industrial BOD discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00) (see page 6.22 of the *2019 Refinement*).

Sector	**Waste**			
Category	**Domestic Wastewater Treatment and Discharge**			
Category Code	**4D1**			
Sheet	**3 of 8 Estimation of Organic Component Removed as Sludge from Aerobic Treatment Plants (New)**			
STEP 1A				
Type of treatment or discharge	A	B	C	D
	Amount of sludge removed from wastewater treatment (S_{mass}) (tonnes sludge/yr)	Sludge factor[1] (K_{rem}) (kg BOD/kg sludge)	Conversion factor of tonnes into kg 1000	Organic component removed as sludge ($S_{aerobic}$) (kg BOD/yr)
				D = A x B x C
Add as needed				
			Total	

[1] See Table 6.6a for default values.

Sector	**Waste**			
Category	**Domestic Wastewater Treatment and Discharge**			
Category Code	**4D1**			
Sheet	**4 of 8 Estimation of Organic Component Removed as Sludge from Septic Systems (New)**			
STEP 1A				
	A	B	C	D
Type of treatment or discharge	Total organics in septic systems (TOW_{septic}) (kg BOD/yr)	Fraction of population managing their septic tank in compliance[1] (F) (fraction)	Faction of organics removed in sludge[2] (0.5) (fraction)	Organic component removed as sludge (S_{septic}) (kg BOD/yr)
	Sheet 2 of 8			D = A x B x C
Add as needed				
			Total	

[1] Default value is 0.5.

[2] Default value is 0.5.

Sector	**Waste**
Category	**Domestic Wastewater Treatment and Discharge**
Category Code	**4D1**
Sheet	**5 of 8 Estimation of Total Organics in Treated Domestic Wastewater Effluent (New)**

STEP 1B				
	A	B	C	D
Type of treatment or discharge	Organically degradable material in wastewater (TOW) (kg BOD/yr)	Fraction of wastewater treated exclusively by each wastewater treatment type *j*[1] (T_j) (fraction)	Faction of organics removed in sludge[2] ($TOW_{REM,j}$) (fraction)	Total organics in treated domestic wastewater effluent ($TOW_{EFFtreat}$) (kg BOD/yr)
	Sheet 1 of 8			D = A x B x (1 – C)
Add as needed				
			Total	

[1] See Table 6.5.

[2] See Table 6.6b.

Sector	**Waste**		
Category	**Domestic Wastewater Treatment and Discharge**		
Category Code	**4D1**		
Sheet	**6 of 8 Estimation of CH_4 Emission Factor for Domestic Wastewater**		
STEP 2			
Type of treatment or discharge	A	B	C
	Maximum methane producing capacity (B_o) (kg CH_4/kgBOD)	Methane correction factor for each treatment system (MCF_j)	Emission factor (EF_j) (kg CH_4/kg BOD)
			C = A x B
Add as needed			

Sector		**Waste**				
Category		**Domestic Wastewater Treatment and Discharge**				
Category Code		**4D1**				
Sheet		**7 of 8 Estimation of CH_4 Emissions from Domestic Wastewater for Each Income Group and Treatment Discharge Pathway (Updated)**				
STEP 3						
		A	B	C	D	E
Type of treatment or discharge pathway	**Income group**	Total organics in wastewater by income group and pathway (TOW_j) (kg BOD/yr)	Sludge removed (S_j)[1] (kg BOD/yr)	Emission Factor (EF_j) (kg CH_4/kg BOD)	Methane recovered and flared (R_j) (kg CH_4/yr)	Net methane emissions (CH_4) (kg CH_4/yr)
		Sheet 2 of 8	Sheet 3 and 4 of 8	Sheet 6 of 8		E = [(A - B) x C - D]
	Rural					
	Urban high income					
	Urban low income					
	Rural					
	Urban high income					
	Urban low income					
	Rural					
	Urban high income					
	Urban low income					
Add as needed						
					Total	

[1] Default value is zero for systems other than centralized aerobic treatment systems or septic systems.

Sector	**Waste**
Category	**Domestic Wastewater Treatment and Discharge**
Category Code	**4D1**
Sheet	**8 of 8 Estimation of Total CH_4 Emissions from Domestic Wastewater Treatment and Discharge (New)**

STEP 3		
A	B	C
Total methane emissions (CH_4) (kg CH_4/yr)	Conversion factor of kg into Gg 10^{-6}	Total methane emissions (CH_4) (Gg CH_4/yr)
Sheet 7 of 8		C = A x B

Sector	**Waste**			
Category	**Industrial Wastewater Treatment and Discharge**			
Category Code	**4D2**			
Sheet	**1 of 3 Total Organic Degradable Material in Wastewater for each Industry Sector**			
STEP 1				
	A	B	C	D
Industry Sectors	Total industry product (P_i) ($t_{product}$/yr)	Wastewater generated (W_i) ($m^3/t_{product}$)	Chemical Oxygen Demand (COD_i) (kg COD/m^3)	Total organic degradable material in wastewater for each industry sector (TOW_i) (kg COD/yr)
				D = A x B x C
Industrial sector 1				
Industrial sector 2				
Industrial sector 3				
add as needed				
			Total	

Sector	**Waste**		
Category	**Industrial Wastewater Treatment and Discharge**		
Category Code	**4D2**		
Sheet	**2 of 3 Estimation of CH_4 Emission Factor for Industrial Wastewater**		
STEP 2			
	A	B	C
Type of treatment or discharge	Maximum Methane Producing Capacity (B_0) (kg CH_4/kg COD)	Methane Correction Factor for the Treatment System (MCF_j)	Emission Factor (EF_j) (kg CH_4/kg COD)
			C = A x B
add as needed			

Sector	**Waste**
Category	**Industrial Wastewater Treatment and Discharge**
Category Code	**4D2**
Sheet	**3 of 3 Estimation of CH_4 Emissions from Industrial Wastewater**

STEP 3							
		A	B	C	D	E	F
Industrial sector	Type of treatment or discharge pathway	Total organic degradable material in wastewater for each industry sector (TOW_i) (kg COD/yr)	Sludge removed in each industry sector (S_i) (kg COD/yr)	Emission factor for each treatment system (EF_i) (kg CH_4/kg COD)	Recovered CH_4 in each industry sector (R_i) (kg CH_4/yr)	Conversion factor of kg into Gg 10^{-6}	Net methane emissions (CH_4) (kg CH_4/yr)
		Sheet 1 of 3		Sheet 2 of 3			F = [[(A – B) x C] – D] x E
Industrial sector 1							
Industrial sector 2							
Industrial sector 3							
add as needed							
						Total	

Sector	**Waste**
Category	**Domestic Wastewater Treatment and Discharge**
Category Code	**4D1**
Sheet	**1 of 5 Estimation of Nitrogen in Domestic Wastewater (New)**

STEP 1

Type of treatment or discharge pathway	A Population served by the treatment pathway, *j* ($P_{treatment}$) (people/year)	B Per capita protein consumption (Protein) (kg/person/ year)	C Fraction of nitrogen in protein (F_{NPR}) (kg N/kg protein)	D Additional nitrogen from household products[1] N_{HH} (fraction)	E Fraction of non-consumed protein and additional nitrogen from household products ($F_{NON-CON}$) (-)	F Fraction of industrial and commercial co-discharged protein ($F_{IND-COM}$) (-)	G Total nitrogen in domestic wastewater (treated) by treatment pathway (TN_{DOM_j}) (kg N/year)
							G = (A x B x C x D x E x F)
Add as needed							
						Total	

[1] Default value is 1.1.

Sector	Waste	
Category	**Domestic Wastewater Treatment and Discharge**	
Category Code	**4D1**	
Sheet	**2 of 5 Estimation of Protein Consumed (New)**	
STEP 1		
A	B	C
Annual per capita protein supply ($Protein_{SUPPLY}$) (kg protein/person/year)	Fraction of protein consumed (FPC) (fraction)	Protein consumed (Protein) (kg protein/person/year)
		C = (A x B)
Total		

Sector	**Waste**			
Category	**Domestic Wastewater Treatment and Discharge**			
Category Code	**4D1**			
Sheet	**3 of 5 Estimation of Nitrogen in Effluent from Domestic Wastewater (New)**			
STEP 1				
	A	B	C	D
Type of treatment or discharge pathway	Total nitrogen in domestic wastewater (TN_{DOM}) (kg N/year)	Fraction of wastewater treated exclusively by each wastewater treatment type *j* (T_j) (fraction)	Fraction of total wastewater nitrogen removed during wastewater treatment per treatment type j ($N_{REM,j}$) (-)	Total nitrogen in effluent ($N_{EFFLUENT,DOM}$) (kg N/year)
	Sheet 1 of 4			D = [A x (B x (1 - C))]
Add as needed				
			Total	

Sector	**Waste**
Category	**Domestic Wastewater Treatment and Discharge**
Category Code	**4D1**
Sheet	**4 of 5 Estimation of N_2O Emissions from Domestic Wastewater Treatment Plants for each Income Group and Treatment Discharge Pathway or System (New)**

STEP 3

Income group	**Type of treatment or discharge pathway**	A Fraction of population in income group *i* in inventory year (U_i) (fraction)	B Degree of utilisation of treatment/ discharge pathway or system, *j*, for each income group, *i* (T_{ij}) (fraction)	C Emission factor for treatment/discharge pathway or system, *j* (EF_j) (kg N_2O-N/kg N)	D Total nitrogen in domestic wastewater (treated) (TN_{DOM}) (kg N/year)	E Conversion factor of kg N_2O-N into kg N_2O 44/28	F N_2O emissions from domestic wastewater treatment plants in inventory year (N_2O $Plants_{DOM}$) (kg N_2O/yr)
					Sheet 1 of 4		F = A x B x C x D x E
Rural							
Urban high income							
Urban low income							
						Total	

Sector	**Waste**			
Category	**Domestic Wastewater Treatment and Discharge**			
Category Code	**4D1**			
Sheet	**5 of 5 Estimation of N2O Emissions from Domestic Wastewater Effluent (New)**			
STEP 4				
Type of treatment or discharge pathway	A	B	C	D
	Nitrogen in effluent ($N_{EFFLUENT,DOM}$) (kg N/year)	Emission factor ($EF_{EFFLUENT}$) (kg N_2O-N/kg N)	Conversion factor of kg N_2O-N into kg N_2O 44/28	Total N_2O emissions (kg N_2O/year)
	Sheet 3 of 5	See Table 6.8a (New)		D = A x B x C
			Total	

Sector	**Waste**			
Category	**Industrial Wastewater Treatment and Discharge**			
Category Code	**4D2**			
Sheet	**1 of 4 Estimation of Nitrogen in Industrial Wastewater (New)**			
STEP 1				
	A	B	C	D
Industry Sectors	Total industry product (P_i) ($t_{product}$/yr)	Wastewater generated (W_i) ($m^3/t_{product}$)	Total nitrogen (TN_i) (kg N/m^3)	Total nitrogen in industrial wastewater (treated) (TN_{INDi}) (kg N/year)
				D = (A x B x C)
Industrial sector 1				
Industrial sector 2				
Industrial sector 3				
Add as needed				
			Total	

Sector	**Waste**			
Category	**Industrial Wastewater Treatment and Discharge**			
Category Code	**4D2**			
Sheet	**2 of 4 Estimation of Nitrogen in Effluent from Industrial Wastewater (New)**			
STEP 1				
	A	B	C	D
Type of treatment or discharge pathway	Total nitrogen in industrial wastewater (TN_{INDi}) (kg N/year)	Fraction of wastewater treated exclusively by each wastewater treatment type *j* (T_j) (fraction)	Fraction of total wastewater nitrogen removed during wastewater treatment per treatment type *j* ($N_{REM,j}$) (-)	Total nitrogen in effluent ($N_{EFFLUENT,IND}$) (kg N/year)
	Sheet 1 of 4			D = [A x (B x (1 - C))]
Add as needed				
			Total	

Sector	**Waste**
Category	**Industrial Wastewater Treatment and Discharge**
Category Code	**4D2**
Sheet	**3 of 4 Estimation of N_2O Emissions from Industrial Wastewater Treatment Plants (New)**

STEP 3					
Type of treatment	A	B	C	D	E
	Degree of utilisation of treatment/discharge pathway or system, *j*, for each industry, *i*	Emission factor for treatment/discharge pathway or system, *j*	Nitrogen in wastewater from industry, *i* (treated)	Conversion factor of kg N_2O-N into kg N_2O	N_2O emissions from industrial wastewater treatment plants in inventory year
	($T_{i,j}$) (fraction)	(EF_j) (kg N_2O-N/kg N)	(TN_{INDi}) (kg N/year)	44/28	(N_2O $Plants_{IND}$) (kg N_2O/year)
			Sheet 1 of 4		E = (A x B x C x D)
Industrial sector 1					
Industrial sector 2					
Industrial sector 3					
Add as needed					
				Total	

Sector	Waste			
Category	**Industrial Wastewater Treatment and Discharge**			
Category Code	**4D2**			
Sheet	**4 of 4 Estimation of N_2O Emissions from Industrial Wastewater Effluent (New)**			
STEP 4				
Type of treatment or discharge pathway	A	B	C	D
	Nitrogen in effluent ($N_{EFFLUENT,IND}$) (kg N/year)	Emission factor ($EF_{EFFLUENT}$) (kg N_2O-N/kg N)	Conversion factor of kg N_2O-N into kg N_2O 44/28	Total N_2O emissions from industrial wastewater effluent ($N_2OEffluent_{IND}$) (kg N_2O/year)
	Sheet 2 of 4	See Table 6.8a		D = A x B x C
Add as needed				
			Total	