CHAPTER 6

WASTEWATER TREATMENT AND DISCHARGE

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6 WASTEWATER TREATMENT AND DISCHARGE

6.1 INTRODUCTION

Wastewater can be a source of methane (CH_4) when treated or disposed anaerobically. 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 of biogenic origin and should not be included in national total emissions. Wastewater originates from a variety of domestic, commercial and industrial sources and may be treated on site (uncollected), sewered to a centralized 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. Also, treatment and discharge systems can differ for rural and urban users, and for urban high income and urban low-income users.

Sewers may be open or closed. 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. In most developed countries and in high-income urban areas in other countries, sewers are usually closed and underground. Wastewater in closed underground sewers is not believed to be a significant source of CH_4. The situation is different for wastewater in open sewers, because it is subject to heating from the sun and the sewers may be stagnant allowing for anaerobic conditions to emit CH_4. (Doorn *et al*., 1997).

The most common wastewater treatment methods in developed countries are centralized 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.

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 centralized 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 meters deep, which may be fitted with a toilet for convenience. Figure 6.1 shows different pathways for wastewater treatment and discharge.

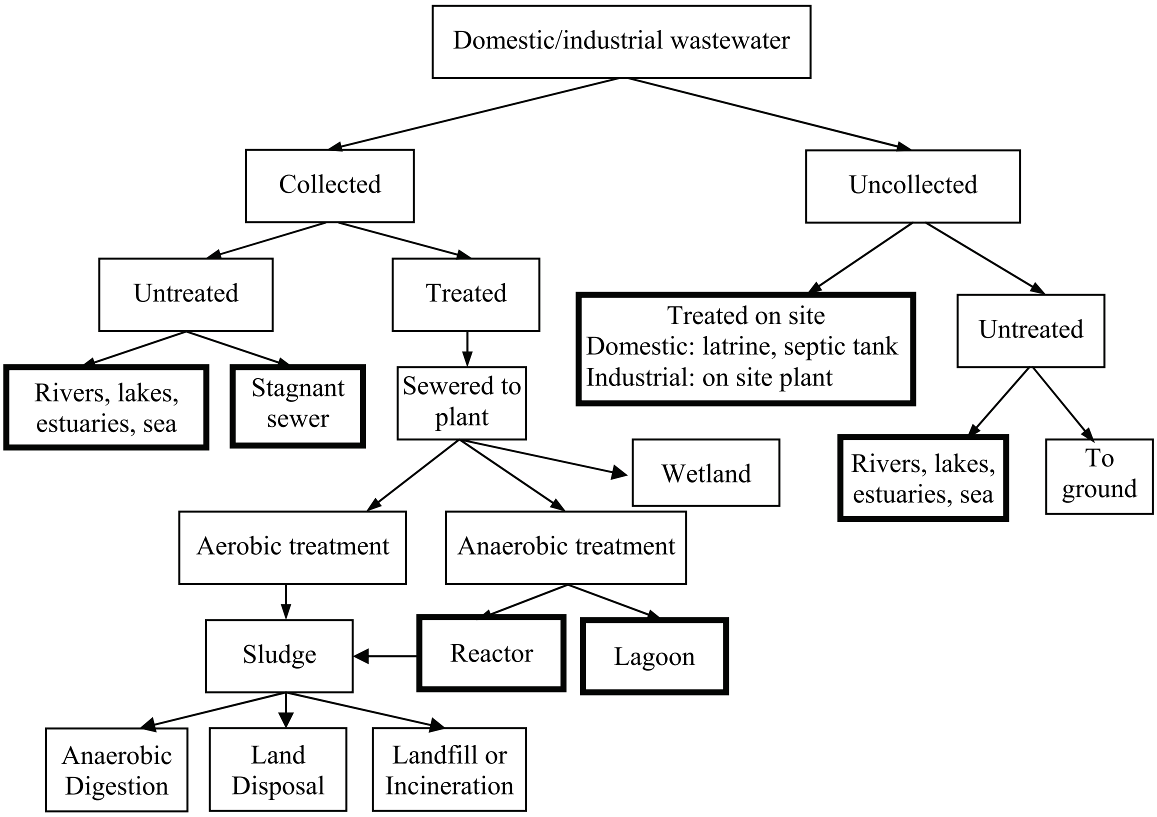
Centralized wastewater treatment methods can be classified as primary, secondary, and tertiary treatment. In primary treatment, physical barriers remove larger solids from the wastewater. Remaining particulates are then allowed to settle. Secondary treatment consists of a combination of biological processes that promote biodegradation by micro-organisms. These may 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 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 and is not accounted for in this category. 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. 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. Some sludge is incinerated before land disposal. N_2O emissions from sludge and wastewater spread on agricultural land are considered in Section 11.2, N_2O emissions from managed

[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.

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 Wastewater treatment systems and discharge pathways



Note: Emissions from boxes with bold frames are accounted for in this chapter.

Methane (CH_4)

Wastewater as well as its sludge components can produce CH_4 if it degrades anaerobically. The extent of CH_4 production depends primarily on the quantity of degradable organic material in the wastewater, the temperature, and the type of treatment system. With increases in temperature, the rate of CH_4 production increases. This is especially important in uncontrolled systems and in warm climates. Below 15°C, significant CH_4 production is unlikely because methanogens are not active and the lagoon will serve principally as a sedimentation tank. However, when the temperature rises above 15°C, CH_4 production is likely to resume.

The principal factor in determining the CH_4 generation potential of wastewater is the amount of degradable organic material in the wastewater. Common parameters used to measure the organic component of the wastewater are the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Under the same conditions, wastewater with higher COD, or BOD concentrations will generally yield more CH_4 than wastewater with lower COD (or BOD) concentrations.

The BOD concentration indicates only the amount of carbon that is aerobically biodegradable. The standard measurement for BOD is a 5-day test, denoted as BOD_5. The term 'BOD' in this chapter refers to BOD_5. The COD measures the total material available for chemical oxidation (both biodegradable and non-biodegradable). [2] Since the BOD is an aerobic parameter, it may be less appropriate for determining the organic components in anaerobic environments. Also, both the type of wastewater and the type of bacteria present in the wastewater influence the BOD concentration of the wastewater. Usually, BOD is more frequently reported for domestic wastewater, while COD is predominantly used for industrial wastewater.

[2] In these guidelines, COD refers to chemical oxygen demand measured using the dichromate method. (American Public Health Association, American Water Works Association and Water Environment Federation, 1998)

Nitrous Oxide (N_2O)

Nitrous oxide (N_2O) is associated with the degradation of nitrogen components in the wastewater, e.g., urea, nitrate and protein. Domestic wastewater includes human sewage mixed with other household wastewater, which can include effluent from shower drains, sink drains, washing machines, etc. Centralized wastewater treatment systems may include a variety of processes, ranging from lagooning to advanced tertiary treatment technology for removing nitrogen compounds. After being processed, treated effluent is typically discharged to a receiving water environment (e.g., river, lake, estuary, etc.). Direct emissions of N_2O may be generated during both nitrification and denitrification of the nitrogen present. Both processes can occur in the plant and in the water body that is receiving the effluent. Nitrification is an aerobic process converting ammonia and other nitrogen compounds into nitrate (NO_3^-), while denitrification occurs under anoxic conditions (without free oxygen), and involves the biological conversion of nitrate into dinitrogen gas (N_2). Nitrous oxide can be an intermediate product of both processes, but is more often associated with denitrification.

Treatment and Discharge Systems and CH_4 and N_2O Generation Potential

Treatment systems or discharge pathways that provide anaerobic environments will generally produce CH_4 whereas systems that provide aerobic environments will normally produce little or no CH_4. For example, for lagoons without mixing or aeration, their depth is a critical factor in CH_4 production. Shallow lagoons, less than 1 metre in depth, generally provide aerobic conditions and little or no CH_4 is likely to be produced. Lagoons deeper than about 2-3 metres will generally provide anaerobic environments and significant CH_4 production can be expected.

Table 6.1 presents the main wastewater treatment and discharge systems in developed and developing countries, and their potentials to emit CH_4 and N_2O.

TABLE 6.1
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
Collected	Untreated	River discharge		Stagnant, oxygen-deficient rivers and lakes may allow for anaerobic decomposition to produce CH_4. Rivers, lakes and estuaries are likely sources of N_2O.
Collected	Untreated	Sewers (closed and under ground)		Not a source of CH_4/N_2O.
Collected	Untreated	Sewers (open)		Stagnant, overloaded open collection sewers or ditches/canals are likely significant sources of CH_4.
Collected	Treated	Aerobic treatment	Centralized aerobic wastewater treatment plants	May produce limited CH_4 from anaerobic pockets. Poorly designed or managed aerobic treatment systems produce CH_4. Advanced plants with nutrient removal (nitrification and denitrification) are small but distinct sources of N_2O.
Collected	Treated	Aerobic treatment	Sludge anaerobic treatment in centralized aerobic wastewater treatment plant	Sludge may be a significant source of CH_4 if emitted CH_4 is not recovered and flared.
Collected	Treated	Aerobic treatment	Aerobic shallow ponds	Unlikely source of CH_4/N_2O. Poorly designed or managed aerobic systems produce CH_4.
Collected	Treated	Anaerobic treatment	Anaerobic lagoons	Likely source of CH_4. Not a source of N_2O.
Collected	Treated	Anaerobic treatment	Anaerobic reactors	May be a significant source of CH_4 if emitted CH_4 is not recovered and flared.
Uncollected	Septic tanks			Frequent solids removal reduces CH_4 production.
Uncollected	Open pits/Latrines			Pits/latrines are likely to produce CH_4 when temperature and retention time are favourable.
Uncollected	River discharge			See above.

6.1.1 Changes compared to 1996 Guidelines and Good Practice Guidance

The Revised 1996 IPCC Guidelines (*1996 Guidelines*, IPCC, 1997) included separate equations to estimate emissions from wastewater and from sludge removed from the wastewater. The distinction has been removed because the CH_4 generation capacities for sludge and wastewater with dissolved organics are generally the same, and separated equations are not necessary. The *2006 Guidelines* include a new section to estimate CH_4 emissions from uncollected wastewater. Also, guidance has been included to estimate N_2O emissions from advanced wastewater treatment plants. Furthermore, the industrial wastewater section has been simplified by suggesting that only the most significant industrial sources need to be addressed. See Section 6.2.3.

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, and agricultural land should be taken into consideration.

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

Wastewater treatment facilities 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 is expressed as R in Equation 6.1.

Note that only a few countries may have sludge removal data and CH_4 recovery data. The default for sludge removal is zero. 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.

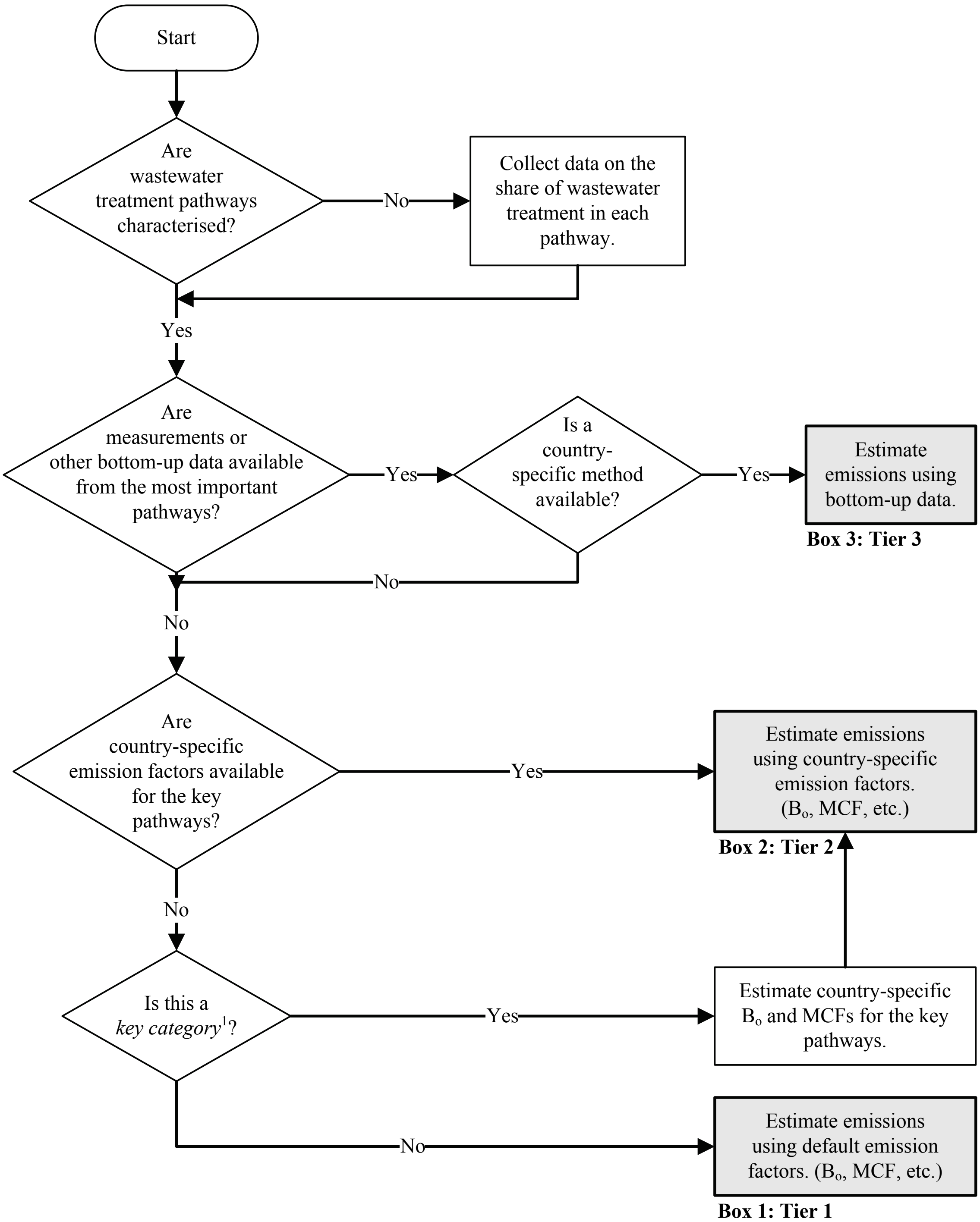
Emissions from flaring are not significant, as the CO_2 emissions are of biogenic origin, and the CH_4 and N_2O emissions are very small so *good practice* in the Waste Sector does not require their estimation. However, if it is wished to do so these emissions should be reported under the Waste Sector. 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

A decision tree for domestic wastewater is included in Figure 6.2.

Figure 6.2 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.

The steps for *good practice* in inventory preparation for CH_4 from domestic wastewater are as follows:

Step 1: Use Equation 6.3 to estimate total organically degradable carbon in wastewater (TOW).

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

Step 3: Use Equation 6.1 to estimate emissions, adjust for possible sludge removal and/or CH_4 recovery 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, 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 judgement can also be applied (see Chapter 2, Approaches to Data Collection, in Volume 1). Urbanisation statistics may provide a useful tool, e.g., city sizes and income distribution.

If sludge separation is practised and appropriate statistics are available, then this category should be separated out as a subcategory. If default factors are being used, emissions from wastewater and sludge should be estimated together. Regardless of how sludge is treated, it is important that CH_4 emissions from sludge sent to landfills, incinerated or used in agriculture are not included in the wastewater treatment and discharge category. If sludge removal data are available, 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 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, a factor U is introduced to express 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 below.

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

EQUATION 6.1
TOTAL CH_4 EMISSIONS FROM DOMESTIC WASTEWATER

$$CH_4\ Emissions = \left[\sum_{i,j} \left(U_i \bullet T_{i,j} \bullet EF_j \right) \right] \left(TOW - S \right) - R$$

Where:

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

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

S = organic component removed as sludge in inventory year, kg BOD/yr

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

$T_{i,j}$ = 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, kg CH_4 / kg BOD

R = amount of CH_4 recovered in inventory year, kg CH_4/yr

6.2.2.2 CHOICE OF EMISSION FACTORS

The emission factor for a wastewater treatment and discharge pathway and system (terminal blocks with bold frames in Figure 6.1) 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 BOD or COD) in the wastewater. 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 Table 6.3.

Good practice is to use country-specific data for B_o, where available, expressed in terms of kg CH_4/kg BOD removed to be consistent with the activity data. If country-specific data are not available, a default value, 0.6 kg CH_4/kg BOD can be used. For domestic wastewater, a COD-based value of B_o can be converted into a BOD-based value by multiplying with a factor of 2.4. Table 6.2 includes default maximum CH_4 producing capacity (B_o) for domestic wastewater.

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)

Table 6.3 includes default MCF values.

TABLE 6.3
DEFAULT MCF VALUES FOR DOMESTIC WASTEWATER

Type of treatment and discharge pathway or system	Comments	MCF [1]	Range
Untreated system			
Sea, river and lake discharge	Rivers with high organics loadings can turn anaerobic.	0.1	0 – 0.2
Stagnant sewer	Open and warm	0.5	0.4 – 0.8
Flowing sewer (open or closed)	Fast moving, clean. (Insignificant amounts of CH_4 from pump stations, etc)	0	0
Treated system			
Centralized, aerobic treatment plant	Must be well managed. Some CH_4 can be emitted from settling basins and other pockets.	0	0 – 0.1
Centralized, aerobic treatment plant	Not well managed. Overloaded.	0.3	0.2 – 0.4
Anaerobic digester for sludge	CH_4 recovery is not considered here.	0.8	0.8 – 1.0
Anaerobic reactor	CH_4 recovery is not considered here.	0.8	0.8 – 1.0
Anaerobic shallow lagoon	Depth less than 2 metres, use expert judgment.	0.2	0 – 0.3
Anaerobic deep lagoon	Depth more than 2 metres	0.8	0.8 – 1.0
Septic system	Half of BOD settles in anaerobic tank.	0.5	0.5
Latrine	Dry climate, ground water table lower than latrine, small family (3-5 persons)	0.1	0.05 – 0.15
Latrine	Dry climate, ground water table lower than latrine, communal (many users)	0.5	0.4 – 0.6
Latrine	Wet climate/flush water use, ground water table higher than latrine	0.7	0.7 – 1.0
Latrine	Regular sediment removal for fertilizer	0.1	0.1

[1] Based on expert judgment by lead authors of this section.

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
TOTAL ORGANICALLY DEGRADABLE MATERIAL IN DOMESTIC WASTEWATER

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

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 in inventory year, g/person/day, See Table 6.4.

0.001 = conversion from grams BOD to kg BOD

I = correction factor for additional industrial BOD discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00.)

The factor *I* values in Equation 6.3 are based on expert judgment by the authors. 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. Total population statistics should be readily available from national statistics agencies or international agencies (e.g., United Nations Statistics, see http://esa.un.org/unpp/). 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 urbanization 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 6.5 includes default values of U_i and $T_{i,j}$ for selected countries.

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).

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

	Urbanization(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

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 UTILIZATION (T) BY INCOME GROUPS

Treatment or discharge system or pathway		T (%)	Notes
Urban high-income	To sea	10	No CH_4
	To aerobic plant	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 %
Reference: Doorn and Liles (1999)			

6.2.2.4 TIME SERIES CONSISTENCY

The same method and data sets should be used for estimating CH_4 emissions from wastewater for each year. The MCF for different treatment systems should not change from year to year, unless such a change is justifiable and documented. If the share of wastewater treated in different treatment systems changes over the time period, the reasons for these changes should be documented.

Sludge removal and CH_4 recovery should be estimated consistently across years in the time series. Methane recovery should be included only if there are sufficient facility-specific data. The quantity of recovered methane should be subtracted from the methane produced as shown in Equation 6.1.

Because activity data are derived from population data, which is available for all countries and all years, countries should be able to construct an entire time series for uncollected and collected wastewater. If data on the share of uncollected wastewater treated onsite vs. untreated are missing for one or more years, the surrogate data and extrapolation/interpolation splicing techniques described in Chapter 5, Time Series Consistency, of Volume 1, General Guidance and Reporting, can be used to estimate emissions. Emissions from wastewater typically do not fluctuate significantly from year to year.

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 judgements which in combination with empirical data can provide overall uncertainty estimates. Table 6.7 provides default uncertainty ranges for 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
DEFAULT UNCERTAINTY RANGES FOR DOMESTIC WASTEWATER

Parameter	Uncertainty Range
Emission Factor	
Maximum CH_4 producing capacity (B_o)	± 30%
Fraction treated anaerobically (MCF)	The MCF is technology dependent. See Table 6.3. Thus the uncertainty range is also technology dependent. The uncertainty range should be determined by expert judgement, bearing in mind that MCF is a fraction and must be between 0 and 1. Suggested ranges are provided below. Untreated systems and latrines, ± 50% Lagoons, poorly managed treatment plants± 30% Centralized well managed plant, digester, reactor, ± 10%
Activity Data	
Human population (P)	± 5%
BOD per person	± 30%
Fraction of population income group (U)	Good data on urbanization are available, however, the distinction between urban high income and urban low income may have to be based on expert judgment. ± 15%
Degree of utilization 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%

Source*:* Judgement by Expert Group (Authors of this section).

6.2.2.6 QA/QC, COMPLETENESS, REPORTING AND DOCUMENTATION

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

Activity Data

- Characterize all wastewater according to the percentages flowing to different treatment systems (aerobic and anaerobic), and the percentage of untreated wastewater. Make sure that all wastewater is characterized so that the wastewater flows sum to 100 percent of the wastewater generated in the country.
- Inventory compilers should compare country-specific data on BOD in domestic wastewater to IPCC default values. If inventory compilers use country-specific values they should provide documented justification why their country-specific values are more appropriate for their national circumstances.

Emission Factors

- For domestic wastewater, inventory compilers can compare country-specific values for B_o with the IPCC default value (0.25 kg CH_4/kg COD or 0.6 kg CH_4/kg BOD). Although there are no IPCC default values for the fraction of wastewater treated anaerobically, inventory compilers are encouraged to compare values for MCFs against those from other countries with similar wastewater handling practices.
- Inventory compilers should confirm the agreement between the units used for degradable carbon in the waste (TOW) with the units for B_o. Both parameters should be based on the same units (either BOD or COD) in order to calculate emissions. This same consideration should be taken into account when comparing the emissions.

CH_4 Recovery and Sludge Removal

- A carbon balance check can be used to ensure that the carbon contained in the inflow and outflow (effluent BOD, methane emission and methane recovery) are comparable.
- 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.

Comparison of emissions estimates using different approaches

- For countries that use country-specific parameters, or Tier 2 or higher methods, inventory compilers can cross-check the national estimate with emissions using the IPCC default method and parameters.

COMPLETENESS

Completeness can be verified on the basis of the degree of utilization of a treatment or discharge system or pathway (T). The sum of T should equal 100 percent. It is a *good practice* to draw a diagram similar to Figure 6.1 for the country to consider all potential anaerobic treatment and discharge systems and pathways, including collected and uncollected, as well as treated and untreated. Any industrial wastewater treated in domestic wastewater treatment facilities should be included in the collected category. If sludge is removed for the purpose of incineration, disposal in landfills or as fertilizer on agricultural lands, the amount of organic material removed as sludge should be consistent with data used in the relevant sectors (see text under Section 6.2.2).

REPORTING AND DOCUMENTATION

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

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

Where CH_4 is recovered for energy use, then the resulting greenhouse gas emissions should be reported under Energy Sector. As discussed in Section 6.2.1, *good practice* in the Waste Sector does not require the estimation of CH_4 and N_2O from CH_4 recovery and flaring. However, if it is wished to do so emissions from flaring should be reported under the Waste Sector.

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

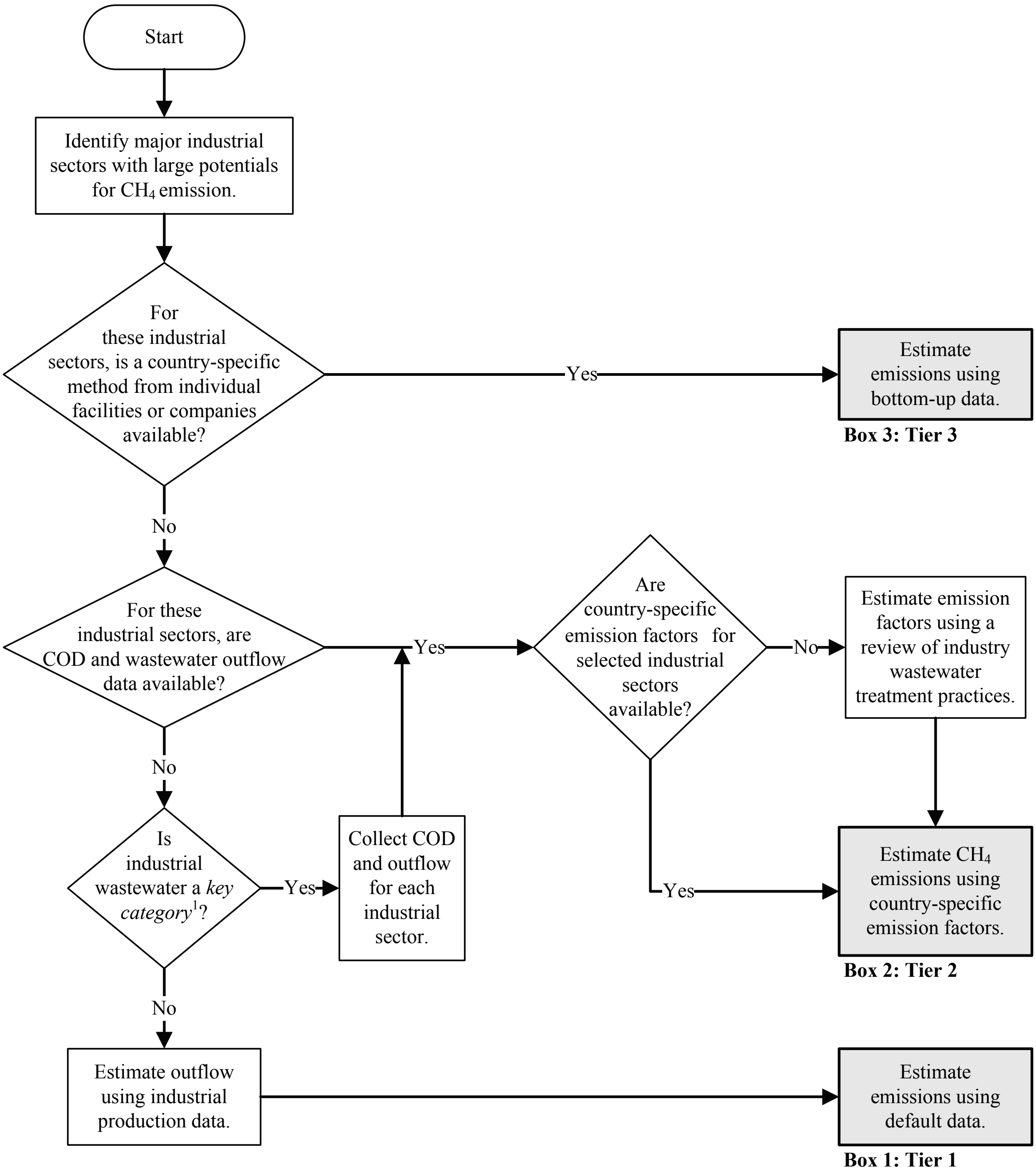
6.2.3 Industrial wastewater

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

A decision tree for industrial wastewater is included in Figure 6.3.

Figure 6.3 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.

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. See the decision tree in Figure 6.3. 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 (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 methane correction factor.

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

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

EQUATION 6.4
TOTAL CH_4 EMISSIONS FROM INDUSTRIAL WASTEWATER

$$CH_4\ Emissions = \sum_i \left[\left(TOW_i - S_i \right) EF_i - R_i \right]$$

Where:

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

The amount of CH_4 which is recovered is expressed as R in Equation 6.4. The recovered gas should be treated as described in Section 6.2.1.

6.2.3.2 CHOICE OF EMISSION FACTORS

There are significant differences in the CH_4 emitting potential of different types of industrial 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. However, most inventory compilers will find detailed industry sector-specific data unavailable or incomplete. If no country-specific data are available, it is *good practice* to use the IPCC COD-default factor for B_o (0.25 kg CH_4/kg COD).

In determining the Methane correction factor (MCF), which is the fraction of waste treated anaerobically, expert judgement 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 judgement 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.

TABLE 6.8
DEFAULT MCF VALUES FOR INDUSTRIAL WASTEWATER

Type of treatment and discharge pathway or system	Comments	MCF [1]	Range
Untreated			
Sea, river and lake discharge	Rivers with high organics loadings may turn anaerobic, however this is not considered here.	0.1	0 – 0.2
Treated			
Aerobic treatment plant	Must be well managed. Some CH_4 can be emitted from settling basins and other pockets.	0	0 – 0.1
Aerobic treatment plant	Not well managed. Overloaded	0.3	0.2 – 0.4
Anaerobic digester for sludge	CH_4 recovery not considered here	0.8	0.8 – 1.0
Anaerobic reactor (e.g., UASB, Fixed Film Reactor)	CH_4 recovery not considered here	0.8	0.8 – 1.0
Anaerobic shallow lagoon	Depth less than 2 metres, use expert judgment	0.2	0 – 0.3
Anaerobic deep lagoon	Depth more than 2 metres	0.8	0.8 – 1.0

[1] Based on expert judgment by lead authors of this section

6.2.3.3 CHOICE OF ACTIVITY DATA

The activity data for this source category is the amount of organically degradable material in the wastewater (TOW). This parameter is a function of industrial output (product) P (tons/yr), wastewater generation W (m^3/ton of product), and degradable organics concentration in the wastewater COD (kg COD/m^3). See Equation 6.6. The following steps are required for determination of TOW:

(i) Identify the industrial sectors that generate wastewater with large quantities of organic carbon, by evaluating total industrial product, degradable organics in the wastewater, and wastewater produced.

(ii) Identify industrial sectors that use anaerobic treatment. Include those that may have unintended anaerobic treatment as a result of overloading of the treatment system. Experience has shown that usually three or four industrial sectors are *key*.

For each selected sector estimate total organically degradable carbon (TOW).

EQUATION 6.6
ORGANICALLY DEGRADABLE MATERIAL IN INDUSTRIAL WASTEWATER

$$TOW_i = P_i \bullet W_i \bullet COD_i$$

Where:

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

i = industrial sector

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

W_i = wastewater generated, $m^3/t_{product}$

COD_i = chemical oxygen demand (industrial degradable organic component in wastewater), kg COD/m^3

Industrial production data and wastewater outflows may be obtained from national statistics, regulatory agencies, wastewater treatment associations or industry associations. In some cases quantification of the COD loading in the wastewater may require expert judgement. In some countries, COD and total water usage per sector data may be available directly from a regulatory agency. An alternative is to obtain data on industrial output and tonnes COD produced per tonne of product from the literature. Table 6.9 provides examples that could be used as default values. These should be used with caution, because they are industry-, process- and country-specific.

TABLE 6.9
EXAMPLES OF INDUSTRIAL WASTEWATER DATA

Industry Type	Wastewater Generation W (m^3/ton)	Range for W (m^3/ton)	COD (kg/m^3)	COD Range (kg/m^3)
Alcohol Refining	24	16 – 32	11	5 – 22
Beer & Malt	6.3	5.0 – 9.0	2.9	2 – 7
Coffee	NA	NA –	9	3 – 15
Dairy Products	7	3 – 10	2.7	1.5 – 5.2
Fish Processing	NA	8 – 18	2.5	
Meat & Poultry	13	8 – 18	4.1	2 – 7
Organic Chemicals	67	0 – 400	3	0.8 – 5
Petroleum Refineries	0.6	0.3 – 1.2	1.0	0.4 – 1.6
Plastics & Resins	0.6	0.3 – 1.2	3.7	0.8 – 5
Pulp & Paper (combined)	162	85 – 240	9	1 – 15
Soap & Detergents	NA	1.0 – 5.0	NA	0.5 – 1.2
Starch Production	9	4 – 18	10	1.5 – 42
Sugar Refining	NA	4 – 18	3.2	1 – 6
Vegetable Oils	3.1	1.0 – 5.0	NA	0.5 – 1.2
Vegetables, Fruits & Juices	20	7 – 35	5.0	2 – 10
Wine & Vinegar	23	11 – 46	1.5	0.7 – 3.0

Notes: NA = Not Available.
Source: Doorn *et al*. (1997).

6.2.3.4 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.

As with domestic wastewater, sludge removal and CH_4 recovery should be treated consistently across years in the time series. CH_4 recovery should be included only if there are facility-specific data. The quantity of recovered CH_4 should be subtracted from the CH_4 produced as shown in Equation 6.4.

6.2.3.5 UNCERTAINTIES

Uncertainty estimates for B_o, MCF, P, W and COD are provided in Table 6.10. The estimates are based on expert judgement.

TABLE 6.10
DEFAULT UNCERTAINTY RANGES FOR INDUSTRIAL WASTEWATER

Parameter	Uncertainty Range
Emission Factor	
Maximum CH_4 producing capacity (B_o)	± 30%
Methane correction factor (MCF)	The uncertainty range should be determined by expert judgement, bearing in mind that this is a fraction and uncertainties cannot take it outside the range of 0 to 1.
Activity Data	
Industrial production (P)	± 25% Use expert judgement 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•COD) is expected to have less uncertainty. An uncertainty value can be attributed directly to kg COD/tonne of product. –50 %, +100% is suggested (i.e., a factor of 2).
COD/unit wastewater (COD)	

Source*:* Judgement by Expert Group (Co-chairs, Editors and Authors of this sector).

6.2.3.6 QA/QC, COMPLETENESS, REPORTING AND DOCUMENTATION

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 COD 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 MCFs against those from other national inventories with similar wastewater characteristics.
- The inventory compilers should review facility-specific data on CH_4 recovery to ensure that it was reported according to criteria on measurements outlined in Chapter 2, Approaches to Data Collection, in Volume 1.
- Use a carbon balance check to ensure that the carbon contained in CH_4 recovery is less than the carbon contained in BOD entering the facility that reports CH_4 recovery.
- If sludge removal is reported in the wastewater inventory, check for consistency with the estimates for sludge applied to agriculture soils, sludge incinerated, and sludge deposited in solid waste disposal.
- For countries that use country-specific parameters or higher tier methods, inventory compilers should cross-check the national estimates with emissions using the IPCC default method and parameters.

COMPLETENESS

Completeness for estimating emissions from industrial wastewater depends on an accurate characterization of industrial sectors that produce organic wastewater. In most countries, approximately 3-4 industrial sectors will account for the majority of the organic 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 organic waste that should be subtracted from available TOW. It is *good practice* to be consistent across sectors: the amount of sludge that is removed from TOW 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. Worksheets are provided at the end of this volume. When country-specific methods and/or emission factors are used, the reasoning for the choices as well as references to how the country-specific data (measurements, literature, expert judgement, etc.) have been derived (measurements, literature, expert judgement, etc.) should be documented and included in the reporting.

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

If CH_4 recovery data are available for industrial wastewater treatment, these should be documented for flaring and energy recovery separately. The treatment of recovered CH_4 and how to report emissions from flaring should be the same as the guidance for domestic wastewater in Section 6.2.2.6.

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

6.3 NITROUS OXIDE EMISSIONS FROM WASTEWATER

6.3.1 Methodological issues

6.3.1.1 CHOICE OF METHOD

Nitrous oxide (N_2O) emissions can occur as direct emissions from treatment plants or from indirect emissions from wastewater after disposal of effluent into waterways, lakes or the sea. Direct emissions from nitrification and denitrification at wastewater treatment plants may be considered as a minor source and guidance is offered in Box 6.1 to estimate these emissions. Typically, these emissions are much smaller than those from effluent and may only be of interest to countries that predominantly have advanced centralized wastewater treatment plants with nitrification and denitrification steps.

No higher tiers are given, so it is *Good practice* to estimate N_2O from domestic wastewater effluent using the method given here, No decision tree is provided. Direct emissions need to be estimated only for countries that have predominantly advanced centralized wastewater treatment plants with nitrification and denitrification steps.

Accordingly, this section addresses indirect N_2O emissions from wastewater treatment effluent that is discharged into aquatic environments. The methodology for emissions from effluent is similar to that of indirect 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
N_2O EMISSIONS FROM WASTEWATER EFFLUENT

$$N_2O\ Emissions = N_{EFFLUENT} \bullet EF_{EFFLUENT} \bullet 44/28$$

Where:

N_2O emissions = N_2O emissions in inventory year, kg N_2O/yr

$N_{EFFLUENT}$ = nitrogen in the effluent discharged to aquatic environments, kg N/yr

$EF_{EFFLUENT}$ = emission factor for N_2O emissions from discharged to wastewater, 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

The default IPCC emission factor for N_2O emissions from domestic wastewater nitrogen effluent is 0.005 (0.0005 - 0.25) kg N_2O-N/kg N. This emission factor is based on limited field data and on specific assumptions regarding the occurrence of nitrification and denitrification in rivers and in estuaries. The first assumption is that all nitrogen is discharged with the effluent. The second assumption is that N_2O production in rivers and estuaries is directly related to nitrification and denitrification and, thus, to the nitrogen that is discharged into the river. (See Volume 4, Table 11.3 of Section 11.2.2 in Chapter 11, N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application.)

6.3.1.3 CHOICE OF ACTIVITY DATA

The activity data that are needed for estimating N_2O emissions are nitrogen content in the wastewater effluent, country population and average annual per capita protein generation (kg/person/yr). Per capita protein generation consists of intake (consumption) which is available from the Food and Agriculture Organization (FAO, 2004), multiplied by factors to account for additional 'non-consumed' protein and for industrial protein discharged into the sewer system. Food (waste) that is not consumed may be washed down the drain (e.g., as result of the use of garbage disposals in some developed countries) and also, bath and laundry water can be expected to contribute to nitrogen loadings. For developed countries using garbage disposals, the default for non-consumed protein discharged to wastewater pathways is 1.4, while for developing countries this fraction is 1.1. 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. The total nitrogen in the effluent is estimated as follows:

EQUATION 6.8
TOTAL NITROGEN IN THE EFFLUENT

$$N_{EFFLUENT} = \left(P \bullet Protein \bullet F_{NPR} \bullet F_{NON-CON} \bullet F_{IND-COM} \right) - N_{SLUDGE}$$

Where:

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

P = human population

Protein = annual per capita protein consumption, kg/person/yr

F_{NPR} = fraction of nitrogen in protein, default = 0.16, kg N/kg protein

$F_{NON-CON}$ = factor for non-consumed protein added to the wastewater

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

N_{SLUDGE} = nitrogen removed with sludge (default = zero), kg N/yr

BOX 6.1
SUBCATEGORY - EMISSIONS FROM ADVANCED CENTRALISED WASTEWATER TREATMENT PLANTS

Emissions from advanced centralised wastewater treatment plants are typically much smaller than those from effluent and may only be of interest for countries that have predominantly advanced centralized wastewater treatment plants with controlled nitrification and denitrification steps. The overall emission factor to estimate N_2O emissions from such plants is 3.2 g N_2O/person/year. This emission factor was determined during field testing at a domestic wastewater treatment plant in the Northern United States (Czepiel *et al*., 1995). The emission data were obtained at a plant that received only domestic wastewater. This wastewater already included non-consumption protein, but did not include any co-discharged industrial and commercial wastewater. No other country-specific emission factors are available. The emissions from N_2O from centralized wastewater treatment processes are calculated as follows:

EQUATION 6.9
N_2O EMISION FROM
CENTRALIZED WASTEWATER TREATMENT PROCESSES

$$N_2O_{PLANTS} = P \bullet T_{PLANT} \bullet F_{IND-COM} \bullet EF_{PLANT}$$

Where:

N_2O_{PLANTS} = total N_2O emissions from plants in inventory year, kg N_2O/yr

P = human population

T_{PLANT} = degree of utilization of modern, centralized WWT plants, %

$F_{IND-COMM}$ = fraction of industrial and commercial co-discharged protein (default = 1.25, based on data in Metcalf & Eddy (2003) and expert judgment)

EF_{PLANT} = emission factor, 3.2 g N_2O/person/year

Note: When a country chooses to include N_2O emissions from plants, the amount of nitrogen associated with these emissions (N_{WWT}) must be back calculated and subtracted from the $N_{EFFLUENT}$. The N_{WWT} can be calculated by multiplying N_2O_{PLANTS} by 28/44, using the molecular weights.

6.3.2 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.

6.3.3 Uncertainties

Large uncertainties are associated with the IPCC default emission factors for N_2O from effluent. Currently insufficient field data exist to improve this factor. Also, the N_2O emission factor for plants is uncertain, because it is based on one field test. Table 6.11 below includes uncertainty ranges based on expert judgment.

TABLE 6.11
N_2O METHODOLOGY DEFAULT DATA

	Definition	Default Value	Range
Emission Factor			
$EF_{EFFLUENT}$	Emission factor, (kg N_2O-N/kg –N)	0.005	0.0005 – 0.25
EF_{PLANTS}	Emission factor, (g N_2O/person/year)	3.2	2 – 8
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 utilization of large WWT plants	Country-specific	± 20 %
$F_{NON\text{-}CON}$	Factor to adjust for non-consumed protein	1.1 for countries with no garbage disposals, 1.4 for countries with garbage disposals	1.0 – 1.5
$F_{IND\text{-}COM}$	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

6.3.4 QA/QC, Completeness, Reporting and Documentation

This method makes use of several default parameters. It is recommended to solicit experts' advice in evaluating the appropriateness of the proposed default factors.

COMPLETENESS

Unless sludge removal data are available, the methodology for estimating emissions from effluent is based on population and on the assumption that all nitrogen associated with consumption and domestic use, as well as nitrogen from co-discharged industrial wastewater, will eventually enter a waterway. As such, this estimate can be seen as conservative estimate and covers the entire source associated with domestic wastewater use.

The methodology does not include N_2O emissions from industrial sources, except for industrial wastewater that is co-discharged with domestic wastewater into the sewer system. The N_2O emissions from industrial sources are believed to be insignificant compared to emissions from domestic wastewater.

Very few countries collect data on wastewater sludge handling. If these data exist, it is suggested to make them available to the appropriate inventory teams.

The emission factor used for N_2O emissions from effluent is the same as the emission factor used for indirect N_2O emissions in the AFOLU Sector.

REPORTING AND DOCUMENTATION

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

If sludge is incinerated, landfilled, or spread on agricultural lands, the associated quantities of sludge should be reported in the waste incineration, SWDS, 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.

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