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VOLUME 5

WASTE

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CHAPTER 1

INTRODUCTION

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1 INTRODUCTION

1.1 INTRODUCTION

The Waste volume gives methodological guidance for estimation of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions from following categories:

- Solid waste disposal (Chapter 3),
- Biological treatment of solid waste (Chapter 4),
- Incineration and open burning of waste (Chapter 5),
- Wastewater treatment and discharge (Chapter 6).

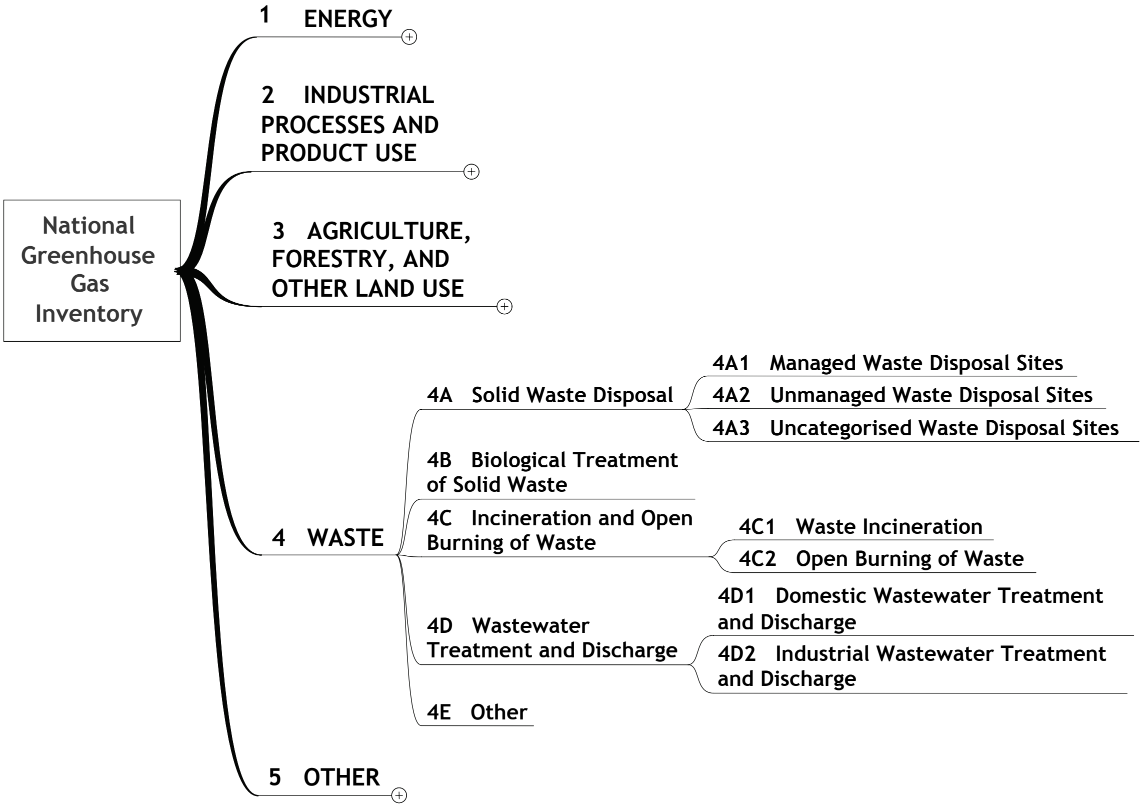
Chapter 3, Solid Waste Disposal, provides also a methodology for estimating changes in carbon stored in solid waste disposal sites (SWDS), which is reported as an information item in the Waste Sector (see also Volume 4, AFOLU, Chapter 12, Harvested Wood Products).

Chapter 2, Waste Generation, Composition and Management Data, gives general guidance of data collection for solid waste management including disposal, biological treatment, waste incineration and open burning of waste.

Categories and activities of the Waste Sector and their definitions can be found in Table 8.2 in Chapter 8 of Volume1, General Guidance and Reporting. It is good practice to apply these categories in reporting as fully as possible.

Figure 1.1 shows the structure of categories within the Waste Sector and coding of their IPCC categories.

Figure 1.1 Structure of Waste Sector



Typically, CH_4 emissions from SWDS are the largest source of greenhouse gas emissions in the Waste Sector. CH_4 emissions from wastewater treatment and discharge may also be important.

Incineration and open burning of waste containing fossil carbon, e.g., plastics, are the most important sources of CO_2 emissions in the Waste Sector. All greenhouse gas emissions from waste-to-energy, where waste material is used directly as fuel or converted into a fuel, should be estimated and reported under the Energy Sector. The guidance given in Chapter 5 of this Volume is generally valid for waste burning with or without energy recovery. CO_2 is also produced in SWDS, wastewater treatment and burning of non-fossil waste, but this CO_2 is of biogenic origin and is therefore not included as a reporting item in this sector.[1] In the Energy Sector, CO_2 emissions resulting from combustion of biogenic materials, including CO_2 from waste-to-energy applications, are reported as an information item. Nitrous oxide is produced in most treatments addressed in the Waste volume. The importance of the N_2O emissions varies much depending on the type of treatment and conditions during the treatment.

Waste and wastewater treatment and discharge can also produce emissions of non-methane volatile organic compounds (NMVOCs), nitrogen oxides (NO_x), and carbon monoxide (CO) as well as of ammonia (NH_3). However, specific methodologies for the estimation of emissions for these gases are not included in this Volume, and the readers are guided to refer to guidelines developed under the Convention of Long Range Transboundary Air Pollution (EMEP/CORINAIR Guidebook, EEA, 2005) and EPA's Compilation of Air Pollutant Emissions Factors (U.S.EPA, 1995). The NO_x and NH_3 emissions from the Waste Sector can cause indirect N_2O emissions. NO_x is produced mainly in burning of waste, while NH_3 in composting. Overall, the indirect N_2O from the Waste Sector are likely to be insignificant. However, when estimates of NO_x and NH_3 emissions are available, it is good practice to estimate the indirect N_2O emissions for complete reporting (see Chapter 7 of Volume 1).

The scope of the Waste Volume is similar to the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (*1996 Guidelines*, IPCC, 1997) and the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (*GPG2000*, IPCC, 2000). Following new subcategories have been added to complement the guidance to cover all major waste management practices:

- Biological treatment of solid waste: Guidance for estimation of CH_4 and N_2O emissions from biological treatment (composting, anaerobic digestion in biogas facilities) has been included in Chapter 4, Biological Treatment of Solid Waste.
- Open burning of waste: Guidance to estimate emissions from open burning of waste as well as for estimation of CH_4 emissions from incineration complements the previous guidance on waste incineration in Chapter 5, Incineration and Open Burning of Waste.
- Septic tanks and latrines: Methods to estimate CH_4 and N_2O emissions from septic tanks and latrines as well as from discharge of wastewater into waterways are included in Chapter 6, Wastewater Treatment and Discharge.

References

EEA (2005). *EMEP/CORINAIR. Emission Inventory Guidebook – 2005*. European Environment Agency. URL: http://reports.eea.eu.int/EMEPCORINAIR4/en

IPCC (1997). *Revised 1996 IPCC Guidelines for National Greenhouse Inventories*. Houghton, J.T., Meira Filho, L.G., Lim, B., Tréanton, K., Mamaty, I., Bonduki, Y., Griggs, D.J. and Callander, B.A. (Eds). Intergovernmental Panel on Climate Change (IPCC), IPCC/OECD/IEA, Paris, France.

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[1] CO_2 emissions of biogenic origin are either covered by the methodologies and reported as carbon stock change in the AFOLU Sector, or do not need to be accounted for because the corresponding CO_2 uptake by vegetation is not reported in the inventory (e.g., annual crops).

CHAPTER 2

WASTE GENERATION, COMPOSITION AND MANAGEMENT DATA

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2 WASTE GENERATION, COMPOSITION AND MANAGEMENT DATA

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 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 *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)[1] 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.

2.2 WASTE GENERATION AND MANAGEMENT DATA

Guidance on how to collect data on waste generation and management practices is given separately for municipal solid waste (MSW), sludge, industrial and other waste. Default definitions for these categories are given below. These default definitions are used in the subsequent methodological guidance. The definitions are transparent to allow for country-specific modifications, as waste categorisation varies much from country to country, and can encompass different waste components.[2] If the available data used in the inventory cover only certain waste types or sources (e.g., municipal waste), this limited availability should be documented clearly in the inventory report and efforts should be made to complement the data to cover all waste types.

In the Section 2.3 Waste Composition, default compositions are given for these default waste categories. The default compositions are used as the basis for the calculations for Tier 1 methods.

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[1] Recycling is often defined to encompass also waste-to-energy activities and biological treatment. For practical reasons a more narrow definition is used here: Recycling is defined as recovery of material resources (typically paper, glass, metals and plastics, sometimes wood and food waste) from the waste stream.

[2] Some countries do not use these broad waste categories but a more detailed classification, e.g., the Regulation of the European Parliament and Council on waste statistics (EC no 2150/2002) that does not include municipal solid waste as a category.

2.2.1 Municipal Solid Waste (MSW)

Municipal waste is generally defined as waste collected by municipalities or other local authorities. However, this definition varies by country. Typically, MSW includes:

- Household waste;
- Garden (yard) and park waste; and
- Commercial/institutional waste.

The regional default composition data for MSW is given in Section 2.3.1.

Default data

Region-specific default data on per capita MSW generation and management practices are provided in Table 2.1. These data are estimated based on country-specific data from a limited number of countries in the regions (see Annex 2A.1). These data are based on weight of wet waste[3] and can be assumed to be applicable for the year 2000. Waste generation per capita for subsequent or earlier years can be estimated using the guidance on how to estimate historical emissions from SWDS in Chapter 3, Section 3.2.2, and the methods for extrapolation and interpolation using drivers in Chapter 6, Time Series Consistency, in Volume 1, General Guidance and Reporting.

TABLE 2.1
MSW GENERATION AND TREATMENT DATA - REGIONAL DEFAULTS

Region	MSW Generation Rate[1, 2, 3] (tonnes/cap/yr)	Fraction of MSW disposed to SWDS	Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified[4]
Asia					
Eastern Asia	0.37	0.55	0.26	0.01	0.18
South-Central Asia	0.21	0.74	-	0.05	0.21
South-East Asia	0.27	0.59	0.09	0.05	0.27
Africa[5]	0.29	0.69	-	-	0.31
Europe					
Eastern Europe	0.38	0.90	0.04	0.01	0.02
Northern Europe	0.64	0.47	0.24	0.08	0.20
Southern Europe	0.52	0.85	0.05	0.05	0.05
Western Europe	0.56	0.47	0.22	0.15	0.15
America					
Caribbean	0.49	0.83	0.02	-	0.15
Central America	0.21	0.50	-	-	0.50
South America	0.26	0.54	0.01	0.003	0.46
North America	0.65	0.58	0.06	0.06	0.29
Oceania[6]	0.69	0.85	-	-	0.15

[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. In many countries, especially developing countries, this encompasses only urban population.

[3] The data are default data for the year 2000, although for some countries the year for which the data are applicable was not given in the reference, or data for the year 2000 were not available. The year for which the data are collected, where available, is given in the Annex 2A.1.

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

[5] A regional average is given for the whole of Africa as data are not available for more detailed regions within Africa.

[6] Data for Oceania are based only on data from Australia and New Zealand.

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[3] Wet waste is not treated before measuring, while dry weight is estimated after drying waste under certain temperature, ventilation and time conditions before measuring. In the conversions in this Volume (see e.g., Table 2.4) the assumption is that no moisture is left in the dry matter.

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, OECD, ADB, JICA, U.S.EPA, IIASA, 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

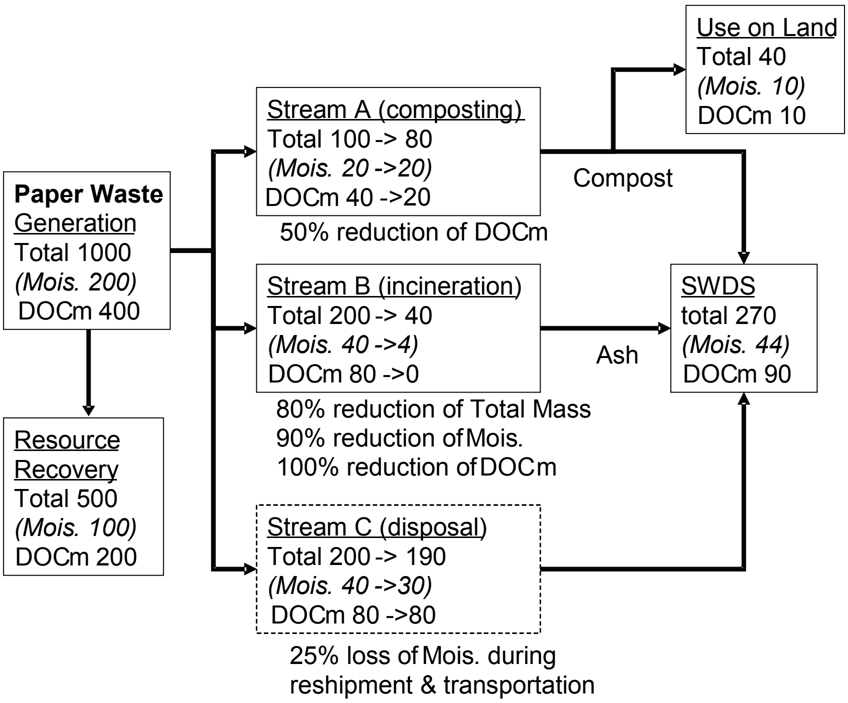
EXAMPLE OF ACTIVITY DATA COLLECTION FOR ESTIMATION OF EMISSIONS FROM SOLID WASTE TREATMENT BASED ON WASTE STREAM ANALYSIS BY WASTE TYPE

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 CH_4 emissions at SWDS.

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



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).

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

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 categorisation is used, it should be documented transparently.

The emissions from sludge treatment at wastewater treatment facilities are treated in Chapter 6, Wastewater Treatment and Discharge. Chapters 3, 4 and 5 consider disposal, composting (and anaerobic digestion of sludge with other organic solid waste) and incineration of sludge, respectively. Sludge that is applied on agricultural land is considered in Volume 4, Agriculture, Forestry and Other Land Use, Chapter 11, Section 11.2, N_2O Emissions from Managed Soils. Double counting of the emissions between the different categories should be avoided. The amount of organic matter removed from wastewater treatment as sludge (see Equation 6.1 in Chapter 6) due to disposal into SWDS, composting, incineration or use in agriculture should be consistent with the amounts reported under these categories.

Default data for sludge generation, disposal into SWDS, composting or incineration are not given here.[4] If no country-specific data are available, the reporting of the emissions is covered by the methodology in Chapter 6. Default values for degradable organic carbon content in sludge are given in Section 2.3 Waste Composition, in this chapter.

2.2.3 Industrial waste

In some countries, significant quantities of organic industrial solid waste are generated.[5] Industrial waste generation and composition vary depending on the type of industry and processes/technologies in the concerned country. Countries apply various categorisations for industrial waste. For example, construction and demolition waste can be included in industrial waste, in MSW, or defined as a separate category. The default categorisation used here assumes construction and demolition waste are part of the industrial waste. In many countries industrial solid waste is managed as a specific stream and the waste amounts are not covered by general waste statistics. OECD (see e.g., OECD, 2002) collects statistical data on industrial waste generation and treatment. These statistics are published periodically. In most developing countries industrial wastes are included in the municipal solid waste stream, therefore, it is difficult to obtain data of the industrial waste separately.

Industrial solid waste disposal data may be obtained by surveys or from national statistics. Only those industrial wastes which are expected to contain DOC and fossil carbon should be considered for the purpose of emission estimation from waste. Construction and demolition waste is mainly inert (concrete, rubble, etc.) but may contain some DOC (see Section 2.3.3) in wood and some fossil carbon in plastics. Recycling and reduction using different technologies applied to industrial waste prior to disposal in SWDS or incineration should be taken into account, where data are available.

Default data

Industrial waste generation data (total industrial waste generation and data for manufacturing industries and construction waste) are given in Table 2.2 for some countries. The total amount includes also other waste types than those from manufacturing industries and construction. The data are based on weight of wet waste. Although significant amounts of industrial waste are generated, the rates of recycling/reuse are often high, and the fraction of degradable organic material from industrial waste disposed at solid waste disposal sites is often less than that of MSW. Incineration of industrial waste may take place in significant amounts, however this will vary from country to country. Composting or other biological treatment is restricted to waste from industries producing food and other putrescible waste. Countries for which no national data on industrial waste generation can be obtained and whose data are not given in Table 2.2, are encouraged to use data from countries, or a cluster of countries, with similar circumstances. Chapter 2, Approaches to Data Collection, in Volume 1 gives general guidance on data collection.

The data in Table 2.2 do not include data on industrial waste management practices. When country-specific data on industrial waste management are not available from other sources, the management can be assumed to follow the same pattern as management of MSW (see Table 2.1). For more accurate data, the inventory compilers are encouraged to contact relevant sources of information in the country, such as governmental agencies and local authorities responsible for industrial waste management as well as industrial organisations.

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[4] For some European countries, data on sewage waste disposal is collected by Eurostat (2005).

[5] The default values provided in Table 2.1 do not include industrial solid waste.

TABLE 2.2
INDUSTRIAL WASTE GENERATION IN SELECTED COUNTRIES

(1,000 tonnes per year)

Region/ Country	Total	Manufacturing Industries	Construction
Asia			
China	1 004 280		
Japan		120 050	76 240
Singapore	1 423.5		
Republic of Korea		39 810	28 750
Israel	1 000		
Europe			
Austria		14 284	27 500
Belgium		14 144	9 046
Bulgaria		3 145	7
Croatia		1 600	142
Czech Republic		9 618	5 083
Denmark		2 950	3 220
Estonia	1 261.5		
Finland		15 281	1 420
France		98 000	
Germany		47 960	231 000
Greece		6 680	1 800
Hungary		2 605	707
Iceland		10	
Ireland		5 361	3 651
Italy		35 392	27 291
Latvia	1 103	422	7
Malta		25	206
Netherlands		17 595	23 800
Norway		415	4
Poland		58 975	143
Portugal		8 356	85
Romania		797	
Slovakia		6 715	223
Slovenia		1 493	
Spain		20 308	
Sweden		18 690	
Switzerland		1 470	6 390
Turkey		1 166	
UK		50 000	72 000
Oceania			
Australia		37 040	10
New Zealand		1 750	NR

Data are based on weight of wet waste.
The data are default data for the year 2000, although for some countries the year for which the data are applicable was not given in the reference, or data for the year 2000 were not available.
References:
Environmental Statistics Yearbook of China (2003)
Eurostat (2005)
Latvian Environment Agency (2004)
OECD (2002)
National environmental agency, Singapore (2001)
Estonian Environment Information Centre (2003)
Statistics Finland (2005)
Milleubalans (2005)

Country-specific industrial waste generation data

Some countries have statistical data on industrial waste generation and management. It is *good practice* to use country-specific data on industrial waste generation, waste composition (see Section 3.2.2) as well as management practices as the basis for the emission estimation. The data should to the extent possible be collected by industry types. If the available data cover only part of industry or industrial waste types, this limited availability should be documented clearly in the inventory report, as well as efforts made to complement the data to cover all industrial waste.

Data for the waste stream analyses

Approaches following the streams of waste from one treatment to another taking the changes in composition and other parameters affecting the emissions discussed in Section 2.2.1 could be used also for industrial waste. Data could be collected using surveys or be collected plant-by-plant.

2.2.4 Other waste

Clinical waste: These wastes include materials like plastic syringes, animal tissues, bandages, cloths, etc. Some countries choose to include these items in the MSW. Clinical waste is usually incinerated. However, some clinical waste may be disposed in SWDS. No regional or country-specific default data are given for clinical waste generation and management. In most countries, the amount of greenhouse gas emissions due to clinical waste appears to be insignificant. Default DOC and fossil carbon content in clinical waste are given in Section 2.3.4, Table 2.6.

Hazardous waste: Waste oil, waste solvents, ash, cinder and other wastes with hazardous nature, such as flammability, explosiveness, causticity, and toxicity, are included in hazardous waste. Hazardous wastes are generally collected, treated and disposed separately from non-hazardous MSW and industrial waste streams. Some hazardous wastes are incinerated and can contribute to the fossil CO_2 emissions from incineration (see Chapter 5) (Eurostat, 2005)[6]. Neutralisation and cement solidification are also treatment processes for hazardous waste. These processes applied together to organic sludge or other liquid-like waste with hazardous nature can reduce (or delay) greenhouse gas emissions at SWDS by isolation. In many countries it is prohibited to dispose hazardous waste at SWDS without pre-treatment. Emissions from solid waste disposal of hazardous waste are likely to be small. No regional or country-specific default data are given for hazardous waste generation and management. Default DOC and fossil carbon content in hazardous waste are given in Section 2.3.4, Table 2.6.

Agricultural waste: Manure management and burning of agricultural residues are considered in the AFOLU Volume. Agricultural waste which will be treated and/or disposed with other solid waste may however be included in MSW or industrial waste. For example, such waste may include manure, agricultural residues, dead body of live stock, plastic film for greenhouse and mulch.

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[6] Eurostat (2005) collects data based on national statistics from European countries on hazardous waste generation and treatment.

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, as different waste types contain different amount of degradable organic carbon (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.

Regional and country-specific default data on waste composition in MSW are given in Table 2.3. These data are based on weight of wet waste. Table 2.3 does not give default data for garden and park waste and nappies. In the Tier 1 default method these waste fractions can be assumed to be zero, i.e., they can be assumed to be encompassed by the other waste types.

TABLE 2.3
MSW COMPOSITION DATA BY PERCENT - REGIONAL DEFAULTS

Region	Food waste	Paper/cardboard	Wood	Textiles	Rubber/leather	Plastic	Metal	Glass	Other
Asia									
Eastern Asia	26.2	18.8	3.5	3.5	1.0	14.3	2.7	3.1	7.4
South-Central Asia	40.3	11.3	7.9	2.5	0.8	6.4	3.8	3.5	21.9
South-Eastern Asia	43.5	12.9	9.9	2.7	0.9	7.2	3.3	4.0	16.3
Western Asia & Middle East	41.1	18.0	9.8	2.9	0.6	6.3	1.3	2.2	5.4
Africa									
Eastern Africa	53.9	7.7	7.0	1.7	1.1	5.5	1.8	2.3	11.6
Middle Africa	43.4	16.8	6.5	2.5		4.5	3.5	2.0	1.5
Northern Africa	51.1	16.5	2	2.5		4.5	3.5	2	1.5
Southern Africa	23	25	15						
Western Africa	40.4	9.8	4.4	1.0		3.0	1.0		
Europe									
Eastern Europe	30.1	21.8	7.5	4.7	1.4	6.2	3.6	10.0	14.6
Northern Europe	23.8	30.6	10.0	2.0		13.0	7.0	8.0	
Southern Europe	36.9	17.0	10.6						
Western Europe	24.2	27.5	11.0						
Oceania									
Australia and New Zealand	36.0	30.0	24.0						
Rest of Oceania	67.5	6.0	2.5						
America									
North America	33.9	23.2	6.2	3.9	1.4	8.5	4.6	6.5	9.8
Central America	43.8	13.7	13.5	2.6	1.8	6.7	2.6	3.7	12.3
South America	44.9	17.1	4.7	2.6	0.7	10.8	2.9	3.3	13.0
Caribbean	46.9	17.0	2.4	5.1	1.9	9.9	5.0	5.7	3.5

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

Note 1: Data are based on weight of wet waste of MSW without industrial waste at generation around year 2000.

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

Sources:

Doorn and Barlaz (1995)

Hoornweg (1999)

Vishwanathan and Trakler (2003a and b)

Shimura *et al*. (2001)

www.defra.gov.uk/environment/statistics/wastats/mwb0203/wbch04.htm

www.climatechange.govt.nz/resources/reports/nir-apr04

CONADE/SEDUE (1992); INE/SMARN (2000)

U.S. EPA (2002)

BID/OPS/OMS (1997)

Monreal (1998)

JICA (1991)

OPS/OMS (1997)

Ministerio de Desarrollo Social y Medio Ambiente/Secretaría de Desarrollo Sustentable y Política Ambiental (1999)

López, C. (2006). Personal Communication.

Ministry of Science and Technology, Brazil (2002)

U.S. EPA (1997)

MAG/SSERNMA/DOA-PNUD/UNITAR (1999)

López *et al*. (2002)

Default values for DOC and fossil carbon content in different waste types is given in Table 2.4. Table 2.4 gives default values also for garden and park waste, and disposable nappies. These waste types were not included in Table 2.3 due to lack of data. All fractions in the Table 2.4 are given as percentages.

TABLE 2.4
DEFAULT DRY MATTER CONTENT, DOC CONTENT, TOTAL CARBON CONTENT AND FOSSIL CARBON FRACTION OF DIFFERENT MSW COMPONENTS

MSW component	**Dry matter content in % of wet weight** [1]	**DOC content in % of wet waste**		**DOC content in % of dry waste**		**Total carbon content in % of dry weight**		**Fossil carbon fraction in % of total carbon**	
	Default	**Default**	**Range**	**Default**	**Range** [2]	**Default**	**Range**	**Default**	**Range**
Paper/cardboard	90	40	36 - 45	44	40 - 50	46	42 - 50	1	0 - 5
Textiles [3]	80	24	20 - 40	30	25 - 50	50	25 - 50	20	0 - 50
Food waste	40	15	8 - 20	38	20 - 50	38	20 - 50	-	-
Wood	85 [4]	43	39 - 46	50	46 - 54	50	46 - 54	-	-
Garden and Park waste	40	20	18 - 22	49	45 - 55	49	45 - 55	0	0
Nappies	40	24	18 - 32	60	44 - 80	70	54 - 90	10	10
Rubber and Leather	84	(39) [5]	(39) [5]	(47) [5]	(47) [5]	67	67	20	20
Plastics	100	-	-	-	-	75	67 - 85	100	95 - 100
Metal [6]	100	-	-	-	-	NA	NA	NA	NA
Glass [6]	100	-	-	-	-	NA	NA	NA	NA
Other, inert waste	90	-	-	-	-	3	0 - 5	100	50 - 100

[1] The moisture content given here applies to the specific waste types before they enter the collection and treatment. In samples taken from collected waste or from e.g., SWDS the moisture content of each waste type will vary by moisture of co-existing waste and weather during handling.

[2] The range refers to the minimum and maximum data reported by Dehoust *et al*., 2002; Gangdonggu, 1997; Guendehou, 2004; JESC, 2001; Jager and Blok, 1993; Würdinger *et al*., 1997; and Zeschmar-Lahl, 2002.

[3] 40 percent of textile are assumed to be synthetic (default). Expert judgement by the authors.

[4] This value is for wood products at the end of life. Typical dry matter content of wood at the time of harvest (that is for garden and park waste) is 40 percent. Expert judgement by the authors.

[5] Natural rubbers would likely not degrade under anaerobic condition at SWDS (Tsuchii et al., 1985; Rose and Steinbüchel, 2005).

[6] Metal and glass contain some carbon of fossil origin. Combustion of significant amounts of glass or metal is not common.

DOC values for different waste types, which are derived from analyses based on sampling during waste collection at SWDS or at incineration facilities, may include impurities, e.g., traces of food in glass and plastic waste. Carbon contents of paper, textiles, nappies, rubber and plastic may also be different between countries and at different time periods. These analyses may therefore result in DOC estimates different from those given in Table 2.4. It is *good practice* to use DOC values consistently with the way the waste composition data are derived.

The best composition data can be obtained by routine monitoring at the gate of SWDS or incineration and other treatment facilities. If these data are not available, composition data obtained at generation and/or transportation, treatment and recycling facilities can be used for disposed DOC estimations using waste stream analysis (see Box 2.1).

Waste can be sampled at pits in waste treatment facilities, at loading yards in transportation stations and SWDS. Composition data of disposed waste can be obtained from field sampling at SWDS. The amount of waste (typically more than 1 m^3 for a representative sample) should be separated manually into each item and weighed by item in order to obtain wet weight composition. A certain amount of each item should be reduced and sampled by quartering and used for chemical analysis including moisture and DOC. Samples should be taken on different days of the week.

MSW composition will vary by city in a same country. It will also vary by the day of the week, season and year in the same city. National representative (or average) composition data should be obtained from sampling at several typical cities on same days of the week in each season. Sampling at SWDS on rainy days will change moisture content (i.e., wet weight composition) significantly, and needs attention in interpretation of that in annual data.

Analyses to determine the national waste composition should be based on appropriate sampling methods (see Volume 1, Chapter 2, Approaches to Data Collection) and be repeated periodically to cover changes in waste generation and management. The sampling methods, frequency of sampling and implications on time series should be documented.

The default DOC values given in Table 2.4 are used in estimating CH_4 emissions from and carbon stored in SWDS (see Chapter 3). The default total carbon contents and fossil carbon fractions for estimating fossil CO_2 emissions from incineration and open burning are also given in Table 2.4.

2.3.2 Sludge

The DOC content in sludge will vary depending on the wastewater treatment method producing the sludge, and also 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).

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, 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).

2.3.3 Industrial waste

The average composition of industrial waste is very different from the average composition of MSW, and varies by type of industry, although many of the waste types can be included in both of industrial waste and MSW. DOC and fossil carbon in industrial waste is mainly found in the same waste types as in MSW. DOC is found in paper and cardboard, textiles, food and wood. Synthetic leather, rubber, and plastics are major sources of fossil carbon. Waste oils and solvents are also important sources of fossil carbon in industrial liquid waste. Paper and cardboard and plastics will be generated at various industries mainly from office work and by packaging waste. Wood will be found in wastes from pulp and paper, wood manufacturing industries and construction and demolition activities. Food, beverage and tobacco industry will be the major source of food waste. Details of product and/or activity of each industry are different country by country. In order to estimate the DOC and fossil carbon in industrial waste, surveys on waste generation and composition at representative industries and estimation of unit generation of certain composition per economic driver, such as production, floor area and employee number, can be used. Non-hazardous waste (like office waste and waste from catering) from industrial activities is sometimes included in MSW. Double counting of the emissions should be avoided.

Table 2.5 provides default values of DOC and fossil carbon contents in industrial waste by industry type per amount waste produced. The default values are only for process waste generated at the facilities (e.g., office waste is assumed to be included in MSW). Countries are encouraged to collect and use national data where available as the default data are very uncertain. The guidance given above and in Chapter 2 of Volume 1 can be used to develop data collection systems for industrial waste. The DOC and fossil carbon contents can be determined using the same sampling methods as for MSW.

TABLE 2.5
DEFAULT DOC AND FOSSIL CARBON CONTENT IN INDUSTRIAL WASTE (PERCENTAGE IN WET WASTE PRODUCED)[1]

Industry type	DOC	Fossil carbon	Total carbon	Water content [2]
Food, beverages and tobacco (other than sludge)	15	-	15	60
Textile	24	16	40	20
Wood and wood products	43	-	43	15
Pulp and paper (other than sludge)	40	1	41	10
Petroleum products, Solvents, Plastics	-	80	80	0
Rubber	(39) [3]	17	56	16
Construction and demolition	4	20	24	0
Other [4]	1	3	4	10

Source: Expert Judgement; Pipatti *et al*. 1996; Yamada *et al*. 2003.

[1] The default values apply only for process waste from the industries, office and other similar waste are assumed to be included in MSW.

[2] Note that water contents of industrial wastes vary enormously, even within a single industry.

[3] Natural rubbers would likely not degrade under anaerobic condition at SWDS (Tsuchii, *et al*., 1985; Rose and Steinbüchel, 2005).

[4] These values can be used also as defaults for total waste from manufacturing industries, when data on waste production by industry type are not available. Waste from mining and quarrying should be excluded from the calculations as the amounts can be large and the DOC and fossil carbon contents are likely to be negligible.

2.3.4 Other waste

Default values for DOC and fossil carbon for hazardous waste and clinical waste are given in Table 2.6. The values should be applied only for total amounts of hazardous and clinical waste generated in the country. Major part of hazardous waste would be generated as sludge or liquid-like nature, as well as ash, cinder and slug which are dry nature.

TABLE 2.6
DEFAULT DOC AND FOSSIL CARBON CONTENTS IN OTHER WASTE (PERCENTAGE IN WET WASTE PRODUCED)

Waste type	DOC	Fossil carbon	Total carbon	Water Content
Hazardous waste	NA	5 - 50 [1]	NA	10 - 90 [1]
Clinical waste	15	25	40	35

NA = not available

Sources: Expert Judgement; IPCC 2000

[1] The higher fossil carbon value is for waste with lower water content. When no data on the water content are available, the mean value of the range should be used.

Annex 2A.1 Waste Generation and Management Data - by country and regional averages

Table 2A.1 in this Annex shows MSW generation and management data for some countries whose data are available. Regional defaults for waste generation and treatment that are provided in Table 2.1 in Chapter 2 are derived based on the information from this table. The data are applicable as default data for the year 2000.

For comparison, data on waste generation and disposal to SWDS from *the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (*1996 IPCC Guidelines*) are also given in the table.

TABLE 2A.1
MSW GENERATION AND MANAGEMENT DATA - BY COUNTRY AND REGIONAL AVERAGES

Region /Country	MSW [1, 2] Generation Rate IPCC -1996 values [4] (tonnes/cap/yr)	MSW [1, 2, 3] Generation Rate Year 2000 (tonnes/cap/yr)	Fraction of MSW disposed to SWDS IPCC-1996 values [4]	Fraction of MSW disposed to SWDS	Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified [5]	Source
Asia								
Eastern Asia	**0.41**	**0.37**	**0.38**	**0.55**	**0.26**	**0.01**	**0.18**	
China		0.27		0.97	0.02	0.01		1
Japan	0.41	0.47	0.38	0.25	0.72	0.02	0.01	2, 31
Rep. of Korea		0.38		0.42	0.04		0.54	3
Southern and Central Asia	**0.12**	**0.21**	**0.60**	**0.74**	**-**	**0.05**	**0.21**	
Bangladesh		0.18		0.95			0.05	4
India	0.12	0.17	0.60	0.70		0.20	0.10	4
Nepal		0.18		0.40			0.60	4
Sri Lanka		0.32		0.90			0.10	4
South-eastern Asia		**0.27**		**0.59**	**0.09**	**0.05**	**0.27**	
Indonesia		0.28		0.80	0.05	0.10	0.05	4
Lao PDR		0.25		0.40			0.60	4
Malaysia		0.30		0.70	0.05	0.10	0.15	4
Myanmar		0.16		0.60			0.40	4
Philippines		0.19		0.62		0.10	0.28	4, 5
Singapore		0.40		0.20	0.58		0.22	6
Thailand		0.40		0.80	0.05	0.10	0.05	4
Vietnam		0.20		0.60			0.40	4
Africa								
Africa [6]		**0.29**		**0.69**			**0.31**	
Egypt				0.70			0.30	4
Sudan		0.29		0.82			0.18	7
South Africa			1.00	0.90			0.10	4
Nigeria				0.40			0.60	4
Europe								
Eastern Europe		**0.38**		**0.9**	**0.04**	**0.01**	**0.02**	
Bulgaria		0.52		1.00	0.00	0.00	0.00	8
Croatia				1.00	0.00	0.00	0.00	8
Czech Republic		0.33		0.75	0.14	0.04	0.06	8
Estonia		0.44		0.98	0.00	0.00	0.02	8
Hungary		0.45		0.92	0.08	0.00	0.00	8
Latvia		0.27		0.92	0.04	0.02	0.02	8
Lithuania		0.31		1.00	0.00	0.00	0.00	8
Poland		0.32		0.98	0.00	0.02	0.00	8

TABLE 2A.1 (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA - BY COUNTRY AND REGIONAL AVERAGES

Region /Country	**MSW ^{1,2} Generation Rate** IPCC -1996 values ^{4} (tonnes/cap/yr)	**MSW ^{1,2,3} Generation Rate** Year 2000 (tonnes/cap/yr)	**Fraction of MSW disposed to SWDS** IPCC-1996 values ^{4}	**Fraction of MSW disposed to SWDS**	**Fraction of MSW incinerated**	**Fraction of MSW composted**	**Fraction of other MSW management, unspecified ^{5}**	**Source**
Romania		0.36		1.00	0.00	0.00	0.00	8
Russian Federation	0.32	0.34	0.94	0.71	0.19	0.00	0.10	9
Slovakia		0.32		1.00	0.00	0.00	0.00	8
Slovenia		0.51		0.90	0.00	0.08	0.02	8
Northern Europe		**0.64**		**0.47**	**0.24**	**0.08**	**0.20**	
Denmark	0.46	0.67	0.2	0.10	0.53	0.16	0.22	8
Finland	0.62	0.50	0.77	0.61	0.1	0.07	0.22	8
Iceland		1.00		0.86	0.06	0.01	0.06	8
Norway	0.51	0.62	0.75	0.55	0.15	0.09	0.22	8
Sweden	0.37	0.43	0.44	0.23	0.39	0.10	0.29	8
Southern Europe		**0.52**		**0.85**	**0.05**	**0.05**	**0.05**	
Cyprus		0.68		1.00	0.00	0.00	0.00	8
Greece	0.31	0.41	0.93	0.91	0.00	0.01	0.08	8
Italy	0.34	0.50	0.88	0.70	0.07	0.14	0.09	8
Malta		0.48		1.00	0.00	0.00	0.00	8
Portugal	0.33	0.47	0.86	0.69	0.19	0.05	0.07	8
Spain	0.36	0.60	0.85	0.68	0.07	0.16	0.09	8
Turkey		0.50		0.99	0.00	0.01	0.00	8
Western Europe	**0.45**	**0.56**	**0.57**	**0.47**	**0.22**	**0.15**	**0.15**	
Austria	0.34	0.58	0.4	0.30	0.10	0.37	0.23	8
Belgium	0.40	0.47	0.43	0.17	0.32	0.23	0.28	8
France	0.47	0.53	0.46	0.43	0.33	0.12	0.13	8
Germany	0.36	0.61	0.66	0.30	0.24	0.17	0.29	8
Ireland	0.31	0.60	1.0	0.89	0.00	0.01	0.11	8
Luxemburg	0.49	0.66	0.35	0.27	0.55	0.18	0.00	8
Netherlands	0.58	0.62	0.67	0.11	0.36	0.28	0.25	8
Switzerland	0.40	0.40	0.23	1.00	0.00	0.00	0.00	8
UK	0.69	0.57	0.90	0.82	0.07	0.03	0.08	8
Central, South America and Caribbean states								
Caribbean		**0.49**		**0.83**	**0.02**		**0.15**	
Bahamas		0.95		0.7			0.3	10
Cuba		0.21		0.90			0.1	11
Dominican Republic		0.25		0.90	0.06		0.04	12
St. Lucia		0.55		0.83			0.17	13
Central America		**0.21**		**0.50**			**0.50**	
Costa Rica		0.17						14, 15
Guatemala		0.22		0.40			0.60	16, 17, 18
Honduras		0.15		0.40			0.60	4
Nicaragua		0.28		0.70			0.30	4
South America								
South America		**0.26**		**0.54**	**0.01**	**0.003**	**0.46**	
Argentina		0.28		0.59			0.41	4
Bolivia		0.16		0.70			0.30	19

TABLE 2A.1 (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA - BY COUNTRY AND REGIONAL AVERAGES

Region /Country	MSW [1, 2] Generation Rate IPCC -1996 values [4] (tonnes/cap/yr)	MSW [1, 2, 3] Generation Rate Year 2000 (tonnes/cap/yr)	Fraction of MSW disposed to SWDS IPCC-1996 values [4]	Fraction of MSW disposed to SWDS	Fraction of MSW incinerated	Fraction of MSW composted	Fraction of other MSW management, unspecified [5]	Source
Brazil		0.18		0.80	0.05	0.03	0.12	20, 21
Chile				0.40			0.60	4
Colombia		0.26		0.31			0.69	22
Ecuador		0.22		0.40			0.60	23
Paraguay (Asuncion)		0.44		0.40			0.60	24
Peru		0.20		0.53			0.47	4, 25
Uruguay		0.26		0.72			0.28	26, 27
Venezuela		0.33		0.50			0.50	28
North America								
North America	**0.70**	**0.65**	**0.69**	**0.58**	**0.06**	**0.06**	**0.29**	
Canada	0.66	0.49	0.75	0.71	0.04	0.19	0.06	29, 30, 31
Mexico		0.31		0.49			0.51	32, 33
USA	0.73	1.14	0.62	0.55	0.14		0.31	34
Oceania								
Oceania	**0.47**	**0.69**	**1.00**	**0.85**			**0.15**	
Australia	0.46	0.69	1.00	1.00				4, 31
New Zealand	0.49		1.00	0.70			0.30	4

[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. In many countries, especially developing countries, this encompasses only urban population.

[3] The data are default data for the year 2000, although for some countries the year for which the data are applicable was not given in the reference, or data for the year 2000 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 *1996 IPCC Guidelines.*

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

[6] A regional average is given for the whole of Africa as data are not available for more detailed regions within Africa.

Source	Year	
1		Urban Construction Statistics Yearbook of China – Year 2000 (2001). Ministry of Chinese Construction. Chinese Construction Industry Publication Company.
2		OECD Environment Directorate, OECD Environmental Data 2002, Waste.
		Ministry of Environment, Japan (1992-2003): Waste of Japan, http://www.env.go.jp/recycle/waste/ippan.html.
3		1) '97 National Status of Solid Waste Generation and Treatment , the Ministry of Environment, Korea, 1998.
		2) '96 National Status of Solid Waste Generation and Treatment , the Ministry of Environment, Korea, 1997.
		3) Korea Environmental Yearbook, the Ministry of Environment, Korea, 1990.
4		Doorn and Barlaz, 1995, Estimate of global methane emissions from landfills and open dumps, EPA-600/R-95-019, Office of Research & Development, Washington DC, USA.
5		Shimura et al. (2001).
6	2001	National Environmental Agency, Singapore (www.nea.gov.sg.) and www.acrr.org/resourcecities/waste_resources/europe_waste.htm.
7		Ministry of Environment and Physical Development, Higher Council for Environment and Natural Resources, Sudan (2003), Sudan's First National Communications under the United Nations Framework Convention on Climate Change.
8	2000	Eurostat (2005). Waste Generated and Treated in Europe. Data 1995-2003. European Commission - Eurostat, Luxemburg. 131p.
9		Problems of waste management in Russia: Not-for-Profit Partnership "Waste Management – Strategic Ecological Initiative" http://www.sagepub.com/journalsProdEditBoards.nav?prodId=Journal201691.

TABLE 2A.1 (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA- BY COUNTRY AND REGIONAL AVERAGES

Source	Year	
10		The Bahamas Environment, Science and Technology Commission (2001). Commonwealth of the Bahamas. First National Communication on Climate Change. Nassu, New Providence, April 2001, 121pp.
11	1990	OPS/OMS (1997). Análisis Sectorial de Residuos Sólidos en Cuba. Serie Análisis 1. Sectoriales No. 13, Organización Panamericana de la Salud, 206 pp., 2. López, C., et al. (2002). República de Cuba. Inventario Nacional de Emisiones y Absorciones de Gases de Invernadero (colectivo de autores). Reporte para el Año 1996/Actualización para los Años 1990 y 1994. CD-ROM Vol. 01. Instituto de Meteorología-AMA-CITMA. La Habana, 320 pp. ISBN: 959-02-0352-3.
12		Secretaría de Estado de Medio Ambiente y Recursos Naturales (2004). República Dominicana. Primera Comunicación Nacional a la Convención Marco de Naciones Unidas sobre Cambio Climático. UNEP/GEF, Santo Domingo, Marzo de 2004, 163 pp.
13	1990	Ministry of Planning, Development, Environment and Housing (2001). Saint Lucias's Initial National Communication on Climate Change, UNEP/GEF, 306 pp.
14		Lammers, P. E. M., J. F. Feenstra, A. A. Olstroorn (1998). Country/Region-Specific Emission Factors in National Greenhouse Gas Inventories. UNEP/Institute for Environmental Studies Vrije Universiteit, 112 pp.
15		Ministerio de Recursos Naturales, Energía y Minas (1995). Inventario Nacional de Fuentes y Sumideros de Gases con Efecto Invernadero en Costa Rica. MRNEM, Instituto Meteorológico Nacional, San José, Septiembre 1995.
16		Ministerio de Ambiente y Recursos Naturales (2001). República de Guatemala. Primera Comunicación Nacional sobre Cambio Climático..
17		JICA (Agencia Japonesa de Cooperación Internacional) (1991). Estudio sobre el Manejo de los Desechos Sólidos en el Area Metropolitana de la Ciudad de Guatemala. Volumen 1.
18		Guatemala de la Asunción, diciembre 2001, 127 p.,OPS/OMS (1995). Análisis Sectorial de Residuos Sólidos en Guatemala, Diciembre 1995, 183 pp.
19	1990	Fondo Nacional de Desarrollo (FNDR). Cantidad de RSM dispuestos en RSA-años 1996 y 1997, La Paz, Bolivia., 2. Ministerio de Desarrollo Sostenible y Medio Ambiente/Secretaría Nacional de Recursos Naturales y Medio Ambiente (1997). Inventariación de Emisiones de Gases de Efecto Invernadero. Bolivia – 1990. MDSMA/SNRNMA/SMA/PNCC/U.S. CSP, La Paz, 1997.
20		Ministry of Science and Technology, Brazil (2002). First Brazilian Inventory of Anthropogenic Greenhouse Gas Emissions. Background Reports. Methane Emissions from Waste Treatment and Disposal. CETESB. 1990 and 1994, Brazília, DF, 85 pp.
21		CETESB (1992). Companhia de Tecnologia de Saneamiento Ambiental. Programa de gerenciamiento de residuos sólidos domiciliares e de services de saúde. PROLIXO, CETESB; Sao Paulo, 29 pp., IBGE: Instituto Brasileiro de Geografía e Estadística. http://www.ibge.gov.br/home/estadistica/populacao/atlassaneamiento/pdf/mappag59.pdf in November 2004.
22	1990	Ministerio de Medio Ambiente/IDEAM (1999). República de Colombia. Inventario Nacional de Fuentes y Sumideros de Gases de Efecto Invernadero. 1990. Módulo Residuos, Santa Fe de Bogotá, DC, Marzo de 1999, 14 pp.
23		BID/OPS/OMS (1997). Diagnóstico de la Situación del Manejo de los Residuos Sólidos Municipales en América Latina y el Caribe., Doorn and Barlaz, 1995, Estimate of global methane emissions from landfills and open dumps, EPA-600/R-95-019, Office of Research & Development, Washington DC, USA.
24	1990	MAG/SSERNMA/DOA – PNUD/UNITAR (1999). Paraguay: Inventario Nacional de Gases de Efecto Invernadero por Fuentes y Sumideros. Año 1990. Proyecto PAR GLO/95/G31. Asunción, Noviembre 1999, 90 pp.
25	1990 1994 1998	Estudios CEPIS-OPS y/o Estudio Sectorial de Residuos Sólidos del Perú. Ditesa/OPS., Lammers, P. E. M., J. F. Feenstra, A. A. Olstroorn (1998). Country/Region-Specific Emission Factors in National Greenhouse Gas Inventories. UNEP/Institute for Environmental Studies Vrije Universiteit, 112 pp.
26		Ministerio de Vivienda, Ordenamiento Territorial y Medio Ambiente/Dirección Nacional de Medio Ambiente/Unidad de Cambio Climático (1998). Uruguay. Inventario Nacional de Emisiones Netas de Gases de Efecto Invernadero 1994/Estudio Comparativo de Emisiones Netas de Gases de Efecto Invernadero para 1990 y 1994. Montevideo, Noviembre de 1998, 363pp.
27		OPS/OMS (1996). Análisis Sectorial de Residuos Só,Ministerio de Vivienda, Ordenamiento Territorial y Medio Ambiente/Dirección Nacional de Medio Ambiente/Unidad de Cambio Climático (2004). Uruguay. Segunda Comunicación a la CMNUCC. 330p. lidos en Uruguay. Plan Regional de Inversiones en Medio Ambiente y Salud, Marzo 1996.
28	2000	Ministerio del Ambiente y de los Recursos Naturales Renovables. Ministerio de Energía y Minas (1996). Venezuela. Inventario de Emisiones de Gases de Efecto Invernadero. Año 1990. GEF/UNEP/U.S CSP.
29	1992	Organization for Economic Cooperation and Development (OECD) http://www.oecd.org/dataoecd/11/15/24111692.PDF

TABLE 2A.1 (CONTINUED)
MSW GENERATION AND MANAGEMENT DATA- BY COUNTRY AND REGIONAL AVERAGES

Source	Year	
30		The Fraser Institute, Environmental Indicators, 4th Edition (2000). http://oldfraser.lexi.net/publications/critical_issues/2000/env_indic/section_05.html.
31		UNFCCC Secretariat, Working paper No.3 (g) (2000). Expert report, prepared for the UNFCCC secretariat, 20 February 2000.
32	1992	http://www.oecd.org/dataoecd/11/15/24111692.PDF.
33		INE/SMARN (2000). Inventario Nacional de Emisiones de Gases de Invernadero 1994-1998, Ciudad de Mexico, Octubre 2000, 461 p.
34		Waste generation from: BioCycle (January 2004). "14th Annual BioCycle Nationwide Survey: The State of Garbage in America", Waste disposition from: BioCycle (December 2001). "13th Annual BioCycle Nationwide Survey: The State of Garbage in America"; Personal Communication: Elizabeth Scheele, U.S. EPA.

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CHAPTER 3

SOLID WASTE DISPOSAL

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3 SOLID WASTE DISPOSAL

3.1 INTRODUCTION

Treatment and disposal of municipal, industrial and other solid waste produces significant amounts of methane (CH_4). In addition to CH_4, solid waste disposal sites (SWDS) also produce biogenic carbon dioxide (CO_2) and non-methane volatile organic compounds (NMVOCs) as well as smaller amounts of nitrous oxide (N_2O), nitrogen oxides (NO_x) and carbon monoxide (CO). CH_4 produced at SWDS contributes approximately 3 to 4 percent to the annual global anthropogenic greenhouse gas emissions (IPCC, 2001). In many industrialised countries, waste management has changed much over the last decade. Waste minimisation and recycling/reuse policies have been introduced to reduce the amount of waste generated, and increasingly, alternative waste management practices to solid waste disposal on land have been implemented to reduce the environmental impacts of waste management. Also, landfill gas recovery has become more common as a measure to reduce CH_4 emissions from SWDS.

Decomposition of organic material derived from biomass sources (e.g., crops, wood) is the primary source of CO_2 released from waste. These CO_2 emissions are not included in national totals, because the carbon is of biogenic origin and net emissions are accounted for under the AFOLU Sector. Methodologies for NMVOCs, NO_x and CO are covered in guidelines under other conventions such as the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP). Links to these methodologies are provided in Chapter 1 of this volume, and additional information in Chapter 7 of Volume 1. No methodology is provided for N_2O emissions from SWDS because they are not significant.

The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (*1996 Guidelines*, IPCC, 1997) and the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (*GPG2000*, IPCC, 2000) described two methods for estimating CH_4 emissions from SWDS: the mass balance method (Tier 1) and the First Order Decay (FOD) method (Tier 2). In this Volume, the use of the mass balance method is strongly discouraged as it produces results that are not comparable with the FOD method which produces more accurate estimates of annual emissions. In place of the mass balance method, this chapter provides a Tier 1 version of the FOD method including a simple spreadsheet model with step-by-step guidance and improved default data. With this guidance, all countries should be able to implement the FOD method.

3.2 METHODOLOGICAL ISSUES

3.2.1 Choice of method

The IPCC methodology for estimating CH_4 emissions from SWDS is based on the First Order Decay (FOD) method. This method assumes that the degradable organic component (degradable organic carbon, DOC) in waste decays slowly throughout a few decades, during which CH_4 and CO_2 are formed. If conditions are constant, the rate of CH_4 production depends solely on the amount of carbon remaining in the waste. As a result emissions of CH_4 from waste deposited in a disposal site are highest in the first few years after deposition, then gradually decline as the degradable carbon in the waste is consumed by the bacteria responsible for the decay.

Transformation of degradable material in the SWDS to CH_4 and CO_2 is by a chain of reactions and parallel reactions. A full model is likely to be very complex and vary with the conditions in the SWDS. However, laboratory and field observations on CH_4 generation data suggest that the overall decomposition process can be approximated by first order kinetics (e.g., Hoeks, 1983), and this has been widely accepted. IPCC has therefore adopted the relatively simple FOD model as basis for the estimation of CH_4 emissions from SWDS.

Half-lives for different types of waste vary from a few years to several decades or longer. The FOD method requires data to be collected or estimated for historical disposals of waste over a time period of 3 to 5 half-lives in order to achieve an acceptably accurate result. It is therefore *good practice* to use disposal data for at least 50 years as this time frame provides an acceptably accurate result for most typical disposal practices and conditions. If a shorter time frame is chosen, the inventory compiler should demonstrate that there will be no significant underestimation of the emissions. These *Guidelines* provide guidance on how to estimate historical waste disposal data (Section 3.2.2, Choice of Activity Data), default values for all the parameters of the FOD model

(Section 3.2.3, Choice of Emission Factors and Parameters), and a simple spreadsheet model to assist countries in using the FOD method.

Three tiers to estimate the CH_4 emissions from SWDS are described:

Tier 1: The estimations of the Tier 1 methods are based on the IPCC FOD method using mainly default activity data and default parameters.

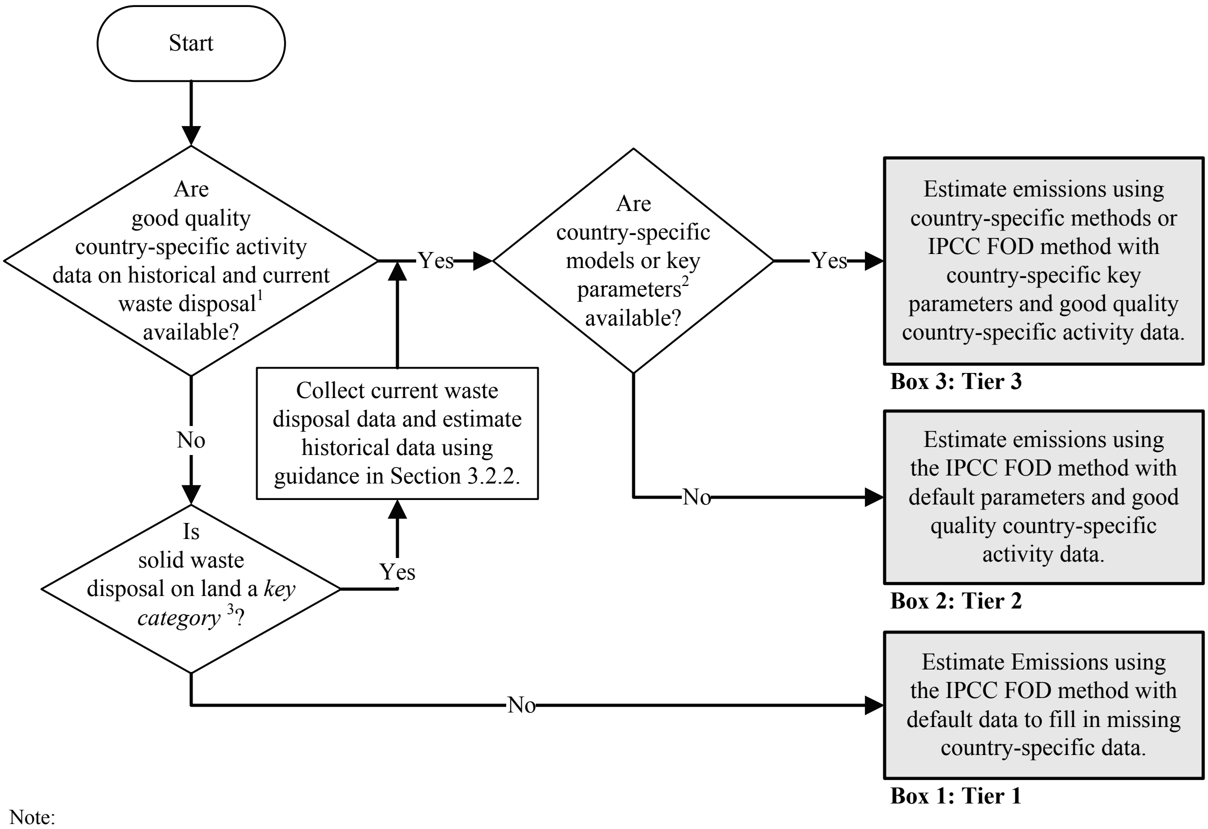
Tier 2: Tier 2 methods use the IPCC FOD method and some default parameters, but require good quality country-specific activity data on current and historical waste disposal at SWDS. Historical waste disposal data for 10 years or more should be based on country-specific statistics, surveys or other similar sources. Data are needed on amounts disposed at the SWDS.

Tier 3: Tier 3 methods are based on the use of good quality country-specific activity data (see Tier 2) and the use of either the FOD method with (1) nationally developed key parameters, or (2) measurement derived country-specific parameters. The inventory compiler may use country-specific methods that are of equal or higher quality to the above defined FOD-based Tier 3 method. Key parameters should include the half-life, and either methane generation potential (L_o) or DOC content in waste and the fraction of DOC which decomposes (DOC_f). These parameters can be based on measurements as described in Box 3.1.

A decision tree for choosing the most appropriate method appears in Figure 3.1. It is *good practice* for all countries to use the FOD method or a validated country-specific method, in order to account for time dependence of the emissions.

The FOD method is briefly described in Section 3.2.1.1 and in more detail in Annex 3A.1. A spreadsheet model has been developed by the IPCC to assist countries in implementing the FOD: *IPCC Spreadsheet for Estimating Methane Emissions from Solid Waste Disposal Sites (IPCC Waste Model)* [1].The *IPCC Waste Model* is described in more detail below and can be modified and used for all tiers.

Figure 3.1 Decision Tree for CH_4 emissions from Solid Waste Disposal Sites



Note:
1. Good quality country-specific activity data mean country-specific data on waste disposed in SWDS for 10 years or more.
2. Key parameters mean DOC/L_o, DOC_f and half-life time.
3. 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.

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[1] See the attached spreadsheets in Excel format. <IPCC_Waste_Model.xls>.

3.2.1.1 FIRST ORDER DECAY (FOD)

METHANE EMISSIONS

The CH_4 emissions from solid waste disposal for a single year can be estimated using Equations 3.1. CH_4 is generated as a result of degradation of organic material under anaerobic conditions. Part of the CH_4 generated is oxidised in the cover of the SWDS, or can be recovered for energy or flaring. The CH_4 actually emitted from the SWDS will hence be smaller than the amount generated.

EQUATION 3.1
CH_4 EMISSION FROM SWDS

$$CH_4\ Emissions = \left[\sum_x CH_4\ generated_{x,T} - R_T \right] \bullet (1 - OX_T)$$

Where:

CH_4 Emissions = CH_4 emitted in year T, Gg

T = inventory year

x = waste category or type/material

R_T = recovered CH_4 in year T, Gg

OX_T = oxidation factor in year T, (fraction)

The CH_4 recovered must be subtracted from the amount CH_4 generated. Only the fraction of CH_4 that is not recovered will be subject to oxidation in the SWDS cover layer.

METHANE GENERATION

The CH_4 generation potential of the waste that is disposed in a certain year will decrease gradually throughout the following decades. In this process, the release of CH_4 from this specific amount of waste decreases gradually. The FOD model is built on an exponential factor that describes the fraction of degradable material which each year is degraded into CH_4 and CO_2.

One key input in the model is the amount of degradable organic matter (DOCm) in waste disposed into SWDS. This is estimated based on information on disposal of different waste categories (municipal solid waste (MSW), sludge, industrial and other waste) and the different waste types/material (food, paper, wood, textiles, etc.) included in these categories, or alternatively as mean DOC in bulk waste disposed. Information is also needed on the types of SWDS in the country and the parameters described in Section 3.2.3. For Tier 1, default regional activity data and default IPCC parameters can be used and these are included in the spreadsheet model. Tiers 2 and 3 require country-specific activity data and/or country-specific parameters.

The equations for estimating the CH_4 generation are given below. As the mathematics are the same for estimating the CH_4 emissions from all waste categories/waste types/materials, no indexing referring to the different categories/waste materials/types is used in the equations below.

The CH_4 potential that is generated throughout the years can be estimated on the basis of the amounts and composition of the waste disposed into SWDS and the waste management practices at the disposal sites. The basis for the calculation is the amount of Decomposable Degradable Organic Carbon (DDOCm) as defined in Equation 3.2. DDOCm is the part of the organic carbon that will degrade under the anaerobic conditions in SWDS. It is used in the equations and spreadsheet models as DDOCm. The index *m* is used for mass. DDOCm equals the product of the waste amount (W), the fraction of degradable organic carbon in the waste (DOC), the fraction of the degradable organic carbon that decomposes under anaerobic conditions (DOC_f), and the part of the waste that will decompose under aerobic conditions (prior to the conditions becoming anaerobic) in the SWDS, which is interpreted with the methane correction factor (MCF).

EQUATION 3.2
DECOMPOSABLE DOC FROM WASTE DISPOSAL DATA

$$DDOCm = W \bullet DOC \bullet DOC_f \bullet MCF$$

Where:

DDOCm = mass of decomposable DOC deposited, Gg

W = mass of waste deposited, Gg

DOC = degradable organic carbon in the year of deposition, fraction, Gg C/Gg waste

DOC_f = fraction of DOC that can decompose (fraction)

MCF = CH_4 correction factor for aerobic decomposition in the year of deposition (fraction)

Although CH_4 generation potential (L_o)[2] is not used explicitly in these *Guidelines*, it equals the product of DDOCm, the CH_4 concentration in the gas (F) and the molecular weight ratio of CH_4 and C (16/12).

EQUATION 3.3
TRANSFORMATION FROM DDOCm TO L_O

$$L_o = DDOCm \bullet F \bullet 16/12$$

Where:

L_o = CH_4 generation potential, Gg CH_4

DDOCm = mass of decomposable DOC, Gg

F = fraction of CH_4 in generated landfill gas (volume fraction)

16/12 = molecular weight ratio CH_4/C (ratio)

Using DDOCma (DDOCm accumulated in the SWDS) from the spreadsheets, the above equation can be used to calculate the total CH_4 generation potential of the waste remaining in the SWDS.

FIRST ORDER DECAY BASICS

With a first order reaction, the amount of product is always proportional to the amount of reactive material. This means that the year in which the waste material was deposited in the SWDS is irrelevant to the amount of CH_4 generated each year. It is only the total mass of decomposing material currently in the site that matters.

This also means that when we know the amount of decomposing material in the SWDS at the start of the year, every year can be regarded as year number 1 in the estimation method, and the basic first order calculations can be done by these two simple equations, with the decay reaction beginning on the 1st of January the year after deposition.

EQUATION 3.4
DDOCm ACCUMULATED IN THE SWDS AT THE END OF YEAR T

$$DDOCma_T = DDOCmd_T + \left(DDOCma_{T-1} \bullet \ e^{-k}\right)$$

EQUATION 3.5
DDOCm DECOMPOSED AT THE END OF YEAR T

$$DDOCm\ decomp_T = DDOCma_{T-1} \bullet \left(1 - e^{-k}\right)$$

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[2] In the *2006 Guidelines* L_o (Gg CH_4 generated) is estimated from the amount of decomposable DOC in the SWDS. The equation in *GPG2000* is different as L_o is estimated as Gg CH_4 per Gg waste disposed, and the emissions are obtained by multiplying with the mass disposed.

Where:

T = inventory year

$DDOCma_T$ = DDOCm accumulated in the SWDS at the end of year *T*, Gg

$DDOCma_{T-1}$ = DDOCm accumulated in the SWDS at the end of year (*T*-1), Gg

$DDOCmd_T$ = DDOCm deposited into the SWDS in year *T*, Gg

DDOCm $decomp_T$ = DDOCm decomposed in the SWDS in year *T*, Gg

k = reaction constant, $k = \ln(2)/t_{1/2}$ (y^{-1})

$t_{1/2}$ = half-life time (y)

The method can be adjusted for reaction start dates earlier than 1st of January in the year after deposition. Equations and explanations can be found in Annex 3A.1.

CH_4 generated from decomposable DDOCm

The amount of CH_4 formed from decomposable material is found by multiplying the CH_4 fraction in generated landfill gas and the CH_4 /C molecular weight ratio.

EQUATION 3.6
CH_4 GENERATED FROM DECAYED DDOCm

$$CH_4\ generated_T = DDOCm\ decomp_T \bullet F \bullet 16/12$$

Where:

CH_4 $generated_T$ = amount of CH_4 generated from decomposable material

DDOCm $decomp_T$ = DDOCm decomposed in year *T*, Gg

F = fraction of CH_4, by volume, in generated landfill gas (fraction)

16/12 = molecular weight ratio CH_4/C (ratio)

Further background details on the FOD, and an explanation of differences with the approaches in previous versions of the guidance (IPCC, 1997; IPCC, 2000), are given in Annex 3A.1.

SIMPLE FOD SPREADSHEET MODEL

The simple FOD spreadsheet model (*IPCC Waste Model*) has been developed on the basis of Equations 3.4 and 3.5 shown above. The spreadsheet keeps a running total of the amount of decomposable DOC in the disposal site, taking account of the amount deposited each year and the amount remaining from previous years. This is used to calculate the amount of DOC decomposing to CH_4 and CO_2 each year.

The spreadsheet also allows users to define a time delay between deposition of the waste and the start of CH_4 generation. This represents the time taken for substantial CH_4 to be generated from the disposed waste (see Section 3.2.3 and Annex 3A.1).

The model then calculates the amount of CH_4 generated from the DDOCm, and subtracts the CH_4 recovered and CH_4 oxidised in the cover material (see Annex 3A.1 for equations) to give the amount of CH_4 emitted.

The *IPCC Waste Model* provides two options for the estimation of the emissions from MSW, that can be chosen depending on the available activity data. The first option is a multi-phase model based on **waste composition data**. The amounts of each type of degradable waste material (food, garden and park waste[3], paper and cardboard, wood, textiles, etc.) in MSW are entered separately. The second option is single-phase model based on **bulk waste** (MSW). Emissions from industrial waste and sludge are estimated in a similar way as for bulk MSW. Countries that choose to use the spreadsheet model may use either the waste composition or the bulk waste option, depending on the level of data available. When waste composition is relatively stable, both options give similar results. However when rapid changes in waste composition occur, options might give different

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[3] ‘garden waste’ may also be called ‘yard waste’ in US English.

outputs. For example, changes in waste management, such as bans to dispose food waste or degradable organic materials, can result in rapid changes in the composition of waste disposed in SWDS.

Both options can be used for estimating the carbon in harvested wood products (HWP) that is long-term stored in SWDS (see Volume 4, Chapter 12, Harvested Wood Products). If no national data are available on bulk waste, it is *good practice* to use the waste composition option in the spreadsheets, using the provided IPCC default data for waste composition.

In the spreadsheet model, separate values for DOC and the decay half-life may be entered for each waste category and in the waste composition option also for each waste type/material. The decay half-life can also be assumed to be the same for all waste categories and/or waste types. The first approach assumes that decomposition of different waste types/materials in a SWDS is completely independent of each other; the second approach assumes that decomposition of all types of waste is completely dependent on each other. At the time of writing these *Guidelines*, no evidence exists that one approach is better than the other (see Section 3.2.3, Half-life).

The spreadsheet calculates the amount of CH_4 generated from each waste component on a different worksheet. The methane correction factor (MCF – see Section 3.2.3) is entered as a weighted average for all disposal sites in the country. MCF may vary by time to take account of changes in waste management practices (such as a move towards more managed SWDS or deeper sites). Finally, the amount of CH_4 generated from each waste category and type/material is summed, and the amounts of CH_4 recovered and oxidised in the cover material are subtracted (if applicable), to give an estimate of total CH_4 emissions. For the bulk waste option, DOC can be a weighted average for MSW.

The spreadsheet model is most useful to Tier 1 methods, but can be adapted for use with all tiers. For Tier 1 the spreadsheets can estimate the activity data from population data and disposal data per capita (for MSW) and GDP (industrial waste), see Section 3.2.2 for additional guidance. When Tier 2 and 3 approaches are used, countries can extend the spreadsheet model to meet their own demands, or create their own models. The spreadsheet model can be extended with more sheets to calculate the CH_4 emissions if needed. MCF, OX and DOC for bulk waste can be made to vary over time. The same can easily be done to other parameters like DOC_f. New half-lives will require new CH_4 calculating sheets. Countries with good data on industrial waste can add new CH_4 calculating sheets and calculate the CH_4 emissions separately for different types of industrial waste. When the spreadsheet model is modified or countries-specific models are used, key assumptions and parameters should be transparently documented. Details on how to use the spreadsheet model can be found in the Instructions spreadsheet.

The model can be copied from the *2006 Guidelines* CDROM or downloaded from the IPCC NGGIP website < http://www.ipcc-nggip.iges.or.jp/ >.

Modelling different geographical or climate regions

It is possible to estimate CH_4 generation in different geographical regions of the country. For example, if the country contains a hot and wet region and a hot and dry region, the decay rates will be different in each region.

Dealing with different waste categories

Some users may find that their national waste statistics do not match the categories used in the model (food, garden and park waste, paper and cardboard, textiles and others as well as industrial waste). Where this is the case, the spreadsheet model will need to be modified to correspond to categorisation used by the country, or country-specific waste types will need to be re-classified into the IPCC categories. For example, clothes, curtain, and rugs are included in textiles, kitchen waste is similar to food waste, and straw and bamboo are similar to wood. The national statistics may contain a category called street sweepings. The user should estimate the composition of this waste. For example, it may be 50 percent inert material, 10 percent food, 30 percent paper and 10 percent garden and park waste. The street sweepings category can then be divided into these IPCC categories and added on to the waste already in these categories. In a similar manner, furniture can be divided into wood, plastic or metal waste, and electronics to metal, plastic and glass waste. This can all be done in a separate worksheet set up by the inventory compiler.

Adjusting waste composition at generation to waste composition at SWDS

The user should establish whether national waste composition statistics refer to the composition of waste generated or waste received at SWDS. The default waste composition statistics presented here are the composition of waste generated, not waste sent to SWDS. The composition should therefore be adjusted if necessary to take account of the impact of recycling or composting activities on the composition of the waste sent to SWDS. This could be best done in a separate spreadsheet set up by the inventory compiler, to estimate the amounts of each waste material generated, then subtract estimates of the amount of each waste material recycled, incinerated or composted, and work out the new composition of the residual waste sent to SWDS.

Open burning of waste at SWDS

Open burning at SWDS is common in many developing countries. The amount of waste (and DDOCm) available for decay at SWDS should be adjusted to the amount burned. Chapter 5 provides methods how to estimate the amount of waste burned. The estimation of emissions from SWDS should be consistent with estimates for open burning of waste at the disposal sites.

3.2.2 Choice of activity data

Activity data consist of the waste generation for bulk waste or by waste component and the fraction of waste disposed to SWDS. Waste generation is the product of the per capita waste generation rate (tonnes/capita/yr) for each component and population (capita). Chapter 2 gives guidance on the collection of data on waste generation and waste composition as well as waste management practices. Regional default values for MSW can be found in Table 2.1 for the generation rate and the fraction disposed in SWDS, and Table 2.3 for the waste composition. For industrial waste default data can be found in Table 2.2. To achieve accurate emission estimates in national inventories it is usually necessary to include data on solid waste disposal (amount, composition) for 3 to 5 half-lives (see Section 3.2.3) of the waste deposited at the SWDS, and specifications of different half-lives for different components of the waste stream or for bulk waste by SWDS type (IPCC, 2000). Changes in waste management practices (e.g., site covering/capping, leachate drainage improvement, compacting, and prohibition of hazardous waste disposal together with MSW) should also be taken into account when compiling historical data.

The FOD methods require data on solid waste disposal (amounts and composition) that are collected by default for 50 years. Countries that do not have historical statistical data, or equivalent data on solid waste disposal that go back for the whole period of 50 years or more will need to estimate these data using surrogates (extrapolation with population, economic or other drivers). The choice of the method will depend on the availability of data in the country.

For countries using default data on MSW disposal on land, or for countries whose own data do not cover the past 50 years, the missing historical data can be estimated to be proportional to urban population[4] (or total population when historical data on urban population are not available, or in cases where waste collection covers the whole population). For countries having national data on MSW generation, management practices and composition over a period of years (Tier 2 FOD), analyses on the drivers for solid waste disposal are encouraged. The historical data could be proportional to economic indicators, or combinations of population and economic indicators. Trend extrapolation could also produce good results. Waste management policies to reduce waste generation and to promote alternatives to solid waste disposal should be taken into account in the analyses. Data on industrial production (amount or value of production, preferably by industry type, depending on availability of data) are recommended as surrogate for the estimation of disposal of industrial waste (Tier 2). When production data are not available, historical disposal of industrial waste can be estimated proportional to GDP or other economic indicators. GDP is used as the driver in the Tier 1 method.

Historical data on urban population (or total population), GDP (or other economic indicators) and statistics in industrial production can be obtained from national statistics. International databases can help when national data are not available, for example:

- Population data (1950 onwards with five-year intervals) can be found in UN Statistics (see http://esa.un.org/unpp/).
- GDP data (1970 onwards, annual data at current prices in national currency) can be found in UN Statistics (see http://unstats.un.org/unsd/snaama/selectionbasicFast.asp).

For those years data are not available interpolation or extrapolation can be used.

Alternative methods have been put forward in literature and can be used when they can be shown to give better estimates than the above-mentioned default methods.

The choice of method and surrogate, and the reasoning behind the choice, should be documented transparently in the inventory report. The use of surrogate methods, interpolation and extrapolation as means to derive missing data is described in more detail in Chapter 6, Time Series Consistency, in Volume 1.

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[4] The choice between urban population and total population should be guided by the coverage of waste collection. When data on coverage of waste collection is not available, the recommendation is to use urban population as the driver.

3.2.3 Choice of emission factors and parameters

DEGRADABLE ORGANIC CARBON (DOC)

Degradable organic carbon (DOC) is the organic carbon in waste that is accessible to biochemical decomposition, and should be expressed as Gg C per Gg waste. The DOC in bulk waste is estimated based on the composition of waste and can be calculated from a weighted average of the degradable carbon content of various components (waste types/material) of the waste stream. The following equation estimates DOC using default carbon content values:

EQUATION 3.7

ESTIMATES DOC USING DEFAULT CARBON CONTENT VALUES

$$DOC = \sum_{i} \left(DOC_i \bullet W_i \right)$$

Where:

DOC = fraction of degradable organic carbon in bulk waste, Gg C/Gg waste

DOC_i = fraction of degradable organic carbon in waste type *i*

e.g., the default value for paper is 0.4 (wet weight basis)

W_i = fraction of waste type *i* by waste category

e.g., the default value for paper in MSW in Eastern Asia is 0.188 (wet weight basis)

The default DOC values for these fractions for MSW can be found in Table 2.4 and for industrial waste by industry in Table 2.5 in Chapter 2 of this Volume. A similar approach can be used to estimate the DOC content in total waste disposed in the country. In the spreadsheet model, the estimation of the DOC in MSW is needed only for the *bulk waste option,* and is the average DOC for the MSW disposed in the SWDS, including inert materials.

The inert part of the waste (glass, plastics, metals and other non-degradable waste, see defaults in Table 2.3 in Chapter 2.) is important when estimating the total amount of DOC in MSW. Therefore it is advised not to use IPCC default waste composition data together with country-specific MSW disposal data, without checking that the inert part is close to the inert part in the IPCC default data.

The use of country-specific values is encouraged if data are available. Country-specific values can be obtained by performing waste generation studies, sampling at SWDS combined with analysis of the degradable carbon content within the country. If national values are used, survey data and sampling results should be reported (see also Section 3.2.2 for activity data and Section 3.8 for reporting).

FRACTION OF DEGRADABLE ORGANIC CARBON WHICH DECOMPOSES (DOC_f)

Fraction of degradable organic carbon which decomposes (DOC_f) is an estimate of the fraction of carbon that is ultimately degraded and released from SWDS, and reflects the fact that some degradable organic carbon does not degrade, or degrades very slowly, under anaerobic conditions in the SWDS . The recommended default value for DOC_f is 0.5 (under the assumption that the SWDS environment is anaerobic and the DOC values include lignin, see Table 2.4 in Chapter 2 for default DOC values) (Oonk and Boom, 1995; Bogner and Matthews, 2003). DOC_f value is dependent on many factors like temperature, moisture, pH, composition of waste, etc. National values for DOC_f or values from similar countries can be used for DOC_f, but they should be based on well-documented research.

The amount of DOC leached from the SWDS is not considered in the estimation of DOC_f. Generally the amounts of DOC lost with the leachate are less than 1 percent and can be neglected in the calculations[5].

Higher tier methodologies (Tier 2 or 3) can also use separate DOC_f values defined for specific waste types. There is some literature giving information about anaerobic degradability (DOC_f) for material types (Barlaz,

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[5] In countries with high precipitation rates the amount of DOC lost through leaching may be higher. In Japan, where the precipitation is high, SWDS with high penetration rate, have been found to leach significant amounts of DOC (sometimes more than 10 percent of the carbon in the SWDS) (Matsufuji *et al*., 1996).

2004; Micales & Skog, 1997; US EPA, 2002; Gardner *et al*., 2002). The reported degradabilities especially for wood, vary over a wide range and is yet quite inconclusive. They may also vary with tree species. Separate DOC_f values for specific waste types imply the assumption that degradation of different types of waste is independent of each other. As discussed further, below under Half-Life, scientific knowledge at the moment of writing these *Guidelines* is not yet conclusive on this aspect.

Hence the use of waste type specific values for DOC_f can introduce additional uncertainty to the estimates in cases where the data on waste composition are based on default values, modelling or estimates based on expert judgement. Therefore, it is *good practice* to use DOC_f values specific to waste types only when waste composition data are based on representative sampling and analyses.

METHANE CORRECTION FACTOR (MCF)[6]

Waste disposal practices vary in the control, placement of waste and management of the site. The CH_4 correction factor (MCF) accounts for the fact that unmanaged SWDS produce less CH_4 from a given amount of waste than anaerobic managed SWDS. In unmanaged SWDS, a larger fraction of waste decomposes aerobically in the top layer. In unmanaged SWDS with deep disposal and/or with high water table, the fraction of waste that degrades aerobically should be smaller than in shallow SWDS. Semi-aerobic managed SWDS are managed passively to introduce air to the waste layer to create a semi-aerobic environment within the SWDS. The MCF in relation to solid waste management is specific to that area and should be interpreted as the waste management correction factor that reflects the management aspect it encompasses.

An MCF is assigned to each of four categories, as shown in Table 3.1. A default value is provided for countries where the quantity of waste disposed to each SWDS is not known. A country's classification of its waste sites into managed or unmanaged may change over a number of years as national waste management policies are implemented.

The Fraction of Solid Waste Disposed to Solid Waste Disposal Sites (SW_F) and MCF reflect the way waste is managed and the effect of site structure and management practices on CH_4 generation. The methodology requires countries to provide data or estimates of the quantity of waste that is disposed of to each of four categories of solid waste disposal sites (Table 3.1). Only if countries cannot categorise their SWDS into four categories of managed and unmanaged SWDS, the MCF for 'uncategorised SWDS' can be used.

TABLE 3.1
SWDS CLASSIFICATION AND METHANE CORRECTION FACTORS (MCF)

Type of Site	Methane Correction Factor (MCF) Default Values
Managed – anaerobic [1]	1.0
Managed – semi-aerobic [2]	0.5
Unmanaged [3] – deep (>5 m waste) and /or high water table	0.8
Unmanaged [4] – shallow (<5 m waste)	0.4
Uncategorised SWDS [5]	0.6

[1] **Anaerobic managed solid waste disposal sites**: These must have controlled placement of waste (i.e., waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and will include at least one of the following: (i) cover material; (ii) mechanical compacting; or (iii) levelling of the waste.

[2] **Semi-aerobic managed solid waste disposal sites**: These must have controlled placement of waste and will include all of the following structures for introducing air to waste layer: (i) permeable cover material; (ii) leachate drainage system; (iii) regulating pondage; and (iv) gas ventilation system.

[3] **Unmanaged solid waste disposal sites – deep and/or with high water table**: All SWDS not meeting the criteria of managed SWDS and which have depths of greater than or equal to 5 metres and/or high water table at near ground level. Latter situation corresponds to filling inland water, such as pond, river or wetland, by waste.

[4] **Unmanaged shallow solid waste disposal sites**; All SWDS not meeting the criteria of managed SWDS and which have depths of less than 5 metres.

[5] **Uncategorised solid waste disposal sites**: Only if countries cannot categorise their SWDS into above four categories of managed and unmanaged SWDS, the MCF for this category can be used.

Sources: IPCC (2000); Matsufuji *et al*. (1996)

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[6] The term methane correction factor (MCF) in this context should not be confused with the methane conversion factor (MCF) referred to in the Agriculture, Forestry, and Other Land Use Sector for livestock manure management emissions.

FRACTION OF CH_4 IN GENERATED LANDFILL GAS (F)

Most waste in SWDS generates a gas with approximately 50 percent CH_4. Only material including substantial amounts of fat or oil can generate gas with substantially more than 50 percent CH_4. The use of the IPCC default value for the fraction of CH_4 in landfill gas (0.5) is therefore encouraged.

The fraction of CH_4 in generated landfill gas should not be confused with measured CH_4 in gas emitted from the SWDS. In the SWDS, CO_2 is absorbed in seepage water, and the neutral condition of the SWDS transforms much of the absorbed CO_2 to bicarbonate. Therefore, it is *good practice* to adjust for the CO_2 absorption in seepage water, if the fraction of CH_4 in landfill gas is based on measurements of CH_4 concentrations measured in landfill gas emitted from the SWDS (Bergman, 1995; Kämpfer and Weissenfels, 2001; IPCC, 1997).

OXIDATION FACTOR (OX)

The oxidation factor (OX) reflects the amount of CH_4 from SWDS that is oxidised in the soil or other material covering the waste.

CH_4 oxidation is by methanotrophic micro-organisms in cover soils and can range from negligible to 100 percent of internally produced CH_4. The thickness, physical properties and moisture content of cover soils directly affect CH_4 oxidation (Bogner and Matthews, 2003).

Studies show that sanitary, well-managed SWDS tend to have higher oxidation rates than unmanaged dump sites. The oxidation factor at sites covered with thick and well-aerated material may differ significantly from sites with no cover or where large amounts of CH_4 can escape through cracks/fissures in the cover.

Field and laboratory CH_4 and CO_2 emission concentrations and flux measurements that determine CH_4 oxidation from uniform and homogeneous soil layers should not be used directly to determine the oxidation factor, since in reality, only a fraction of the CH_4 generated will diffuse through such a homogeneous layer. Another fraction will escape through cracks/fissures or via lateral diffusion without being oxidised. Therefore, unless the spatial extent of measurements is wide enough and cracks/fissures are explicitly included, results from field and laboratory studies may lead to over-estimation of oxidation in SWDS cover soils.

The default value for oxidation factor is zero. See Table 3.2. The use of the oxidation value of 0.1 is justified for covered, well-managed SWDS to estimate both diffusion through the cap and escape by cracks/fissures. The use of an oxidation value higher than 0.1, should be clearly documented, referenced, and supported by data relevant to national circumstances. It is important to remember that any CH_4 that is recovered must be subtracted from the amount generated before applying an oxidation factor.

TABLE 3.2
OXIDATION FACTOR (OX) FOR SWDS

Type of Site	Oxidation Factor (OX) Default Values
Managed [1], unmanaged and uncategorised SWDS	0
Managed covered with CH_4 oxidising material [2]	0.1

[1] Managed but not covered with aerated material

[2] Examples: soil, compost

HALF-LIFE

The half-life value, $t_{1/2}$ is the time taken for the DOCm in waste to decay to half its initial mass. In the FOD model and in the equations in this Volume, the reaction constant k is used. The relationship between k and $t_{1/2}$ is: $k = \ln(2)/t_{1/2}$. The half-life is affected by a wide variety of factors related with the composition of the waste, climatic conditions at the site where the SWDS is located, characteristics of the SWDS, waste disposal practices and others (Pelt *et al.*, 1998; Environment Canada, 2003).

The half-life value applicable to any single SWDS is determined by a large number of factors associated with the composition of the waste and the conditions at the site. Recent studies have provided more data on half-lives (experimental or by means of models), but the results obtained are based on the characteristics of developed countries under temperate conditions. Few available results reflect the characteristics of developing countries and tropical conditions. Measurements from SWDS in Argentina, New Zealand, the United States, the United Kingdom and the Netherlands support values for $t_{1/2}$ in the range of approximately 3 to 35 years (Oonk and Boom, 1995; USEPA, 2005; Scharff *et al*., 2003; Canada, 2004; and Argentina, 2004).

The most rapid rates (k = 0.2, or a half-life of about 3 years) are associated with high moisture conditions and rapidly degradable material such as food waste. The slower decay rates (k = 0.02, or a half-life of about 35 years) are associated with dry site conditions and slowly degradable waste such as wood or paper. A much longer half-life of 70 years or above could be justified for shallow dry SWDS in a temperate climate or for wood waste in a dry, temperate climate. A half-life of less than 3 years may be appropriate for managed SWDS in a wet, temperate climate or rapidly degrading waste in a wet, tropical climate. The inventory compiler is encouraged to establish country specific half-life values. Current knowledge and data limitations constrain the development of a default methodology for estimating half-lives from field-data at SWDS.

There are two alternative approaches to select the half-life (or k value) for the calculation: (a) calculate a weighted average for $t_{1/2}$ for mixed MSW (Jensen and Pipatti, 2002) or (b) divide the waste stream into categories of waste according to their degradation speed (Brown *et al*., 1999). The first approach assumes degradation of different types of waste to be completely dependent on each other. So the decay of wood is enhanced due to the present of food waste, and the decay of food waste is slowed down due to the wood. The second approach assumes degradation of different types of waste is independent of each other. Wood degrades as wood, irrespective whether it is in an almost inert SWDS or in a SWDS that contains large amounts of more rapidly degrading wastes. In reality the truth will probably be somewhere in the middle. However there has been little research performed to identify the better one of both approaches (Oonk and Boom, 1995; Scharff *et al*., 2003) and this research was not conclusive. Two options of the IPCC spreadsheet model apply either of above approaches to select the half-life as follows:

Bulk waste option**:** The bulk waste option requires alternative (a) above, and is suitable for countries without data or with limited data on waste composition, but with good information on bulk waste disposed at SWDS. Default values are estimated as a function of the climate zone.

Waste composition option**:** The waste composition option requires alternative (b) and is applicable for countries having data on waste composition. Specification of the half-life ($t_{1/2}$) of each component of the waste stream (IPCC, 2000) is required to achieve acceptably accurate results.

For both options default half-life values are estimated as a function of the climate zone. The main assumptions and considerations made are:

- Waste composition (especially the organic component) is one of the main factors influencing both the amount and the timing of CH_4 production.
- Moisture content of a SWDS is an essential element for anaerobic decomposition and CH_4 generation. A simplified method assumes that the moisture content of a SWDS is proportional to the mean annual precipitation (MAP) in the location of the SWDS (Pelt *et al*., 1998; U.S. EPA, 1998; Environment Canada, 2003) or to the ratio of MAP and potential evapotranspiration (PET).
- The extent to which ambient air temperatures influence the temperature of the SWDS and gas generation rates depends mainly on the degree of waste management and the depth of SWDS.
- Wastes in shallow open dumps generally decompose aerobically and produce little $CH_{4,}$ and the emissions decline in shorter time than the anaerobic conditions. Managed (and also deep unmanaged) SWDS creates anaerobic conditions.

Countries may develop specific half-life values (or k values) more appropriate for their circumstances and characteristics. It is *good practice* that countries which develop their own half-life values document the experimental procedures used to derive to them.

Default *k* values and the corresponding half-lives are provided below in Table 3.3 and in Table 3.4.

TABLE 3.3
RECOMMENDED DEFAULT METHANE GENERATION RATE (*k*) VALUES UNDER TIER 1

(Derived from *k* values obtained in experimental measurements, calculated by models, or used in greenhouse gas inventories and other studies)

Type of Waste		**Climate Zone***							
		Boreal and Temperate (MAT ≤ 20°C)				**Tropical[1] (MAT > 20°C)**			
		Dry (MAP/PET < 1)		**Wet (MAP/PET > 1)**		**Dry (MAP < 1000 mm)**		**Moist and Wet (MAP ≥ 1000 mm)**	
		Default	**Range[2]**	**Default**	**Range[2]**	**Default**	**Range[2]**	**Default**	**Range[2]**
Slowly degrading waste	**Paper/textiles waste**	0.04	0.03[3,5] – 0.05[3,4]	0.06	0.05 – 0.07[3,5]	0.045	0.04 – 0.06	0.07	0.06 – 0.085
	Wood/ straw waste	0.02	0.01[3,4] – 0.03[6,7]	0.03	0.02 – 0.04	0.025	0.02 – 0.04	0.035	0.03 – 0.05
Moderately degrading waste	**Other (non – food) organic putrescible/ Garden and park waste**	0.05	0.04 – 0.06	0.1	0.06 – 0.1[8]	0.065	0.05 – 0.08	0.17	0.15 – 0.2
Rapidly degrading waste	**Food waste/Sewage sludge**	0.06	0.05 – 0.08	0.185[4]	0.1[3,4] – 0.2[9]	0.085	0.07 – 0.1	0.4	0.17 – 0.7[10]
Bulk Waste		0.05	0.04 – 0.06	0.09	0.08[8] – 0.1	0.065	0.05 – 0.08	0.17	0.15[11] – 0.2

[1] The available information on the determination of k and half-lives in tropical conditions is quite limited. The values included in the table, for those conditions, are indicative and mostly have been derived from the assumptions described in the text and values obtained for temperate conditions.

[2] The range refers to the minimum and maximum data reported in literature or estimated by the authors of the chapter. It is included, basically, to describe the uncertainty associated with the default value.

[3] Oonk and Boom (1995).

[4] IPCC (2000).

[5] Brown *et a*l. (1999). A near value (16 yr) was used, for slow degradability, in the GasSim model verification (Attenborough *et al*., 2002).

[6] Environment Canada (2003).

[7] In this range are reported longer half-lives values (up to 231 years) that were not included in the table since are derived from extremely low *k* values used in sites with mean daily temperature < 0ºC (Levelton, 1991).

[8] Estimated from RIVM (2004).

[9] Value used for rapid degradability, in the GasSim model verification (Attenborough *et al*., 2002);

[10] Estimated from Jensen and Pipatti (2003).

[11] Considering t1/2 = 4 - 7 yr as characteristic values for most developing countries in a tropical climate. High moisture conditions and higly degradable waste.

*Adapted from: Chapter 3 in *GPG-LULUCF* (IPCC, 2003).

MAT – Mean annual temperature; MAP – Mean annual precipitation; PET – Potential evapotranspiration.

MAP/PET is the ratio of MAP to PET. The average annual MAT, MAP and PET during the time series should be selected to estimate emissions and indicated by the nearest representative meteorological station.

TABLE 3.4
RECOMMENDED DEFAULT HALF-LIFE ($t_{1/2}$) VALUES (YR) UNDER TIER 1

(Derived from *k* values obtained in experimental measurements, calculated by models, or used in greenhouse gas inventories and other studies)

Type of Waste		**Climate Zone***							
		Boreal and Temperate (MAT ≤ 20°C)				**Tropical[1] (MAT > 20°C)**			
		Dry (MAP/PET < 1)		**Wet (MAP/PET > 1)**		**Dry (MAP < 1000 mm)**		**Moist and Wet (MAP ≥ 1000 mm)**	
		Default	**Range[2]**	**Default**	**Range[2]**	**Default**	**Range[2]**	**Default**	**Range[2]**
Slowly degrading waste	**Paper/textiles waste**	17	14[3,5] – 23[3,4]	12	10 – 14[3,5]	15	12 – 17	10	8 – 12
	Wood/ straw waste	35	23[3,4] – 69[6,7]	23	17 – 35	28	17 – 35	20	14 – 23
Moderately degrading waste	**Other (non – food) organic putrescible/ Garden and park waste**	14	12 – 17	7	6 – 9[8]	11	9 – 14	4	3 – 5
Rapidly degrading waste	**Food waste/Sewage sludge**	12	9 – 14	4[4]	3[3,4] – 6[9]	8	6 – 10	2	1[10] – 4
Bulk Waste		14	12 – 17	7	6 – 9[8]	11	9 – 14	4	3 – 5[11]

[1] The available information on the determination of k and half-lives in tropical conditions is quite limited. The values included in the table, for those conditions, are indicative and mostly have been derived from the assumptions described in the text and values obtained for temperate conditions.

[2] The range refers to the minimum and maximum data reported in literature or estimated by the authors of the chapter. It is included, basically, to describe the uncertainty associated with the default value.

[3] Oonk and Boom (1995).

[4] IPCC (2000).

[5] Brown *et al*. (1999). A near value (16 yr) was used, for slow degradability, in the GasSim model verification (Attenborough *et al*., 2002).

[6] Environment Canada (2003).

[7] In this range are reported longer half-lives values (up to 231 years) that were not included in the table since are derived from extremely low *k* values used in sites with mean daily temperature < 0ºC (Levelton,1991).

[8] Estimated from RIVM (2004).

[9] Value used for rapid degradability, in the GasSim model verification (Attenborough *et al*., 2002).

[10] Estimated from Jensen and Pipatti (2003).

[11] Considering t1/2 = 4 - 7 yr as characteristic values for most developing countries in a tropical climate. High moisture conditions and higly degradable waste.

*Adapted from: Chapter 3 –*GPG-LULUCF* (IPCC, 2003).

MAT – Mean annual temperature; MAP – Mean annual precipitation; PET – Potential evapotranspiration.

MAP/PET is the ratio of MAP to PET. The average annual MAT, MAP and PET during the time series should be selected to estimate emissions and indicated by the nearest representative meteorological station.

METHANE RECOVERY (R)

CH_4 generated at SWDS can be recovered and combusted in a flare or energy device. The amount of CH_4 which is recovered is expressed as R in Equation 3.1. If the recovered gas is used for energy, then the resulting greenhouse gas emissions should be reported under the Energy Sector. Emissions from flaring are however 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. Emissions from flaring are not treated at Tier 1.

The default value for CH_4 recovery is zero. CH_4 recovery should be reported only when references documenting the amount of CH_4 recovery are available. Reporting based on metering of all gas recovered for energy and flaring, or reporting of gas recovery based on the monitoring of produced amount of electricity from the gas (considering the availability of load factors, heating value and corresponding heat rate, and other factors impacting the amount of gas used to produce the monitored amount of electricity) is consistent with *good practice*.

Estimating the amount of CH_4 recovered using more indirect methods should be done with great care, using substantiated assumptions. Indirect methods might be based on the number of SWDS in a country with CH_4 collection or the total capacity of utilisation equipment or flaring capacity sold.

When CH_4 recovery is estimated on the basis of the number of SWDS with landfill gas recovery a default estimate of recovery efficiency would be 20 percent. This is suggested due to the many uncertainties in using this methodology. There have been some measurements of efficiencies at gas recovery projects, and reported efficiencies have been between 10 and 85 percent Oonk and Boom (1995) measured efficiencies at closed, unlined SWDS to be in between 10 and 80 percent, the average over 11 SWDS being 37 percent. More recently Scharff *et al.* (2003) measured efficiencies at four SWDS to be 9 percent, 50 percent, 55 percent and 33 percent. Spokas *et al.* (2006) and Diot *et al.* (2001) recently measured efficiencies above 90 percent. In general, high recovery efficiencies can be related to closed SWDS, with reduced gas fluxes, well-designed and operated recovery and thicker and less permeable covers. Low efficiencies can be related to SWDS with large parts still being in exploitation and with e.g., temporary sandy covers.

Country-specific values may be used but significant research would need to be done to understand the impact on recovery of following parameters: cover type, percentage of SWDS covered by recovery project, presence of a liner, open or closed status, and other factors.

When the amount of CH_4 recovered is based on the total capacity of utilisation equipment or flares sold, an effort should be made in order to identify what part of this equipment is still operational. A conservative estimate of amount of CH_4 generated could be based on an inventory of the minimum capacities of the operational utilisation equipment and flares. Another conservative approach is to estimate total recovery as 35 percent of the installed capacities. Based on Dutch and US studies (Oonk, 1993; Scheehle, 2006), recovered amounts varied from 35 to 70 percent of capacity rates. The reasons for the range included (i) running hours from 95 percent down to 80 percent, due to maintenance or technical problems; (ii) overestimated gas production and as result oversized equipment; (iii) back-up flares being largely inactive. The higher rates took these considerations already into account when estimating capacity. If a country uses this method for flaring, care must be taken to ensure that the flare is not a back-up flare for a gas-to-energy project. Flares should be matched to SWDS wherever possible to ensure that double counting does not occur.

In all cases, the recovered amounts should be reported as CH_4, not as landfill gas, as landfill gas contains only a fraction of CH_4. The basis for the reporting should be clearly documented. When reporting is based on the number of SWDS with landfill gas recovery or the total capacity of utilisation equipment, it is essential that all assumptions used in the estimation of the recovery are clearly described and justified with country-specific data and references.

DELAY TIME

In most solid waste disposal sites, waste is deposited continuously throughout the year, usually on a daily basis. However, there is evidence that production of CH_4 does not begin immediately after deposition of the waste.

At first, decomposition is aerobic, which may last for some weeks, until all readily available oxygen has been used up. This is followed by the acidification stage, with production of hydrogen. The acidification stage is often said to last for several months. After which there is a transition period from acidic to neutral conditions, when CH_4 production starts.

The period between deposition of the waste and full production of CH_4 is chemically complex and involves successive microbial reactions. Time estimates for the delay time are uncertain, and will probably vary with waste composition and climatic conditions. Estimates of up to one year have been given in the literature (Gregory *et al.*, 2003; Bergman, 1995; Kämpfer and Weissenfels, 2001; Barlaz, 2004). The IPCC provides a default value of six months for the time delay (IPCC, 1997). This is equivalent to a reaction start time of 1st of January in the year after deposition, when the average residence time of waste in the SWDS has been six months. However, the uncertainty of this assumption is at least 2 months.

The IPCC Waste Model allows the user to change the default delay of six months to a different value. It is *good practice* to choose a delay time of between zero and six months. Values outside this range should be supported by evidence.

3.3 USE OF MEASUREMENT IN THE ESTIMATION OF CH_4 EMISSIONS FROM SWDS

The FOD model and other methods for estimating CH_4 generation at SWDS are constructed using scientific knowledge as well as assumptions on microbial metabolism under anaerobic conditions in the SWDS. As with all models, validation that includes some form of direct measurements to compare model predictions to actual measurements increases the user's confidence in the model and can be used to refine and improve the model predictions. These measurements can also be used to validate a model by comparing model predictions to CH_4 generation rates developed from measurements and to document the choice of country-specific values for parameters used in the model in preparing national inventories.

Measurements can be measured amounts of gas recovered in the gas collection system (in combination with an estimate of the recovery efficiency), measured amounts of diffuse CH_4 emissions to air and combinations of both.

Several studies have used measurement data from gas collection systems to develop estimates of the parameters needed for the FOD model (such as the decay rate constant and CH_4 generation potential) for specific SWDS, for classes of SWDS in specific regions, and for application to SWDS on a national basis (Oonk and Boom, 1995; Huitric *et al*., 1997; SWANA, 1998; SCS Engineers, 2003; U.S. EPA, 1998; U.S. EPA, 2005). The technique uses statistical procedures to develop best fit values for the model parameters, such as a nonlinear regression that evaluates model parameters in an iterative fashion to find the best estimate for the model parameters, based on the smallest sum of squared errors. With sufficient site-specific detail and an adequate large database of SWDS, the statistical analysis can identify the effects of variations in waste composition, geographical location, rainfall, and other factors on appropriate values for the model parameters. For example, several studies have found that the decay rate constant increases with precipitation (U.S. EPA, 2005).

The use of direct measurements of extracted amounts of gas to estimate FOD model parameters is one option for the *good practice* of developing country-specific values. This technique was used to develop some of the default values for half-life presented in Table 3.4. It is applicable for those countries with accurate measurement data from landfill gas collection systems for a representative set of SWDS with well known amounts, composition and age-distribution of waste deposited. If site-specific CH_4 collection data are used to estimate parameters for the FOD model for the national inventory, it is *good practice* to ensure that the SWDS used in the analysis are representative of all SWDS in the country in terms of the major factors that affect the values of the parameters and CH_4 emissions. Additional details on this technique are provided in Box 3.1.

BOX 3.1
DIRECT MEASUREMENTS FROM GAS COLLECTION SYSTEMS TO ESTIMATE FOD MODEL PARAMETERS

The key element in developing estimates of the parameters for the FOD model is a representative database of landfills that has the following characteristics:

(i) Contain types of wastes representative of landfills nationwide,

(ii) Include a range of sizes, waste age, and geographical regions (especially if the effect of precipitation is to be evaluated),

(iii) Have site-specific measurements of the landfill gas (LFG) collection rate and percent CH_4 that include seasonal variations over time (covering at least one year and preferably longer),

(iv) Have site-specific measurements of annual waste acceptance rates or total waste in place and year the landfill opened (i.e., the waste in place or average annual acceptance rate for the area of the landfill under the influence of the collection system,

(v) Include site-specific estimates of percent recovery (based on design and operational characteristics or other information), and

(vi) Include annual average precipitation (if this effect is to be evaluated).

Accuracy of direct measurements of LFG flow rate, percent CH_4, and annual waste disposal rates can be better than ±10 percent. The most significant source of error in using the direct measurement of CH_4 collection rates to estimate CH_4 generation rates is the determination of LFG collection efficiency. However, this error can be reduced and controlled if collection rate data are used only for landfills that are known or can be shown to have efficient and well-maintained collection systems and cover materials.

BOX 3.1 (CONTINUED)

The use of a collection efficiency will need to be researched and justified in order to be used with confidence. Several factors must be considered, such as the type of final cover, surface monitoring conducted on a regular basis showing low levels or no detectable CH_4, and a program of corrective action if CH_4 is detected (e.g., performing maintenance to improve the integrity of the cover or increasing the vacuum of collection wells). The estimate of collection efficiency can be based on site-specific considerations and adjusted to the upper or lower end of the range after considering these factors. The overall error and effect on the final results would tend to be lower when averaged over a large database of landfills because the errors would tend to cancel when using an unbiased midrange estimate.

Although surface measurements can be used to detect CH_4 as noted above, the use of surface measurements at the landfill to directly estimate collection efficiency is only recommended when the limitations of methods are fully taken into account, as discussed in more detail in the following section that describe the difficulties and inaccuracies of such measurements. Effects to take into account when measuring collection efficiencies are (i) CH_4 oxidation, that reduces the ratios of amount of CH_4 emitted and (ii) solution of CO_2 in the water phase in the waste or in the top-layer, when comparing the ratio of CH_4 and CO_2 emissions and CH_4 and CO_2 recovery.

Once a representative database has been established, measurements and collection efficiencies are estimated, the measurement data can be analyzed to determine country or region specific parameters. If a country has good waste composition data by landfill, this information could be used together with measurements and modelling to deduce parameters such as DDOC. For a country with less reliable waste composition data, parameters may have to be estimated at a broader level, considering L_o and k instead of more waste type specific parameters. It is not recommended for a country to directly estimate national emissions from measurements. Using measurements to deduce national level parameters based on the characteristics of the landfills analysed is the preferred approach to incorporating measurement data from collection systems.

Direct measurements of CH_4 emissions at the SWDS surface (rather than measuring CH_4 collection or generation) at a specific SWDS can in principle be of similar value for validating the FOD model parameters and developing national inventory estimates. In practice there are however limitations for several reasons:

(i) Monitoring and measuring CH_4 emissions at the SWDS's surface is a demanding task, and there are no generally agreed or standardised methods available for routine or long-term monitoring because the emissions come from a large area and vary throughout the year.

(ii) There are very few representative data available from direct measurements of CH_4 emissions for individual SWDS, much less to give good estimates for national emission inventories. It is therefore at the moment considered *good practice* to use emission estimates from individual sites based on monitoring and measurements only if the representativeness of the monitoring can be justified. If site-specific emissions data are used to estimate national emissions, it is *good practice* to group all SWDS in the country according to their characteristics and to base the national estimate on representative emission behaviour in each group.

Atmospheric emissions measurement techniques, their difficulties, and other considerations are discussed in more detail in Box 3.2.

BOX 3.2
DIRECT MEASUREMENTS OF METHANE EMISSIONS FROM THE SWDS SURFACE

Surface landfill gas (LFG) emissions are highly variable both spatially and temporally. Emissions vary on a daily basis as a result of changes in air-pressure and due to rainfall which affects the permeability of the top-layer. On top of that there is a seasonal variation in emissions as a result of reduced oxidation in winter. Additionally, emissions vary over the sections of the SWDS, due to differences in waste amounts, age and composition. Due to the high horizontal permeability, compared to vertical permeability, the slopes of a SWDS generally have higher emissions than the upper surface. On a more local scale, emissions are highly variable due to regions of reduced permeability in the subsurface and due to cracks in the surface. As a result, emissions at locations a few metres away from each other can vary over a factor 1000.

Measurement of diffuse CH_4 emissions in this context should give an indication of annual average emissions from the entire SWDS. So, temporal and seasonal fluctuation of gas emission (Maurice and Lagerkvist, 1997; Park and Shin, 2001) should be considered as part of the evaluation of site-specific data. The data collection period should be sufficient to cover temporal variation at the site. Seasonal variation might be comparably easily taken into consideration.

When performing measurements of diffuse emissions, one should realise that one measures the flux after oxidation, which can be a significant part of the percent of CH_4 generated that is not recovered.

Several techniques for direct measurement at the surface and/or below and above-ground have been proposed. The most important techniques are:

(i) Static or forced flux chamber measurements,

(ii) Mass balance methods,

(iii) Micrometeorological measurements,

(iv) Plume measurements.

The *flux chamber method* has been widely applied to measure the CH_4 flux on the SWDS surface (e.g., Park and Shin, 2001; Mosher *et al*., 1999; UK Environment Agency, 2004). A drawback of this method is the necessity of large number of measuring points in order to obtain reliable estimates of total emissions, which makes the method very labour intensive and thus expensive. There are a number of ways to improve the accuracy or reduce the number of measurements required, e.g., to expand the estimates from a smaller section to the whole SWDS through geostatistical methods (Börjesson *et al*., 2000; Spokas *et al*., 2003) or to identify the main emitting zones by observing cracks, stressed vegetation, interfaces between capped zone, edges and slope condition, etc. (UK Environment Agency, 2004), or to use portable gas-meter, olfaction or surface temperature as a first indicator (Yamada *et al*, 2005).

In the *mass-balance method* emissions are obtained by measuring the flux through an imaginary vertical plane on the SWDS by interpreting of wind velocity and the CH_4 concentrations at different heights over the SWDS surface. This plane can be both one-dimensional (Oonk and Boom, 1995; Scharff *et al*., 2003) or two-dimensional. The advantage of this method is that it is easily automated and can measure emissions from a large surface (in many case the whole SWDS) for longer period of times (weeks to months). Another advantage is that the both CH_4 and CO_2 emissions can be obtained which gives information on CH_4 oxidation and collection efficiencies. The disadvantage of the method is its limited scope (250 m) which makes it hard to measure emissions from the largest SWDS.

In the *micrometeorological method* emissions are measured as a flux through an imaginary horizontal plane and recalculated as vertical fluxes. CH_4 concentrations above the SWDS are used in combination with information on air transport and mixing at the scale of a few m^3 (hence micrometeorology, Fowler and Duyzer, 1989). Laurila *et al.* (2005) propose the micrometeorological Eddy-covariance method as suitable for estimation of landfill gas emission, with advantages of easy automation which enables measurements over longer periods of time and the simultaneous monitoring of CH_4 and CO_2 emissions. The drawback of the method seems to be its limited footprint (about 25 m), as a result of which it might not produce representative emissions from the entire SWDS.

BOX 3.2 (CONTINUED)

Plume measurements are designed to measure the emissions from an entire SWDS by measuring the difference in CH_4 flux in a transect screen downwind and upwind from the SWDS. Emissions might be assessed comparing increase in CH_4 concentrations with tracer concentrations (e.g., from a known amount of N_2O or SF_6 released on the SWDS) or using a dispersion model. Variations of this method are used around the world by Czepiel *et al.* (1996), Savanne *et al.* (1997), Galle *et al.*, (1999) and Hensen and Scharff (2001). The advantage of the method is its accuracy and its possibility to measure emissions from the entire SWDS, this being very effective to cope with spatial variation. However, the method is very expensive and normally only applied for one or a few specific days. Therefore the result seems to be not representative for the annual average emissions from the site (Scharff *et al.*, 2003). For this reason Scharff *et al.* (2003) developed a stationary version of the mobile plume measurement (SPM) for plume measurements around a SWDS for longer times.

At this moment (2006), there is no scientific agreement on what methodology is preferred to obtain annual average emissions from an entire SWDS. Intercomparisons of methods are performed by Savanne *et al.* (1995) and Scharff *et al.* (2003) and the conclusion is more or less that no single method can deal with spatial and temporal variability and is yet affordable. According to Scharff *et al.* (2003) the mass-balance method and the static plume method are the best candidates for further development and validation. However there has been little scientific discussion on this conclusion at the moment of writing of the *Guidelines*.

3.4 CARBON STORED IN SWDS

Some carbon will be stored over long time periods in SWDS. Wood and paper decay very slowly and accumulate in the SWDS (long-term storage). Carbon fractions in other waste types decay over varying time periods (see Half-life under Section 3.2.3.)

The amount of carbon stored in the SWDS can be estimated using the FOD model (see Annex 3A.1). The long-term storage of carbon in paper and cardboard, wood, garden and park waste is of special interest as the changes in carbon stock in waste originating from harvested wood products which is reported in the AFOLU volume (see Chapter 12, Harvested Wood Products). The FOD model of this Volume provides these estimates as a by-product. The *waste composition* option calculates the long-term stored carbon from wood, paper and cardboard, and garden and park waste in the SWDS, as this is simply the portion of the DOC that is not lost through decay (the equations to estimate the amount are given in Annex 3A.1). When using *the bulk waste* option it is necessary to estimate the appropriate portion of DOC originating from harvested wood products in the total DOC of the waste, before finding the amounts of long-term stored carbon. When country-specific estimates are not available, the IPCC default fractions of paper and cardboard, wood, and garden and park waste can be used.

The long-term stored carbon in SWDS is reported as an information item in the Waste sector. The reported value for waste derived from harvested wood products (paper and cardboard, wood and garden and park waste) is equal to the variable 1B, $\Delta C_{HWP\ SWDS\ _{DC}}$, i.e., the carbon stock change of HWP from domestic consumption disposed into SWDS of the reporting country used in Chapter 12, Harvested Wood Products, of the AFOLU Volume. This parameter as well as the annual CH_4 emissions from disposal of HWP in the country can be estimated with the FOD model (see sheet HWP in the spreadsheet).

3.5 COMPLETENESS

Previous versions of the *IPCC Guidelines* have focused on emissions from MSW disposal sites, although inventory compilers were encouraged to consider emissions from other waste types. However, it is now recognised that there is often a significant contribution to emissions from other waste types. The *2006 Guidelines* therefore provide default data and methodology for estimating the generation and DOC content of the following waste types:

- Municipal Solid Waste (MSW) – the default definition and composition is given in Chapter 2,
- Sewage sludge (from both municipal and industrial sewage treatment),
- Industrial solid waste (including waste from wood and paper industries and construction and demolition waste, which may be largely inert materials, but also include wood as a source of DDOCm),

- Residues from mechanical-biological treatment plants (see Chapter 4, Biological Treatment of Solid Waste).

Countries should provide their own estimates of the fractions of these waste types disposed in SWDS, incinerated or recycled.

Waste types addressed elsewhere in the *2006 Guidelines*:

- Emissions from manure management (included in the AFOLU sector.)

Waste management types to include:

- Managed SWDS,
- Unmanaged SWDS (open dumps, including above-ground piles, holes in the ground and dumping into natural features such as ravines).

Waste management types addressed elsewhere in the *2006 Guidelines*:

- Emissions from incineration (Chapter 5 of this Volume),
- Emissions from open burning at SWDS (Chapter 5 of this Volume),
- Emissions from biological treatment of solid waste including centralised composting facilities, and home composting (Chapter 4 of this Volume).

Closed SWDS continue to emit CH_4. This is automatically accounted for in the FOD method because historical waste disposal data are used.

All of the management types listed above should be included in this sector where they occur to a significant extent.

3.6 DEVELOPING A CONSISTENT TIME SERIES

Two major changes from the *1996 Guidelines* are introduced in the *2006 Guidelines*. These are:

- Replacing the old default (mass balance) method with the first-order decay (FOD) method,
- Inclusion of industrial waste and other non-MSW categories for all countries.

Both of these changes may require countries to recalculate their results for previous years, so that the time series will be consistent. The new spreadsheet provided for the IPCC FOD method automatically calculates emissions for all past years. However, it is important to ensure that the data input into the model form a consistent time series. The FOD model requires historical data as far back as 1950, so this is a significant task.

Guidance is given in Section 3.2.2 to enable countries to estimate past MSW and industrial waste disposal based on urban population, GDP and other drivers.

As waste statistics generally improve over time, countries may find that country-specific data are available for recent years but not for the whole time series. It is *good practice* to use country-specific data where possible. Where default data and country-specific data are mixed in a time series, it is important to check for consistency. It may also be necessary to use backward extrapolation or splicing techniques to reconcile the two datasets. The general guidance on these techniques is given in Chapter 6 of Volume 1 (Time Series Consistency).

3.7 UNCERTAINTY ASSESSMENT

There are two areas of uncertainty in the estimate of CH_4 emissions from SWDS: (i) the uncertainty attributable to the method; and (ii) the uncertainty attributable to the data (activity data and parameters).

3.7.1 Uncertainty attributable to the method

The FOD model consists of a pre-exponential term, describing the amount of CH_4 generated throughout the life-time of the SWDS, and an exponential term that describes how this CH_4 is generated over time. Therefore the uncertainties in using the FOD model can be divided into uncertainties in the total amount of CH_4 formed throughout the life-time of the SWDS and uncertainties in the distribution of this amount over the years.

The uncertainties in the total amount of CH_4 formed during the life-time of the SWDS stem from uncertainties in the amount and the composition of the waste disposed in SWDS (W and DOC), the decomposition (DOC_f) and the CH_4 correction factor (MCF). These uncertainties are addressed hereafter.

The uncertainties in distribution of CH_4 generation over the years are highly dependent on the specific situation. When amounts of waste disposed and waste management practices only slowly develop over the years, the uncertainty due to the model will be low. For example, when decomposition is slower than expected, an underestimation of CH_4 formation in 2005 from waste disposed in 1990 will be counteracted by an overestimation of amounts formed from waste disposed in e.g., 2000. However, when the annual amounts of waste or waste composition change significantly, errors in the model are of importance.

The best way of evaluating the error due to the model in a specific case can be obtained from the model by performing a sensitivity analysis, varying the k-values within the error ranges assumed (see Table 3.5 for default uncertainty values) or in a Monte Carlo analysis using the model and varying all relevant variables.

The use of the mass balance method, which was the default (Tier 1) method in previous versions of the IPCC guidance, tends to lead to over-estimation of emissions in cases where the trend is for increased disposal of waste to SWDS over time. It was assumed that all CH_4 would be released in the same year that the waste was deposited. The use of the FOD method removes this error and reduces the uncertainty associated with the method. However, it is important to remember that the FOD method is a simple model of a very complex and poorly understood system. Uncertainty arises from the following sources:

- Decay of carbon compounds to CH_4 involves a series of complex chemical reactions and may not always follow a first-order decay reaction. Higher order reactions may be involved, and reaction rates will vary with conditions at the specific SWDS. Reactions may be limited by restricted access to water and local variations in populations of bacteria.
- SWDS are heterogeneous. Conditions such as temperature, moisture, waste composition and compaction vary considerably even within a single site, and even more between different sites in a country. Selection of ‘average’ parameter values typical for a whole country is difficult.
- Use of the FOD method introduces additional uncertainty associated with decay rates (half-lives) and historical waste disposal amounts. Neither of these are well understood or thoroughly researched.

However, it is likely that the main source of uncertainty lies in selection of values for parameters for the model, rather than with the methodology of the model itself.

3.7.2 Uncertainty attributable to data

This source of uncertainty is simply the uncertainty attributable to each of the parameter inputs. The uncertainty attributable to the data can be classified into activity data and parameters.

3.7.2.1 UNCERTAINTIES ASSOCIATED WITH ACTIVITY DATA

The quality of CH_4 emission estimates is directly related to the quality and availability of the waste generation, composition and management data used to derive these estimates. The activity data in the waste sector include the total municipal solid waste, total industrial waste, waste composition, and the fraction of solid waste sent to solid waste disposal sites.

The uncertainty in waste disposal data depends on how the data is obtained. Uncertainty can be reduced when the amounts of waste in the SWDS are weighed. If the estimates are based on waste delivery vehicle capacity or visual estimation, uncertainty will be higher. Estimates based default activity data will have the highest uncertainties.

If waste scavenging takes place at the SWDS, it needs to be taken into account with the waste disposal data, otherwise, the uncertainty in waste disposal data will increase. Scavenging will also increase uncertainties in the composition of waste disposed in the SWDS, and hence also the total DOC in the waste. Uncertainty estimates for the default model parameters are given in Table 3.5. The estimates are based on expert judgement.

Waste generation may be estimated from population (or urban population) and per-capita waste generation rates. Uncertainty can be introduced if the population does not match the population whose waste is collected. Typically, in many countries, waste is only collected from urban populations. Urban population could fluctuate daily or seasonally by migration of the workforce.

3.7.2.2 UNCERTAINTIES ASSOCIATED WITH PARAMETERS

Methane correction factor (MCF)

There are two sources of uncertainty in the MCF.

- Uncertainty in the value of the MCF for each type of site (managed-anaerobic, managed-semi-aerobic, unmanaged deep and/or high water table, unmanaged shallow): These MCF values are based on one experimental study and expert judgement and not on measured data.
- Uncertainty in the classification of sites into the different site types: For example, the distinction between deep and shallow sites (5 m depth of waste) is based on expert opinion. Inevitably, few, if any, countries will be able to classify their unmanaged waste disposal sites into deep and shallow based on measured data. It can also be difficult to determine the sites that meet the IPCC criteria for managed sites.

Degradable organic carbon (DOC)

There are two sources of uncertainty in DOC values.

- Uncertainty in setting the DOC for different types of waste types/materials (paper, food, etc.): There are few studies of DOC, and different types of paper, food, wood and textiles can have very different DOC values. The water content of the waste also has an influence. DOC for industrial waste is very poorly known.
- Uncertainty in the waste composition affects estimates of total DOC in the SWDS: Waste composition varies widely even within countries (for example, between urban and rural populations, between households on different incomes, and between seasons) as well as between countries.

Fraction of degradable organic carbon which decomposes (DOC_f)

The uncertainty in DOC_f is very high. There have been few studies, and it is difficult to replicate real SWDS conditions in experimental studies.

Fraction of CH_4 in landfill gas (F)

The CH_4 fraction of generated landfill gas, F, is usually taken to be 0.5, but can vary between 0.5 and 0.55, depending on several factors (see Section 3.2.3). The uncertainty in this figure is relatively low, as F depends largely on the stoichiometry of the chemical reaction producing CH_4. The concentration of CH_4 in recovered landfill gas may be lower than the actual value because of potential dilution by air, so F values estimated in this way will not necessarily be representative.

Methane recovery (R)

CH_4 recovery is the amount of CH_4 generated at SWDS that is recovered and burned in a flare or energy recovery device. The uncertainty depends on the method used to estimate recovered CH_4. The uncertainty is likely to be relatively small compared to other uncertainties if metering is used. If other methods are used, for example by estimating the efficiency of CH_4 recovery equipment, the uncertainty will be larger. (See Section 3.2.3.)

Oxidation factor (OX)

The oxidation factor is very uncertain because it is difficult to measure, varies considerably with the thickness and nature of the cover material, atmospheric conditions and climate, the flux of methane, and the escape of methane through cracks/fissures in the cover material. Field and laboratory studies which determine oxidation of CH_4 only through uniform and homogeneous soil layers may lead to over-estimations of oxidation in landfill cover soils.

The half-life

There is high uncertainty in the estimates of half-life because it is difficult to measure decay rates under conditions equivalent to those prevailing in real SWDS. Also, since there is considerable variation in half-life with waste composition, climate and site type, it is difficult to select values representative of a whole country.

Uncertainty estimates for MSW_T (total MSW generated) and MSW_F (fraction of MSW_T disposed at SWDS) and the default model parameters are given in Table 3.5. The estimates are based on expert judgement.

TABLE 3.5
ESTIMATES OF UNCERTAINTIES ASSOCIATED WITH THE DEFAULT ACTIVITY DATA AND PARAMETERS IN THE FOD METHOD FOR CH_4 EMISSIONS FROM SWDS

Activity data and emission factors	**Uncertainty Range**
Total Municipal Solid Waste (MSW_T)	**Country-specific:** 30% is a typical value for countries which collect waste generation data on regular basis. ±10% for countries with high quality data (e.g., weighing at all SWDS and other treatment facilities). For countries with poor quality data: more than a factor of two.
Fraction of MSW_T sent to SWDS (MSW_F)	±10% for countries with high quality data (e.g., weighing at all SWDS). ±30% for countries collecting data on disposal at SWDS. For countries with poor quality data: more than a factor of two.
Total uncertainty of Waste composition	±10% for countries with high quality data (e.g., regular sampling at representative SWDS). ±30% for countries with country-specific data based on studies including periodic sampling. For countries with poor quality data: more than a factor of two.
Degradable Organic Carbon (DOC)[7]	**For IPCC default values** : ±20% **For country-specific values**: Based on representative sampling and analyses: ±10%
Fraction of Degradable Organic Carbon Decomposed (DOC_f)	**For IPCC default value (0.5)**: ± 20% **For country-specific value** ± 10% for countries based on the experimental data over longer time periods.
Methane Correction Factor (MCF)	**For IPCC default value:**
= 1.0	–10%, +0%
= 0.8	±20%
= 0.5	±20%
= 0.4	±30%
= 0.6	–50%, +60%
Fraction of CH_4 in generated Landfill Gas (F) = 0.5	**For IPCC default value**: ±5%
Methane Recovery (R)	The uncertainty range will depend on how the amounts of CH_4 recovered and flared or utilised are estimated: ± 10% if metering is in place. ± 50% if metering is not in place.
Oxidation Factor (OX)	Include OX in the uncertainty analysis if a value other than zero has been used for OX itself. In this case the justification for a non-zero value should include consideration of uncertainties.
half-life ($t_{1/2}$)	Ranges for the IPCC default values are provided in Table 3.4. Country-specific values should include consideration of uncertainties.

Source: Expert judgement by Lead Authors of the Chapter.

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[7] The uncertainty range given applies to the DOC content in bulk waste. The ranges for DOC for different waste components in MSW given in Table 2.4 can be used to estimate the uncertainties for these components.

3.8 QA/QC, Reporting and Documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Chapter 6, Quality Assurance and Quality Control and Verification, in Volume 1, General Guidance and Reporting. Some examples of specific documentation and reporting relevant to this source category are provided below.

- Countries using the IPCC FOD model should include the model in the reporting. Countries using other methods or models should provide similar data (description of the method, key assumptions and parameters).
- If country-specific data are used for any part of the time series, it should be documented.
- The distribution of waste to managed and unmanaged sites for the purpose of MCF estimation should also be documented with supporting information.
- If CH4 recovery is reported, an inventory of known recovery facilities is desirable. Flaring and energy recovery should be documented separately from each other.
- Changes in parameters from year to year should be clearly explained and referenced.

It is not practical to include all documentation in the national inventory report. However, the inventory should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and steps in their calculation may be retraced.

It is *good practice* to conduct quality control checks and an expert review of the emissions estimates as outlined in Chapter 6 of Volume 1, Quality Assurance and Quality Control, and Verification.

Inventory compilers should cross-check country-specific values for MSW generated, industrial waste generated and waste composition against the default IPCC values, to determine whether the national parameters used are considered reasonable relative to the IPCC default values.

Where survey and sampling data are used to compile national values for solid waste activity data, QC procedures should include:

(i) Reviewing survey data collection methods, and checking the data to ensure that they were collected and aggregated correctly. Inventory compilers should cross-check the data with previous years to ensure the data are reasonable.

(ii) Evaluating secondary data sources and referencing QA/QC activities associated with the secondary data preparation. This is particularly important for solid waste data, since most of these data are originally prepared for purposes other than greenhouse gas inventories.

Inventory compilers should provide the opportunity for experts to review input parameters.

Inventory compilers should compare national emission rates with those of similar countries that have comparable demographic and economic attributes. Inventory compilers should study significant discrepancies to determine if they represent errors in the calculation or actual differences.

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Annex 3A.1 First Order Decay Model

3A1.1 INTRODUCTION

The first order decay (FOD) model introduced in Chapter 3 is the default method for calculating methane (CH_4) emissions from solid waste disposal sites (SWDS). This Annex provides the supplementary information on this model:

- mathematical basis for the FOD model (see Section 3A1.2),
- key issues in the model, such as the estimation of the mass of degradable organic carbon available for anaerobic decomposition at SWDS (DDOCm) (Section 3A1.2) and the delay time from disposal of waste in the SWDS till the decomposition starts (Section 3A1.3),
- introduction of the spreadsheet model developed to facilitate the use of the FOD method (3A1.4),
- how to estimate the long-term storage of carbon in SWDS (Section 3A1.5),
- different approaches to the FOD model, including an explanation of the differences between the current and earlier IPCC methods (Section 3A1.6).

3A1.2 FIRST ORDER DECAY (FOD) MODEL – BASIC THEORY

The basis for a first order decay reaction is that the reaction rate is proportional to the amount of reactant remaining (Barrow and Gordon, 1996), in this case the mass of degradable organic carbon decomposable under anaerobic conditions (DDOCm). The DDOCm reacted over a period of time *dt* is described by the differential equation 3A.1.1:

EQUATION 3A1.1
DIFFERENTIAL EQUATION FOR FIRST ORDER DECAY

$$d(DDOCm) = -k \bullet DDOCm \bullet dt$$

Where:

DDOCm = mass of degradable organic carbon (DOC) in the disposal site at time *t*

k = decay rate constant in y^{-1}

The solution to this equation is the basic FOD equation.

EQUATION 3A1.2
FIRST ORDER DECAY EQUATION

$$DDOCm = DDOCm_0 \bullet \ e^{-kt}$$

Where:

DDOCm = mass of degradable organic carbon that will decompose under anaerobic conditions in disposal site at time *t*

$DDOCm_0$ = mass of DDOC in the disposal site at time 0, when the reaction starts

k = decay rate constant in y^{-1}

t = time in years.

Substituting *t* =1 into Equation 3A1.2 shows that at the end of year 1 (the year after disposal), the amount of DDOCm remaining in the disposal site is:

EQUATION 3A1.3
DDOCM REMAINING AFTER 1 YEAR OF DECAY

$$\text{At t = 1,} \quad DDOCm = DDOCm_0 \bullet \ e^{-k}$$

The DDOCm decomposed into CH_4 and CO_2 at the end of year 1 (DDOCm decomp) will then be:

EQUATION 3A1.4
DDOCm DECOMPOSED AFTER 1 YEAR OF DECAY

$$\text{At t = 1,}\quad DDOCm\, decomp = DDOCm_0 \bullet \left(1 - e^{-k}\right)$$

The equation for the general case, for DDOCm decomposed in period T^8 between time (t–1) and t, will be:

EQUATION 3A1.5
DDOCm DECOMPOSED IN YEAR T

$$DDOCm\, decomp_T = DDOCm_0 \bullet \left[e^{-k(t-1)} - e^{-kt}\right]$$

Equations 3A1.4 and 3A1.5 are based on the mass balance over the year.

In Section 3.2.3, the parameter half-life time of the decay is discussed. Half-life is the time it takes for the amount of reaction to be reduced by 50 percent. The relationship between half-life time and the reaction rate constant k is found by substituting DDOCm in Equation 3A1.2 with 1/2DDOCm$_0$, and t with $t_{1/2}$:

EQUATION 3A1.6
RELATIONSHIP BETWEEN HALF-LIFE AND REACTION RATE CONSTANT

$$k = \text{In}(2) \,/\, t_{1/2}$$

3A1.3 CHANGING THE TIME DELAY IN THE FOD EQUATION

In most SWDS, waste is disposed continuously throughout the year, usually on a daily basis. However, there is evidence that production of CH_4 does not begin immediately after disposal of the waste (see Section 3.2.3 in Chapter 3).

Equations 3A1.3 and 3A1.4 assume that the decay reaction starts on January 1 in the year **after** disposal, i.e., an average six month delay before the reaction commences.

The equations can easily be transformed to model an earlier start to the decay reaction, i.e., start of the decay reaction in the year of disposal. This is done by moving the e^{-kt} curve backwards along the time axis. For example, to model a reaction start on the first of October in the year of disposal (i.e., an average time delay of three months before the decay reaction commences, instead of six months), Equation 3A1.2 will be transformed into the following:

EQUATION 3A1.7
FOD EQUATION FOR DECAY COMMENCING AFTER 3 MONTHS

$$DDOCm = DDOCm_0 \bullet e^{-k(t+0.25)}$$

Then there will be two solutions, one for the year of disposal and one for the rest of the years:

EQUATION 3A1.8
DDOCm DECOMPOSED IN YEAR OF DISPOSAL (3 MONTH DELAY)

$$DDOCm\, decomp_Y = DDOCm_0 \bullet \left(1 - e^{-0.25k}\right)$$

EQUATION 3A1.9
DDOCm DISSIMILATED IN YEAR (T) (3 MONTH DELAY)

$$DDOCm\, decomp_T = DDOCm_0 \bullet \left[e^{-k(T-0.75)} - e^{-k(T+0.25)}\right]$$

---

[8] T denotes the year for which the estimate is done in relation to deposition year.

Where:

$DDOCm\ decomp_Y$ = DDOCm decomposed in year of disposal

$DDOCm\ decomp_T$ = DDOCm decomposed in year *T* (from point *t*–1 to point *t* on time axis)

T = year from point *t*–1 to *t* on the time axis, where year 1 is the year after disposal.

Y = disposal year

The same can be done to find the equations for reaction start within the year after disposal.

3A1.3.1 Disposal profile

The method presented here assumes that CH_4 production from all of the waste disposed during the first year (Year *Y*) begins on the 1st of January on the year after disposal. Year 1 is defined as the year after disposal.

Some inaccuracy will be introduced by the fact that, in reality, waste disposed at the beginning of the year will begin to produce CH_4 earlier, and waste disposed at the end of the year will begin to produce CH_4 later. Comparison of results calculated with the simple FOD method presented here and the exact day-by-day method, which is presented in Section 3A1.6.3, has been used to evaluate this error. With a half-life time of 10 years, evaluating CH_4 emissions with the exact method gives a decay profile only 1 day difference from the simplified version of the method. With a half-life time of 3 years, the simple method gives 3.5 days difference from the exact method. Even with a half-life time of 1 year, the difference between the exact and simple methods is just 10 days. The error introduced by the assumption in this simple method is very small in comparison with other uncertainties in the parameters, especially given that the uncertainty in delay time is at least two months.

3A1.4 SPREADSHEET FOD MODEL

In order to estimate CH_4 emissions for all solid waste disposal sites in a country, one method is to model the emissions from the waste disposed in each year as a separate row in a spreadsheet. In the *IPCC Waste Model*, CH_4 formation is calculated separately for each year of disposal, and the total amount of CH_4 generated is found by a summation at the end. A typical example, for six years of disposal of 100 units of DDOCm each year, with a decay rate constant of 0.1 (half-life time of 6.9 years), and CH_4 generation beginning in the year after disposal, is shown in the table below. The figures in the table are the DDOCm decomposed from that waste each year, from which the CH_4 emissions can be calculated.

When considered over a period of 50 years, which is necessary for the FOD method, this leads to a rather large calculation matrix. The spreadsheet uses a more compact and elegant approach to the calculations. This is done by adding the DDOCm disposed into the disposal site in one year to the DDOCm left over from the previous years. The CH_4 emission for the next year is then calculated from this 'running total' of the DDOCm remaining in the site. In this way, the full calculation for one year can be done in only three columns, instead of having one column for each year (see Table 3A1.1).

The basis for this approach lies in the first order reaction. With a first order reaction the amount of product (here DDOCm decomposed) is always proportional to the amount of reactant (here DDOCm). This means that the time of disposal of the DDOCm is irrelevant to the amount of CH_4 generated each year - it is just the total DDOCm remaining in the site that matters.

This also means that when we know the amount of DDOCm in the SWDS at the start of the year, every year can be regarded as year number 1 in the estimation method, and all calculation can be done by these two simple equations:

EQUATION 3A1.10
MASS OF DEGRADABLE ORGANIC CARBON ACCUMULATED AT THE END OF YEAR T

$$DDOCma_T = DDOCmd_T + \left(DDOCma_{T-1} \bullet e^{-k} \right)$$

EQUATION 3A1.11
MASS OF DEGRADABLE ORGANIC CARBON DECOMPOSED IN YEAR T

$$DDOCm\,decomp_T = DDOCma_{T-1} \bullet \left(1 - e^{-k} \right)$$

Where:

the decay reaction begins on the 1st of January the year after disposal.

$DDOCma_T$ = DDOCm accumulated in the SWDS at the end of year *T*

$DDOCmd_T$ = mass of DDOC disposed in the SWDS in year *T*

$DDOCma_{T-1}$ = DDOCm accumulated in the SWDS at the end of year (*T*–1)

$DDOCm\ decomp_T$ = DDOCm decomposed in year *T*

TABLE 3A1.1
NEW FOD CALCULATING METHOD

year	DDOCm disposed	DDOCm accumulated	DDOCm decomposed
0	100	100	0
1	100	190.5	9.5
2	100	272.4	18.1
3	100	346.4	25.9
4	100	413.5	33.0
5	100	474.1	39.3
6	100	529.0	45.1

3A1.4.1 Introducing a different time delay into the spreadsheet model

The table and equations presented above assume that anaerobic decomposition of DDOCm to CH_4 begins on 1st of January in the year after disposal (an average delay of 6 months before the decay reaction begins).

If the anaerobic decomposition is set to start earlier than this, i.e., in the year of disposal, separate calculations will have to be made for the year of disposal. As the mathematics of every waste category or waste type/fraction is the same, only parameters are different, indexing for different waste categories and types/fractions are omitted in the equations 3A1.12-17, and 3A1.19:

EQUATION 3A1.12
DDOCm REMAINING AT END OF YEAR OF DISPOSAL

$$DDOCm\ rem_T = DDOCmd_T \bullet\ e^{-k \bullet (13-M)/12}$$

(Column F in CH_4 calculating sheets in the spreadsheet model)

EQUATION 3A1.13
DDOCm DECOMPOSED DURING YEAR OF DISPOSAL

$$DDOCm\ dec_T = DDOCmd_T \bullet \left[\ 1 - e^{-k \bullet (13-M)/12}\ \right]$$

(Column G in the CH_4 calculating sheets in the spreadsheet model)

Where:

$DDOCm\ rem_T$ = DDOCm disposed in year *T* which still remains at the end of year *T* (Gg)

$DDOCmd_T$ = DDOCm disposed in year *T* (Gg)

$DDOCm\ dec_T$ = DDOCm disposed in year *T* which has decomposed by the end of year *T* (Gg)

T = year *T* (inventory year)

M = month when reaction is set to start, equal to the average delay time + 7 (month)

k = rate of reaction constant (y^{-1})

Equations 3A1.10 and 3A1.11 will then become:

EQUATION 3A1.14
DDOCm ACCUMULATED AT THE END OF YEAR T

$$DDOCma_T = DDOCm\,rem_T + \left(DDOCma_{T-1} \bullet e^{-k} \right)$$

(Column H in the CH_4 calculating sheets in spreadsheet model)

EQUATION 3A1.15
DDOCm DECOMPOSED IN YEAR T

$$DDOCm\,decomp_T = DDOCm\,dec_T + DDOCma_{T-1} \bullet \left(1 - e^{-k} \right)$$

(Column I in the CH_4 calculating sheets in the spreadsheet model)

Where:

$DDOCma_T$ = DDOCm accumulated in the SWDS at the end of year *T*, Gg

$DDOCma_{T-1}$ = DDOCm accumulated in the SWDS at the end of year (*T*–1), Gg

$DDOCm\ decomp_T$ = DDOCm decomposed in year *T*, Gg

The spreadsheets are based on Equations 3A1.12 to 3A1.15. If the reaction start is set to the first of January the year after disposal, this is equivalent to an average time delay of 6 months (month 13). Equations 3A1.14 and 3A1.15 will then be identical to Equations 3A1.10 and 3A1.11.

3A1.4.2 Calculating DDOCm from amount of waste disposed

Data on waste disposal is entered into the spreadsheet. The data can be given by waste type (waste composition option) or as bulk waste. In the waste composition option, waste is split by waste type/material (paper and cardboard, food garden and park waste, wood, textiles and other waste). In the bulk waste option, waste is split only by main waste category (MSW and industrial waste). Not all DOCm entering the site will decompose under the anaerobic conditions in the SWDS. The parameter DOC_f is the fraction of DOCm which will actually degrade in the SWDS (see Section 3.2.3 in Chapter 3). The decomposable DOCm (DDOCm) entering the SWDS is calculated as follows:

EQUATION 3A1.16
CALCULATION OF DECOMPOSABLE DOCm FROM WASTE DISPOSAL DATA

$$DDOCmd_T = W_T \bullet DOC \bullet DOC_f \bullet MCF$$

(Column D in the CH_4 calculating sheet in the spreadsheet model)

Where:

$DDOCmd_T$ = DDOCm disposed in year *T*, Gg

W_T = mass of waste disposed in year *T*, Gg

DOC = Degradable organic carbon in disposal year (fraction), Gg C/Gg waste

DOC_f = fraction of DOC that can decompose in the anaerobic conditions in the SWDS (fraction)

MCF = CH_4 correction factor for year of disposal (fraction) (see Section 3.2.3)

3A1.4.3 Calculating CH_4 generation from DDOCm decomposed

The amount of CH_4 generated from the DDOCm which decomposes is calculated as follows:

EQUATION 3A1.17
CH_4 GENERATED FROM DECOMPOSED DDOCm

$$CH_4\ generated_T = DDOCm\ decomp_T \bullet F \bullet 16/12$$

(Column J in the CH_4 calculating sheets in the spreadsheet model)

Where:

$CH_4\ generated_T$ = amount of CH_4 generated from the DDOCm which decomposes

DDOCm $decomp_T$ = DDOCm decomposed in year T, Gg

F = fraction of CH_4, by volume, in generated landfill gas

16/12 = molecular weight ratio CH_4/C (ratio).

The CH_4 generated by each category of waste disposed is added to get total CH_4 generated in each year. Finally, emissions of CH_4 are calculated by subtracting first the CH_4 gas recovered from the disposal site, and then CH_4 oxidised to carbon dioxide in the cover layer.

EQUATION 3A1.18
CH_4 EMITTED FROM SWDS

$$CH_4\ emitted_T = \left(\sum_x CH_4\ generated_{x,T} - R_T \right) \bullet \left(1 - OX_T \right)$$

(The final result calculating column in the Results sheet)

Where:

CH_4 $emitted_T$ = CH_4 emitted in year T, Gg

x = waste type/material or waste category

R_T = CH_4 recovered in year T, Gg

OX_T = Oxidation factor in year T, (fraction)

3A1.5 CARBON STORED IN SWDS

Only part of the DOCm in waste disposed in SWDS will decay into both CH_4 and CO_2. An MCF value lower than 1, means that part of the DOCm will decompose aerobically to CO_2, but not to CH_4. The DOCm available for anaerobic decay will not decompose completely either. The decomposing part of this DOCm (DDOCmd) is given in Equation 3A1.16. The part of DOCm that will not decompose will be stored long-term in the SWDS, which will then be:

EQUATION 3A1.19
CALCULATION OF LONG-TERM STORED DOCm FROM WASTE DISPOSAL DATA

$$DOCm\ long\text{-}term\ stored_T = W_T \bullet DOC \bullet \left(1 - DOC_f \right) \bullet MCF$$

Using the default value for DOC_f = 0.5, 50 percent of the disposed DOCm will remain there for long term. Equation 19 describes the annual increase in the stock of long-term stored carbon in the SWDS. The long-term stored carbon in harvested wood products (HWP) disposed in SWDS (see Chapter 12 in the AFOLU volume) can be estimated using this equation. For the waste composition option, the amount of DOCm which is long-term stored in HWP waste disposed in SWDS is calculated directly from material information in the Activity sheet. Using the bulk waste option, the fraction of waste originating from HWP needs to be estimated first. If this is not known, the regional or country-specific default fractions for paper and cardboard, garden and park and wood waste can be used (see Section 2.3). The calculations are performed in the spreadsheet model in the sheet called 'Stored C' and 'HWP'.

3A1.6 DIFFERENT FOD APPROACHES

Different FOD approaches have been used to estimate the CH_4 emissions from SWDS. The differences between the approach used in these *Guidelines*, previous IPCC approaches and the so-called exact FOD method are discussed below. The approach used in this Volume has been chosen mainly for the following reasons:

- the method describes the FOD reaction mathematically more accurately than the previous IPCC approaches,
- it is easy to understand,
- it is easy to use in a spreadsheet model,
- it gives, as a by-product, an estimate of changes in carbon stored in SWDS (annual changes in carbon stock, for both long-term and short-term storage as the mass-balance of conversions of carbon into CH_4 and CO_2 in the SWDS are maintained by the approach).

3A1.6.1 *1996 Guidelines* - The rate of reaction approach

In the *Revised 1996 IPCC guidelines* (*1996 Guidelines*, (IPCC, 1997)) the estimation of the CH_4 emissions from SWDS was based on the rate of reaction equation. This is a common way of looking at the mass transformation in a chemical reaction. This is obtained by differentiating Equation 3A1.2 with respect to time:

EQUATION 3A1.20
FIRST ORDER RATE OF REACTION EQUATION

$$DDOCm\ reaction\ rate = -\,d(DDOCm)/\,dt = k \bullet DDOCm_0 \bullet e^{-kt}$$

The rate of reaction equation shows the rate of reaction at any time, and the rate of reaction moves along a curve. Therefore it has to be integrated to find the amount of reacted DDOCm over a period of time.

We want to find the DDOCm decomposed into CH_4 and CO_2 per calendar year. The start is year number 1 going from point 0 to point 1 on the time axis. Year number 1 is associated to point 1 on the time axis. Therefore the integration has to be performed from t–1 to t, which leads to an equation identical to Equation 3A1.5.

However, the equation presented in the *1996 Guidelines* (Equation 4, Chapter 6) is:

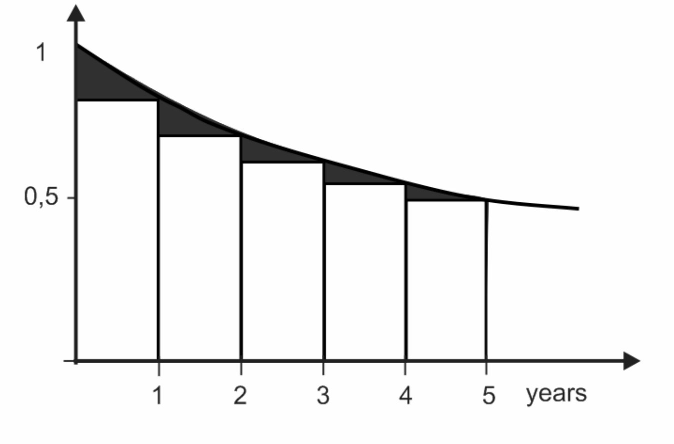
EQUATION 3A1.21
IPCC *1996 GUIDELINES* EQUATION FOR DOC REACTING IN YEAR T

$$DDOCm\ \ decomp_T = k \bullet DDOCm_0 \bullet\ e^{-kt}$$

In fact, this is the rate of reaction equation. Effectively this means that the yearly CH_4 production is calculated from the rate of reaction at the end of the year. This is an approximation which involves summing a series of rectangles under the rate of reaction curve, instead of accurately integrating the whole area under the curve. An error is introduced by the approximation; the small triangles shown on the top of the columns in Figure 3A1.1 are neglected, and mass balance over the year is not obtained. The method based on the equation in the *1996 Guidelines* using a half-life time of 10 years would give results 3.5 percent lower than the full mass balance calculations used in these *Guidelines* (see equations 3A.1.4-5).

However, where the method in the *1996 Guidelines* is used with half life times developed specifically for this method, calculations will be correct.

Figure 3A1.1 Error introduced by not fully integrating the rate of reaction curve



3A1.6.2 IPCC 2000 Good Practice Guidance

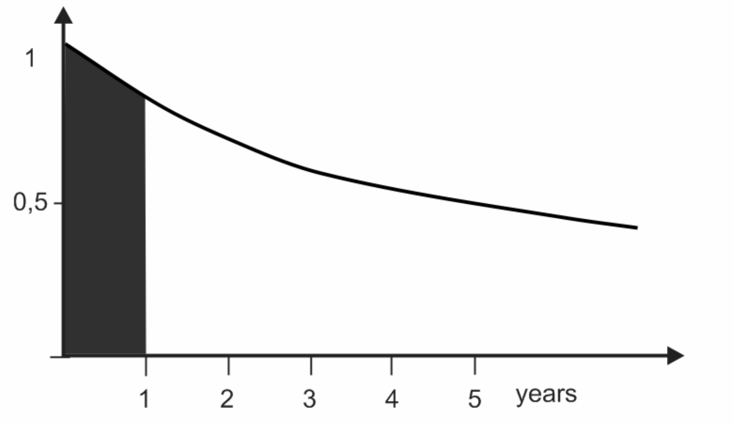
In the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (*GPG2000*, IPCC, 2000), Equation 5.1, a normalisation factor A is introduced into the rate of reaction equation. When this 'normalisation factor' is multiplied into Equation 5.1 the result is a solved integral:

EQUATION 3A1.22
IPCC *2000GPG* FOD EQUATION FOR DDOCm REACTING IN YEAR T

$$DDOCm\,decomp_T = DDOCm_0 \bullet \left[\; e^{-kt} - e^{-k(t+1)} \; \right]$$

This is equivalent to the correct equation (Equation 3A1.5) as it integrates the decay curve. However, for year 1 it integrates from point 1 to point 2 on the time axis, and therefore the CH_4 formed in the first year of reaction is not counted (see Figure 3A1.2). This means that with a half life time of 10 years the *GPG2000* equation calculates results that are 7 percent lower than those calculated with approach taking the full mass balance into account.

Figure 3A1.2 Effect of error in the *GPG2000* equation



The intention of the normalisation factor has obviously been to fill in the small triangles on top of the columns in Figure 3A1.1. It fails because the normalisation factor used is equivalent to an integration going from point t to (t +1) on the time axis. As the integration using year number as a basis has to go from t-1 to 1, the normalisation factor filling in the whole area under the rate of reaction curve would be A = $((1/e^{-k}) - 1)/k$.

3A1.6.3 Mathematically Exact First-Order Decay Model

The First Order Decay (FOD) model as described above can be shown to be mathematically equivalent to a model for which the total amount of DOC is assumed to be disposed at a single point in time in each disposal year, i.e., on a single date. If there is no delay in the commencement of the decay process, this date would be the middle of the year, i.e., 1st of July, with a delay of 6 months the assumed reaction start with the full amount of material is 31st December/1st January. This assumption, though counter-intuitive, leads to numerical errors that are small compared to the uncertainty in the understanding of the chemical processes, activity data, emission factors and other parameters of the emission calculation.

An alternative formulation of the FOD method is presented here for completeness. The delay in the commencement of the decay process can be represented, and simple recursive formulations can be given.

Equation 3A1.23 represents the formulation of the FOD with disposal rate D(t). The first term in the bracket represents the inflow into the carbon pool in the SWDS (disposal), the second term represents the outflow from the site (carbon in form of CH_4); the sum of the two terms represents the overall change in carbon stock in the SWDS.

EQUATION 3A1.23
FOD WITH DISPOSAL RATE D(t)

$$dDOCm(t) = \left[\; D(t) - k \bullet DDOCm(t) \;\right]\; dt$$

Where:

dDDOCm(t) = change in DDOCm at time t

D(t) = DDOCm disposal rate at time t

DDOCm(t) = DDOCm available at time t for decay

If there is a delay of Δ years in the commencement of the decay process after the DDOCm has been disposed, it will be necessary to distinguish the part of the stock that is available for decay, to which Equation 3A1.23

applies, and the inert part of the stock. For a disposal rate D(t) that is constant during each disposal year (and equal to the amount of DDOC disposed during that year divided by one year) it can be shown that the carbon stocks at the end of year *i* can be expressed in terms of the carbon stocks at the end of year *i*–1 and the amounts of disposal in year *i* and year *i*–1 (Pingoud and Wagner, 2006):

EQUATION 3A1.24

DEGRADABLE ORGANIC CARBON ACCUMULATED DURING A YEAR

$$DDOCma(i+1) = a \bullet DDOCma(i) + b \bullet DDOCmd(i-1) + c \bullet DDOCmd(i)$$

Where:

DDOCma (i) = DDOCm stock in the SWDS at the beginning of year *i*, Gg C

DDOCmd (i) = DDOCm disposed during year *i*, Gg C

a = e^{-k} (constant)

b = $1/k \bullet (e^{-k(1-\Delta)} - e^{-k}) - \Delta \bullet e^{-k}$ (constant)

c = $1/k \bullet (1-e^{-k(1-\Delta)}) + \Delta$ (constant)

Δ = delay constant, in years (between 0 and 1 years)

For an immediately starting decay (Δ=0), the constant b is equal to zero, so that Equation 3A1.24 reduces to an equation that relates the carbon pool in a given year *i* to the carbon pool in the previous year *i*-1 and the amount of DOC being deposited during year *i*.

It can further be shown (Pingoud and Wagner, 2006) that this form can be used to calculate recursively the corresponding CH_4 produced in a given year:

EQUATION 3A1.25

CH_4 GENERATED DURING A YEAR

$$CH_4\,gen(i) = q \bullet \left[a' \bullet DDOCma(i) - b' \bullet DDOCmd(i-1) + c' \bullet DDOCmd(i)\right]$$

Where:

CH_4 gen (i) = CH_4 generated during year *i*, Gg C

DDOCma(i) = DDOC stock in the SWDS at the beginning of year *i*, Gg C

DDOCmd(i) = DDOC disposed during year *i*, Gg C

q = MCF • F • 16/12

a’ = $1 - e^{-k} = 1 - a$ (constant)

b’ = $1/k \bullet (e^{-k(1-\Delta)} - e^{-k}) - \Delta \bullet e^{-k} = b$ (constant)

c’ = $1 - \Delta - 1/k \bullet (1-e^{-k(1-\Delta)}) = 1 - c$ (constant)

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CHAPTER 4

BIOLOGICAL TREATMENT OF SOLID WASTE

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4 BIOLOGICAL TREATMENT OF SOLID WASTE

4.1 METHODOLOGICAL ISSUES

Composting and anaerobic digestion of organic waste, such as food waste, garden (yard) and park waste and sludge, is common both in developed and developing countries. Advantages of the biological treatment include: reduced volume in the waste material, stabilisation of the waste, destruction of pathogens in the waste material, and production of biogas for energy use. The end products of the biological treatment can, depending on its quality, be recycled as fertiliser and soil amendment, or be disposed in SWDS.

Anaerobic treatment is usually linked with methane (CH_4) recovery and combustion for energy, and thus the greenhouse gas emissions from the process should be reported in the Energy Sector. Anaerobic sludge treatment at wastewater treatment facilities is addressed in Chapter 6, Wastewater Treatment and Discharge, and emissions should be reported under the categories of Wastewater. However, when sludge from wastewater treatment is transferred to an anaerobic facility which is co-digesting sludge with solid municipal or other waste, any related CH_4 and nitrous oxide (N_2O) emissions should be reported under this category, biological treatment of solid waste. Where these gases are used for energy, then associated emissions should be reported in the Energy Sector.

Composting is an aerobic process and a large fraction of the degradable organic carbon (DOC) in the waste material is converted into carbon dioxide (CO_2). CH_4 is formed in anaerobic sections of the compost, but it is oxidised to a large extent in the aerobic sections of the compost. The estimated CH_4 released into the atmosphere ranges from less than 1 percent to a few per cent of the initial carbon content in the material (Beck-Friis, 2001; Detzel *et al*., 2003; Arnold, 2005).

Composting can also produce emissions of N_2O. The range of the estimated emissions varies from less than 0.5 percent to 5 percent of the initial nitrogen content of the material (Petersen *et al*., 1998; Hellebrand 1998; Vesterinen, 1996; Beck-Friis, 2001; Detzel *et al*., 2003). Poorly working composts are likely to produce more both of CH_4 and N_2O (e.g., Vesterinen, 1996).

Anaerobic digestion of organic waste expedites the natural decomposition of organic material without oxygen by maintaining the temperature, moisture content and pH close to their optimum values. Generated CH_4 can be used to produce heat and/or electricity, wherefore reporting of emissions from the process is usually done in the Energy Sector. The CO_2 emissions are of biogenic origin, and should be reported only as an information item in the Energy Sector. Emissions of CH_4 from such facilities due to unintentional leakages during process disturbances or other unexpected events will generally be between 0 and 10 percent of the amount of CH_4 generated. In the absence of further information, use 5 percent as a default value for the CH_4 emissions. Where technical standards for biogas plants ensure that unintentional CH_4 emissions are flared, CH_4 emissions are likely to be close to zero. N_2O emissions from the process are assumed to be negligible, however, the data on these emissions are very scarce.

Mechanical-biological (MB) treatment of waste is becoming popular in Europe. In MB treatment, the waste material undergoes a series of mechanical and biological operations that aim to reduce the volume of the waste as well as stabilise it to reduce emissions from final disposal. The operations vary by application. Typically, the mechanical operations separate the waste material into fractions that will under go further treatment (composting, anaerobic digestion, combustion, recycling). These may include separation, shredding and crushing of the material. The biological operations include composting and anaerobic digestion. The composting can take place in heaps or in composting facilities with optimisation of the conditions of the process as well as filtering of the produced gas. The possibilities to reduce the amount of organic material to be disposed at landfills are large, 40 - 60 percent (Kaartinen, 2004). Due to the reduced amount in material, organic content and biological activity, the MB-treated waste will produce up to 95 percent less CH_4 than untreated waste when disposed in SWDS. The practical reductions have been smaller and depend on the type and duration of MB treatments in question (see e.g., Binner, 2002). CH_4 and N_2O emissions during the different phases of the MB treatment depend on the specific operations and the duration of the biological treatment.

Overall, biological treatment of waste affects the amount and composition of waste that will be deposited in SWDS. Waste stream analyses (see example in Box 3.1) are recommended methodologies for estimating the impact of the biological treatment on emissions from SWDS.

The estimation of CH_4 and N_2O emissions from biological treatment of solid waste involves following steps:

Step 1: Collect data on the amount and type of solid waste which is treated biologically. Data on composting and anaerobic treatment should be collected separately, where possible. Regional default data on composting are provided in Table 2.1 in Chapter 2, and country-specific data for some countries can be found in Annex 2A.1 of this Volume. Anaerobic digestion of solid waste can be assumed to be zero where no data are available. The default data should be used only when country-specific data are not available (see also Section 4.1.2).

Step 2: Estimate the CH_4 and N_2O emissions from biological treatment of solid waste using Equations 4.1 and 4.2. Use default or country-specific emission factors in accordance with the guidance as provided in Sections 4.1.1, 4.1.2 and 4.1.3.

Step 3: Subtract the amount of recovered gas from the amount of CH_4 generated to estimate net annual CH_4 emissions, when CH_4 emissions from anaerobic digestion are recovered.

Consistency between CH_4 and N_2O emissions from composting or anaerobic treatment of sludge and emissions from treatment of sludge reported in the Wastewater Treatment and Discharge category should be checked. Also, if emissions from anaerobic digestion are reported under Biological Treatment of Solid Waste, the inventory compilers should check that these emissions are not also included under the Energy Sector.

Relevant information on activity data collection, choice of emission factor and method used in estimating the emissions should be documented following the guidance in Section 4.6.

4.1.1 Choice of method

The CH_4 and N_2O emissions of biological treatment can be estimated using the default method given in Equations 4.1 and 4.2 shown below:

EQUATION 4.1
CH_4 EMISSIONS FROM BIOLOGICAL TREATMENT

$$CH_4\ Emissions = \sum_i (M_i \bullet EF_i) \bullet 10^{-3} - R$$

Where:

CH_4 Emissions = total CH_4 emissions in inventory year, Gg CH_4

M_i = mass of organic waste treated by biological treatment type *i*, Gg

EF = emission factor for treatment *i*, g CH_4/kg waste treated

i = composting or anaerobic digestion

R = total amount of CH_4 recovered in inventory year, Gg CH_4

When CH_4 emissions from anaerobic digestion are reported, the amount of recovered gas should be subtracted from the amount CH_4 generated. The recovered gas can be combusted in a flare or energy device. The amount of CH_4 which is recovered is expressed as R in Equation 4.1. If the recovered gas is used for energy, then also the resulting greenhouse gas emissions from the combustion of the gas should be reported under Energy Sector. The emissions from combustion of the recovered gas are however 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 estimate such emissions, the emissions from flaring should be reported under the Waste Sector. A discussion of emissions from flaring and more detailed information are given in Volume 2, Energy, Chapter 4.2. Emissions from flaring are not treated at Tier 1.

EQUATION 4.2
N_2O EMISSIONS FROM BIOLOGICAL TREATMENT

$$N_2O\ Emissions = \sum_i (M_i \bullet EF_i) \bullet 10^{-3}$$

Where:

N_2O Emissions = total N_2O emissions in inventory year, Gg N_2O

M_i = mass of organic waste treated by biological treatment type *i*, Gg

EF = emission factor for treatment *i*, g N_2O/kg waste treated

i = composting or anaerobic digestion

Three tiers for this category are summarised below.

Tier 1: Tier 1 uses the IPCC default emission factors.

Tier 2: Country-specific emission factors based on representative measurements are used for Tier 2.

Tier 3: Tier 3 methods would be based on facility or site-specific measurements (on-line or periodic).

4.1.2 Choice of activity data

Activity data on biological treatment can be based on national statistics. Data on biological treatment can be collected from municipal or regional authorities responsible for waste management, or from waste management companies. Table 2.1 in Chapter 2, Waste Generation, Composition and Management Data, gives regional default values on biological treatment. Country-specific default values for some countries can be found in Annex 2A.1 of this Volume. These data can be used as a starting point. It is *good practice* that countries use national, annually or periodically collected data, where available.

4.1.3 Choice of emission factors

4.1.3.1 TIER 1

The emissions from composting, and anaerobic digestion in biogas facilities, will depend on factors such as type of waste composted, amount and type of supporting material (such as wood chips and peat) used, temperature, moisture content and aeration during the process.

Table 4.1 gives default factors for CH_4 and N_2O emissions from biological treatment for Tier 1 method.

TABLE 4.1
DEFAULT EMISSION FACTORS FOR CH_4 AND N_2O EMISSIONS FROM BIOLOGICAL TREATMENT OF WASTE

Type of biological treatment	**CH_4 Emission Factors (g CH_4/kg waste treated)**		**N_2O Emission Factors (g N_2O/kg waste treated)**		**Remarks**
	on a dry weight basis	**on a wet weight basis**	**on a dry weight basis**	**on a wet weight basis**	
Composting	10 (0.08 - 20)	4 (0.03 - 8)	0.6 (0.2 - 1.6)	0.3 (0.06 - 0.6)	Assumptions on the waste treated: 25-50% DOC in dry matter, 2% N in dry matter, moisture content 60%. The emission factors for dry waste are estimated from those for wet waste assuming a moisture content of 60% in wet waste.
Anaerobic digestion at biogas facilities	2 (0 - 20)	1 (0 - 8)	Assumed negligible	Assumed negligible	

Sources: Arnold, M.(2005) Personal communication; Beck-Friis (2002); Detzel *et al*. (2003); Petersen *et al*. 1998; Hellebrand 1998; Hogg, D. (2002); Vesterinen (1996).

Emission from MB treatment can be estimated using the default values in Table 4.1 for the biological treatment. Emissions during mechanical operations can be assumed negligible.

4.1.3.2 TIER 2 AND TIER 3

In Tier 2, the emissions factors should be based on representative measurements that cover relevant biological treatment options applied in the country. In Tier 3, emission factors would be based on facility/site-specific measurements (on-line or periodic).

4.2 COMPLETENESS

Reporting on CH_4 and N_2O emissions from biological treatment, where present, will complement the reporting of emissions from SWDS and burning of waste and contribute to full coverage of all sources in the Waste Sector. This will be particularly important in countries for which biological treatment is, or is becoming, significant.

4.3 DEVELOPING A CONSISTENT TIME SERIES

As the methodological guidance for estimating and reporting of emissions from biological treatment was not included in the previous *IPCC Guidelines*, it is recommended that the whole time series is estimated using the same methodology. The activity data for earlier years may not be available in all countries. Also current data on biological treatment may not be collected on an annual basis. The methods for obtaining missing data are described in Volume 1, Chapter 5, Time Series Consistency.

The default emission factors are based on limited amount of studies. The data availability is expected to improve in coming years. It is *good practice* to use updated scientific information to improve emission factors when it becomes available. Then, the estimates for the whole times series should be recalculated accordingly.

4.4 UNCERTAINTY ASSESSMENT

The uncertainty in activity data will depend on how the data are collected. The uncertainty estimates for waste generation and the fraction of waste treated biologically can be estimated in the same manner as for MSW disposed at SWDS (see Table 3.5). The uncertainties will depend on the quality of data collection in the country.

Uncertainties in the default emission factors can be estimated using the ranges given in Table 4.1. Uncertainties in country-specific emission factors will depend on the sampling design and measurement techniques used to determine the emission factors.

4.5 QA/QC

The requirements on QA/QC addressed in Section 3. 8 in Chapter 3, Solid Waste Disposal, are also applicable for biological treatment of waste.

4.6 REPORTING AND DOCUMENTATION

It is *good practice* to document and archive all information required to produce the national greenhouse gas inventory as outlined in Section 6.11 of Chapter 6, QA/QC and Verification, in Volume 1 of these *Guidelines*. A few examples of specific documentation and reporting relevant to this category are outlined in the following paragraphs.

- The sources of activity data should be described and referenced. The information on the collection frequency and coverage (e.g., whether composting at households is included or not) should be given.
- Information on types of waste (e.g., food waste, garden and park waste) composted or treated anaerobically should be provided, if available.
- Country-specific emission factors should be justified and referenced.
- In cases where reporting of biological treatment will be split under several sectors and/or categories, the reporting should be clarified under all relevant sectors/categories, to avoid double counting or omissions.

The worksheets developed for the estimation of the greenhouse gas emissions from biological treatment are included at the end of this Volume. These worksheets include information on activity data and emission factors used to calculate the estimates.

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CHAPTER 5

INCINERATION AND OPEN BURNING OF WASTE

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5 INCINERATION AND OPEN BURNING OF WASTE

5.1 INTRODUCTION

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 municipal solid waste (MSW), industrial waste, hazardous waste, clinical waste and sewage sludge[1]. 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.

Emissions from waste incineration without energy recovery are reported in the Waste Sector, while emissions from incineration 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 this chapter is applicable in general both to incineration with and without energy recovery. 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*.

This chapter provides guidance on methodological choices for estimating and reporting CO_2, CH_4 and N_2O emissions from incineration and open burning of all types of combustible waste. Where possible, default values for activity data, emission factors and other parameters are provided.

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 (USEPA, 1995), EPA Emission Inventory Improvement Program Technical Report Series, Vol. III Chapter 16: Open Burning (USEPA, 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

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

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 in Chapter 2, Waste Generation, Composition and Management Data, and country-specific data for a limited number of countries in Annex 2A.1 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.

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.

5.2.1 Choice of method for estimating CO_2 emissions

The common method for estimating CO_2 emissions from incineration and open burning of waste is based on an estimate of the fossil carbon content in the waste combusted, multiplied by the oxidation factor, and converting the product (amount of fossil carbon oxidised) to CO_2. The activity data are the waste inputs into the incinerator or the amount of waste open-burned, and the emission factors are based on the oxidised carbon content of the waste that is of fossil origin. Relevant data include the amount and composition of the waste, the dry matter content, the total carbon content, the fossil carbon fraction and the oxidation factor.

The following sections describe the tiers to be applied for the estimation of CO_2 emissions from incineration and open burning of waste. The tiers differ to what extent the total amount of waste, the emission factors and parameters used are default (Tier 1), country-specific (Tier 2a, Tier 2b) or plant-specific (Tier 3).

5.2.1.1 TIER 1

The Tier 1 method is a simple method used when CO_2 emissions from incineration/open burning are not a *key category*. Data on the amount of waste incinerated/open-burned are necessary[2]. Default data on characteristic parameters (such as dry matter content, carbon content and fossil carbon fraction) for different types of waste (MSW, sewage sludge, industrial waste and other waste such as hazardous and clinical waste) are provided in Table 5.2 in this chapter and Tables 2.3 to 2.6 in Section 2.3, on waste composition in Chapter 2 of this Volume. The calculation of the CO_2 emissions is based on an estimate of the amount of waste (wet weight) incinerated or open-burned taking into account the dry matter content, the total carbon content, the fraction of fossil carbon and the oxidation factor. The method based on the total amount of waste combusted is outlined in Equation 5.1, and the method based on the MSW composition is given in Equation 5.2. It is preferable to apply Equation 5.2 for MSW, but if the required MSW data are not available, Equation 5.1 should be used instead.

EQUATION 5.1
CO_2 EMISSION ESTIMATE BASED ON THE TOTAL AMOUNT OF WASTE COMBUSTED

$$CO_2\ Emissions = \sum_i \left(SW_i \bullet dm_i \bullet CF_i \bullet FCF_i \bullet OF_i \right) \bullet 44/12$$

Where:

CO_2 Emissions = CO_2 emissions in inventory year, Gg/yr

SW_i = total amount of solid waste of type *i* (wet weight) incinerated or open-burned, Gg/yr

dm_i = dry matter content in the waste (wet weight) incinerated or open-burned, (fraction)

CF_i = fraction of carbon in the dry matter (total carbon content), (fraction)

FCF_i = fraction of fossil carbon in the total carbon, (fraction)

OF_i = oxidation factor, (fraction)

44/12 = conversion factor from C to CO_2

i = type of waste incinerated/open-burned specified as follows:

MSW: municipal solid waste (if not estimated using Equation 5.2), ISW: industrial solid waste, SS: sewage sludge, HW: hazardous waste, CW: clinical waste, others (that must be specified)

If the activity data of wastes are available on a dry matter basis, which is preferable, the same equation can be applied without specifying the dry matter content and the wet weight separately. Also if a country has data on the fraction of fossil carbon in the dry matter, it does not need to provide CF_i and FCF_i separately but instead it should combine them into one component.

For MSW, it is *good practice* to calculate the CO_2 emissions on the basis of waste types/material (such as paper, wood, plastics) in the waste incinerated or open-burned as shown in Equation 5.2.

EQUATION 5.2
CO_2 EMISSION ESTIMATE BASED ON THE MSW COMPOSITION

$$CO_2\ Emissions = MSW \bullet \sum_j \left(WF_j \bullet dm_j \bullet CF_j \bullet FCF_j \bullet OF_j \right) \bullet 44/12$$

Where:

CO_2 Emissions = CO_2 emissions in inventory year, Gg/yr

MSW = total amount of municipal solid waste as wet weight incinerated or open-burned, Gg/yr

WF_j = fraction of waste type/material of component *j* in the MSW (as wet weight incinerated or open-burned)

dm_j = dry matter content in the component *j* of the MSW incinerated or open-burned, (fraction)

CF_j = fraction of carbon in the dry matter (i.e., carbon content) of component *j*

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[2] The methodology is addressed under Section 5.3, Choice of Activity data, and Chapter 2, Waste Generation, Composition and Management.

FCF_j = fraction of fossil carbon in the total carbon of component *j*

OF_j = oxidation factor, (fraction)

44/12 = conversion factor from C to CO_2

with: $\sum_j WF_j = 1$

j = component of the MSW incinerated/open-burned such as paper/cardboard, textiles, food waste, wood, garden (yard) and park waste, disposable nappies, rubber and leather, plastics, metal, glass, other inert waste.

If data by waste type/material are not available, the default values for waste composition given in Section 2.3 Waste composition could be used.

If CO_2 emissions from incineration and open burning of waste is a *key category*, it is *good practice* to apply a higher tier.

5.2.1.2 TIER 2

The Tier 2 method is based on country-specific data regarding waste generation, composition and management practices. Here, Equations 5.1 and 5.2 are also applied, as outlined for the Tier 1 method. It is *good practice* to use the Tier 2 method when CO_2 emission from incineration and open burning of waste is a *key category* or when more detailed data are available or can be gathered.

Tier 2a requires the use of country-specific activity data on the waste composition and default data on other parameters for MSW (Equation 5.2). For other categories of waste, country-specific data on the amounts are required (Equation 5.1). Country-specific MSW composition, even if using default data on other parameters, will reduce uncertainties compared to the use of aggregated MSW statistics.

A Tier 2a method for open burning of waste could incorporate annual surveys on the amounts and the composition of waste burned by households, authorities and companies responsible for the waste management.

Tier 2b requires country-specific data on the amount of waste incinerated/open-burned by waste type (Equation 5.1) or MSW composition (Equation 5.2), dry matter content, carbon content, fossil carbon fraction and oxidation factor, in addition to country-specific waste composition data. If these data are available, an estimate according to Tier 2b will have lower uncertainty than Tier 2a.

A Tier 2b method for open burning of waste could incorporate annual and detailed surveys on the amounts and the composition of waste burned by households, authorities and companies responsible for the waste management described in Tier 2a, with a combined measurement programme for emission factors related to the practices of open burning in the country.

It is *good practice* to implement those measurement programmes in different periods of the year to allow consideration of all seasons since emission factors depend on the combustion conditions. For example, in some countries where there is a rainy season and open burning is practised, more waste is burned during the dry season because of better burning conditions. Under these circumstances emission factors may vary with season.

In any case, all country-specific methods, activity data and parameters used should be described and justified in a transparent manner. The documentation should include descriptions on any experimental procedures, measurements and analyses made as well as information on atmospheric parameters such as temperature, wind, and rainfall in the case of open burning.

5.2.1.3 TIER 3

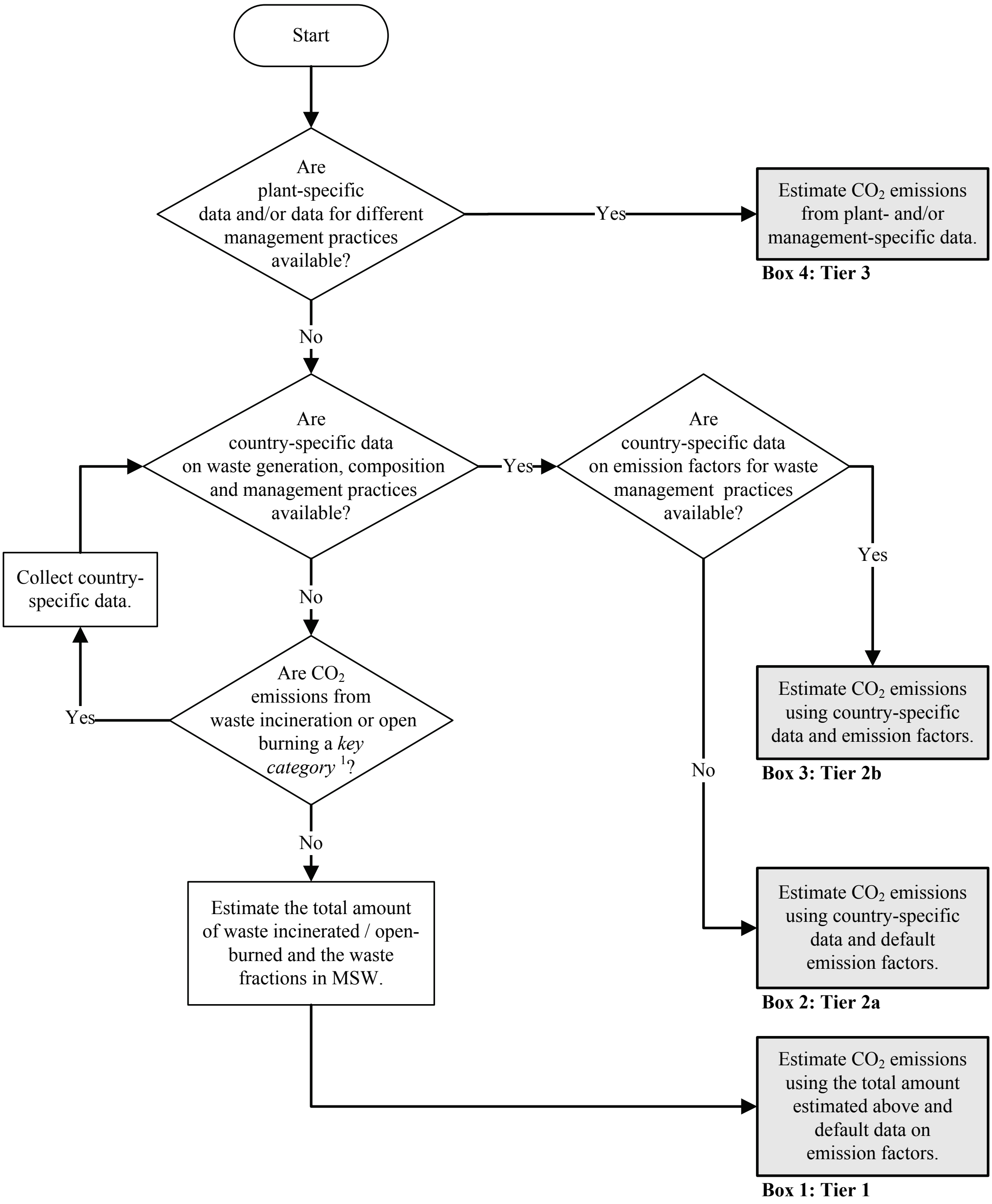
The Tier 3 method utilises plant-specific data to estimate CO_2 emissions from waste incineration. It is *good practice* at this tier level to consider parameters affecting both the fossil carbon content and the oxidation factor. Factors affecting the oxidation factor include:

- type of installation/technology: fixed bed, stoker, fluidised bed, kiln,
- operation mode: continuous, semi-continuous, batch type,
- size of the installation,
- parameters such as the carbon content in the ash.

The total fossil CO_2 emissions from waste incineration are calculated as the sum of all plant-specific fossil CO_2 emissions. It is *good practice* to include all waste types and the entire amount incinerated as well as all types of incinerators in the inventory. The estimation is done similarly as in the Tier 1 and Tier 2 methods and at the end, the CO_2 emissions from all plants, installations and other subcategories are added up to estimate the total emissions from waste incineration in the country.

The decision tree in Figure 5.1 gives guidance on the choice of method. The choice will depend on the national circumstances and the availability of data. Management practices in the decision tree are related to incineration and open burning.

Figure 5.1 Decision Tree for CO_2 emissions from incineration and open burning of waste



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 following Table 5.1 gives an overview on Tier levels at which default values or country-specific data are to be applied for calculating CO_2 emissions.

TABLE 5.1
OVERVIEW OF DATA SOURCES OF DIFFERENT TIER LEVELS

Data sources / **Tiers**	**Total waste amount (W)**	**Waste fraction (WF): % of each component mainly for MSW**	**Dry matter content (dm)**	**Carbon fraction (CF)**	**Fossil carbon fraction (FCF)**	**Oxidation factor (OF)**
Tier 3	plant- / management-specific	plant- / management-specific	plant- / management-specific	plant- / management-specific	plant- / management-specific	plant- / management-specific
Tier 2b	country-specific	country-specific	country-specific	country-specific	default / country-specific	default / country-specific
Tier 2a	country-specific	country-specific	default	default	default	default
Tier 1	default / country-specific	default	default	default	default	default

5.2.1.4 CO_2 EMISSIONS FROM INCINERATION OF FOSSIL LIQUID WASTE

Fossil liquid waste is here defined as industrial and municipal residues, based on mineral oil, natural gas or other fossil fuels. It includes waste formerly used as solvents and lubricants. It does not include wastewater, unless it is incinerated (e.g., because of a high solvent content). Biogenic liquid waste, e.g., waste oil from food processing, does not need to be accounted for, unless biogenic and fossil oil are mixed and a significant portion of its carbon is of fossil origin.

Fossil liquid waste is here considered as a specific type of waste, for which combustion is a common management practice. In some countries it is not incinerated together with solid waste (e.g., hazardous waste) but treated separately. Fossil liquid waste is in many cases not taken into account in the waste statistics, because in some countries they are not included as part of the main waste streams discussed in Section 5.2.1.1.

Fossil liquid waste is not taken into account in Section 5.2.1.1 to 5.2.1.3 because the equations are not applicable for this type of waste. Unless fossil liquid waste is included in other types of waste (e.g., industrial waste, hazardous waste), the emissions need to be calculated separately. Consistent with the reporting guidance, emissions from incineration of fossil liquid waste are reported in the Energy Volume when it is used for energy purposes.

CO_2 emissions from incineration of fossil liquid waste can be estimated using Equation 5.3.

EQUATION 5.3
CO_2 EMISSION FROM INCINERATION OF FOSSIL LIQUID WASTE

$$CO_2\ Emissions = \sum_i \left(AL_i \bullet CL_i \bullet OF_i\right) \bullet 44/12$$

Where:

CO_2 Emissions = CO_2 emissions from incineration of fossil liquid waste, Gg

AL_i = amount of incinerated fossil liquid waste type *i*, Gg

CL_i = carbon content of fossil liquid waste type *i*, (fraction)

OF_i = oxidation factor for fossil liquid waste type *i*, (fraction)

44/12 = conversion factor from C to CO_2

If the amount of fossil liquid waste is in terms of volume, this should be converted into mass using the density. If no information on the density of fossil liquid waste in the country is available, the default density provided can be used.

Three tiers to estimate the CO_2 emissions from incineration of fossil liquid waste are described as:

Tier 1: The default values are provided in Table 5.2.

Tier 2: Country-specific data on amount of fossil liquid waste incinerated, carbon content and country-specific oxidation factor are required at this tier, for each type of fossil liquid waste.

Tier 3: Plant-specific data should be used if available. The required data are the same as for Tier 1 and Tier 2. Estimates should consider all plants incinerating fossil liquid waste as well as the total amount of fossil liquid waste incinerated.

5.2.2 Choice of method for estimating CH_4 emissions

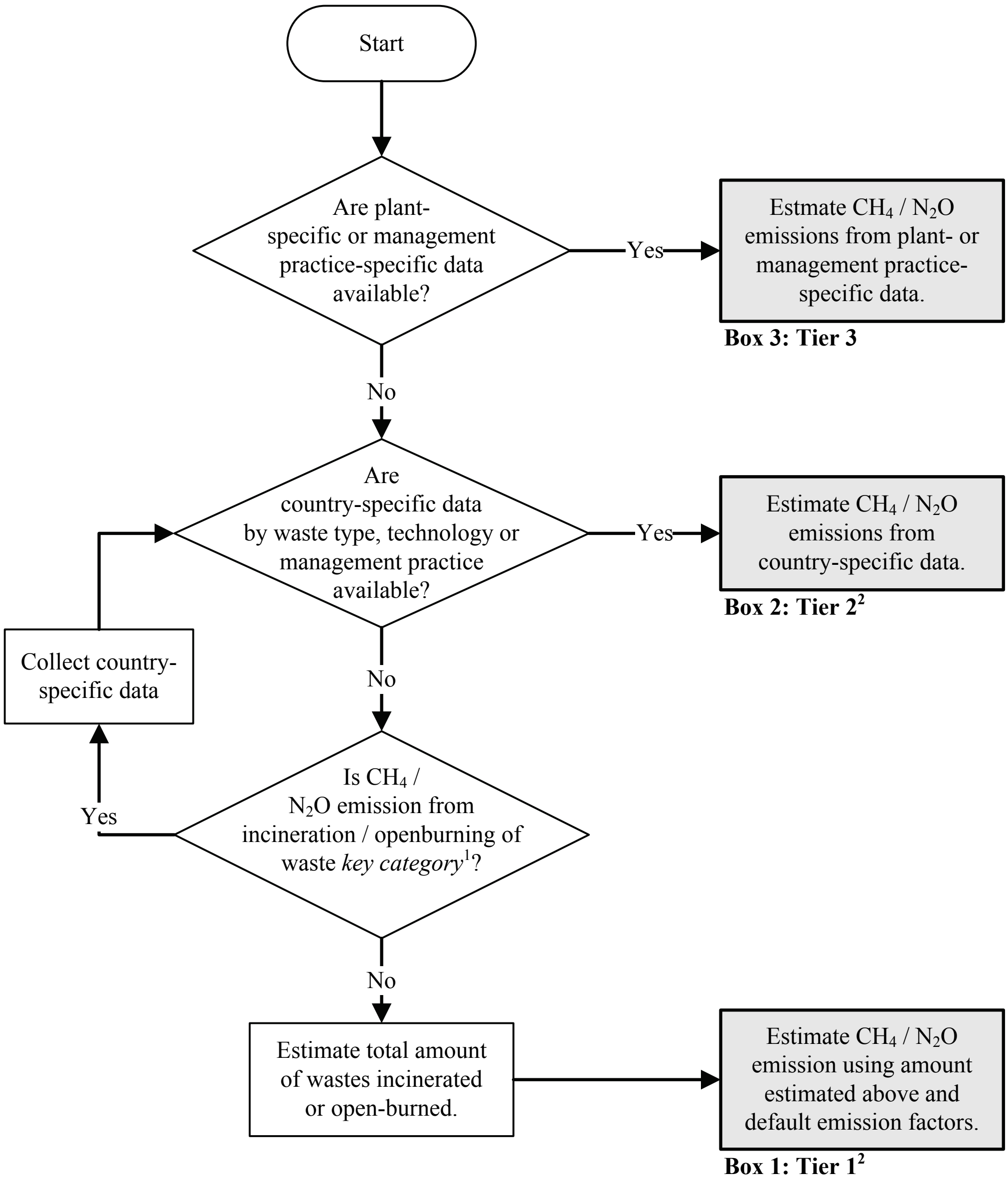
CH_4 emissions from incineration and open burning of waste are a result of incomplete combustion. Important factors affecting the emissions are temperature, residence time, and air ratio (i.e., air volume in relation to the waste amount). The CH_4 emissions are particularly relevant for open burning, where a large fraction of carbon in the waste is not oxidised. The conditions can vary much, as waste is a very heterogeneous and a low quality fuel with variations in its calorific value.

In large and well-functioning incinerators, CH_4 emissions are usually very small. It is *good practice* to apply the CH_4 emission factors provided in Chapter 2, Stationary Combustion, of Volume 2.

Methane can also be generated in the waste bunker of incinerators if there are low oxygen levels and subsequent anaerobic processes in the waste bunker. This is only the case where wastes are wet, stored for long periods and not well agitated. Where the storage area gases are fed into the air supply of the incineration chamber, they will be incinerated and emissions will be reduced to insignificant levels (BREF, 2005).

Figure 5.2 shows the decision tree for CH_4 and N_2O emissions from the incineration and open burning of waste.

Figure 5.2 **Decision Tree for CH_4 and N_2O emissions from incineration/open-burning of waste**



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.

2. The Tier 1 and Tier 2 methods follow the same approach but differ to the extent country-specific data are applied.

5.2.2.1 TIER 1

The calculation of CH_4 emissions is based on the amount of waste incinerated/open-burned and on the related emission factor as shown in Equation 5.4.

EQUATION 5.4
CH_4 EMISSION ESTIMATE BASED ON THE TOTAL AMOUNT OF WASTE COMBUSTED

$$CH_4\ Emissions = \sum_i \left(IW_i \bullet EF_i\right) \bullet 10^{-6}$$

Where:

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

IW_i = amount of solid waste of type *i* incinerated or open-burned, Gg/yr

EF_i = aggregate CH_4 emission factor, kg CH_4/Gg of waste

10^{-6} = conversion factor from kilogram to gigagram

i = category or type of waste incinerated/open-burned, specified as follows:

MSW: municipal solid waste, ISW: industrial solid waste, HW: hazardous waste,
CW: clinical waste, SS: sewage sludge, others (that must be specified)

The amount and composition of waste should be consistent with the activity data used for estimating CO_2 emissions from incineration/open burning.

Default emission factors are provided under Section 5.4.2, CH_4 emission factors, for incineration and open burning of waste.

If the CH_4 emissions from incineration or open burning of waste are *key categories*, it is *good practice* to use a higher tier.

5.2.2.2 TIER 2

Tier 2 is similar to Tier 1 but takes country-specific data into account. Tier 2 also follows Equation 5.4, as Tier 1. Inventory compilers should use country-specific data including activity data, emission factors by waste, technology or management practice.

Countries with a high proportion of open burning or batch-type/semi-continuous incinerators should consider further investigation of CH_4 emission factors.

5.2.2.3 TIER 3

It is *good practice* to use the Tier 3 method when plant-specific data are available. All incinerators should be considered and their emissions summed.

Figure 5.2 provides a general decision tree for estimating CH_4 emissions from incineration and open burning of waste. The best results will be obtained if country-specific or plant-specific CH_4 emission factors are available. Information on CH_4 from incineration and open burning of waste to satisfy the requirement of Tier 3 method is currently scant.

If detailed monitoring shows that the concentration of a greenhouse gas in the discharge from a combustion process is equal to or less than the concentration of the same gas in the ambient intake air to the combustion process then emissions may be reported as zero. Reporting these emissions as ‘negative emissions’ would require continuous high-quality monitoring of both the air intake and the atmospheric emissions.

5.2.3 Choice of method for estimating N_2O emissions

Nitrous oxide is emitted in combustion processes at relatively low combustion temperatures between 500 and 950 °C. Other important factors affecting the emissions are the type of air pollution control device, type and nitrogen content of the waste and the fraction of excess air (BREF, 2005; Korhonen *et al*., 2001; Löffler *et al*., 2002; Kilpinen, 2002; Tsupari *et al*., 2005). N_2O emissions from the combustion of fossil liquid waste can be considered negligible, unless country-specific data indicate otherwise.

Figure 5.2 provides a general decision tree for the estimation of N_2O emissions from incineration and open burning of waste. The most accurate results will be obtained if N_2O emissions are determined for each plant based on the plant-specific monitoring data, and then summed.

5.2.3.1 TIER 1

The calculation of N_2O emissions is based on the waste input to the incinerators or the amount of waste open-burned and a default emission factor. This relationship is summarised in the following Equation 5.5:

EQUATION 5.5
N_2O EMISSION ESTIMATE BASED ON THE WASTE INPUT TO THE INCINERATORS

$$N_2O\ Emissions = \sum_i \left(IW_i \bullet EF_i \right) \bullet 10^{-6}$$

Where:

N_2O Emissions = N_2O emissions in inventory year, Gg/yr

IW_i = amount of incinerated/open-burned waste of type *i* , Gg/yr

EF_i = N_2O emission factor (kg N_2O/Gg of waste) for waste of type *i*

10^{-6} = conversion from kilogram to gigagram

i = category or type of waste incinerated/open-burned, specified as follows:

MSW: municipal solid waste, ISW: industrial solid waste, HW: hazardous waste,
CW: clinical waste, SS: sewage sludge, others (that must be specified)

The amount and composition of waste should be consistent with the activity data used for the calculation of CO_2 and CH_4 emissions.

Default emission factors are provided in Section 5.4.3. However, inventory compilers should be aware that default emission factors for N_2O emissions from incineration and open burning of waste have a relatively high level of uncertainty. The use of country-specific data are preferable, if they meet quality assurance and quality control criteria outlined in Section 5.8 and in Chapter 6, QA/QC and Verification, in Volume 1. If N_2O emissions from incineration or open burning of waste are *key categories*, it is *good practice* to use a higher tier.

5.2.3.2 TIER 2

Tier 2 uses the same method as for the Tier 1, however, country-specific data are used to obtain emission factors. Where practical, N_2O emission factors should be derived from emission measurements. Where measured data are not available, other reliable means can be used to develop emission factors.

Emission factors for N_2O differ with type of facility and type of waste. Emission factors for fluidised-bed plants are higher than those for plants with grate furnaces. Emission factors for MSW are usually lower than for sewage sludge. Ranges of N_2O emission factors reflect abatement techniques, such as the injection of ammonia or urea used in some NO_x abatement technologies that may increase emissions of N_2O, temperature, and the residence time of the waste in the incinerator.

Tier 2 is applicable when country-specific emission factors are available but no detailed information on a plant-by-plant basis or further differentiated by management practices are available.

5.2.3.3 TIER 3

Tier 3 methods are based on site-specific data on flue gas concentrations. Equation 5.6 indicates the relevant factors of influence and enables to estimate N_2O emissions.

EQUATION 5.6
N_2O EMISSION ESTIMATE BASED ON INFLUENCING FACTORS

$$N_2O\ Emissions = \sum_i \left(IW_i \bullet EC_i \bullet FGV_i \right) \bullet 10^{-9}$$

Where:

N_2O Emissions = N_2O emissions in inventory year, Gg/yr

IW_i = amount of incinerated waste of type *i*, Gg/yr

EC_i = N_2O emission concentration in flue gas from the incineration of waste type *i*, mg N_2O/m^3

FGV_i = flue gas volume by amount of incinerated waste type *i*, m^3/Mg

10^{-9} = conversion to gigagram

i = category or type of waste incinerated/open-burned, specified as follows:

MSW: municipal solid waste, ISW: industrial solid waste, HW: hazardous waste,
CW: clinical waste, SS: sewage sludge, others (that must be specified)

Tier 3 outlines the most detailed and accurate approach, where data on a plant-by-plant basis or for various management practices are available. It requires data on the flue gas volume and concentration of N_2O emissions in the flue gas. Continuous emission monitoring is technically feasible, but not necessarily cost-effective. Periodic measurements should be conducted sufficiently often to account for the variability of N_2O generation (i.e., due to the nitrogen content in the waste), and different types of incinerator operating conditions (e.g., combustion temperature, with or without daily shut down).

5.3 CHOICE OF ACTIVITY DATA

General guidance for activity data collection for solid waste treatment and disposal as well as default values on waste generation, management practices and composition are given in Chapter 2, Waste Generation, Composition and Management. Activity data needed in the context of incineration and open burning of waste includes the amount of waste incinerated or open-burned, the related waste fractions (composition) and the dry matter content.

As the type of waste combusted and the applied management practice are relevant for the CO_2, CH_4 and N_2O emissions, the choice of activity data section is outlined according to the common factors related to activity data and not separately for each of the emitted gases. In addition, the waste composition is particularly relevant for the CO_2 emissions. The N_2O emissions are mainly determined by technology, combustion temperature and waste composition. Completeness of combustion (temperature, oxygen, residence time) is particularly relevant for the CH_4 emissions. The N content and technology-specific activity data are related to higher tiers, and country-specific schemes to collect the data (surveys to plants, research projects, etc.) need to be established. The composition of MSW generated in the country can be used as a default for MSW incinerated or open-burned when data by management practice are not available. More accurate emission estimates can be obtained if data on the composition of waste incinerated or open-burned are available (Tier 2). It is *good practice* to make a distinction between composition of wastes incinerated/open-burned and the composition of all waste delivered to the waste management system, if data are available. If a certain waste type/material in MSW (e.g., paper waste) or industrial waste is incinerated separately, country-specific data on the incinerated or open-burned fraction should be determined taking this into account.

Particular attention should be paid to the representativeness of the country-specific data. Ideally, the data used should be representative for the waste incinerated and open-burned. If such data are not available, country-specific data without differentiation by waste type or incineration technology used are still more appropriate than default data.

Results of sampling, measurements and waste sorting studies applied in the data collection should be documented transparently and quality assurance and quality control practices outlined in Section 5.8 should be applied.

In developing countries, basic data on amount of waste and treatment practices may not be available. Waste incineration in some developing countries is likely to take place only in minor quantities. Therefore, emissions from open burning of waste should be considered in detail (see Section 5.3.2), while emissions from incineration should also be quantified if expected to be relevant. If emissions from incineration are assumed to be negligible, the reasons for the assumption should clearly be explained and documented by the inventory compiler.

5.3.1 Amount of waste incinerated

Obtaining data on the amount of waste incinerated is a prerequisite for preparing an emission inventory for incineration of waste. Many countries that use waste incineration should have plant-specific data on the amount of MSW and other types of waste incinerated. For hazardous and clinical wastes, the activity data may be difficult to obtain since waste incinerated in some of these plants (e.g., on-site incinerators in chemical and pharmaceutical industry) may not be included in waste statistics. For these waste types, even though plant-specific data may not be available, overall data for total waste incinerated may be available from the waste administration.

The default data given in Chapter 2, Section 2.2 on waste generation and management data (see particularly Tables 2.1, 2.3, and 2.4) and Annex 2A.1: Waste generation and management data – by country and regional averages, from the respective region or neighbouring countries with similar conditions could be used when country-specific data are not available.

It is *good practice* to apply accurate boundaries system for the distinction to report emissions under the energy, waste or industry sections. Also, agricultural residue burning should be reported in the AFOLU Sector. See Section 5.8.2, Reporting and Documentation.

5.3.2 Amount of waste open-burned

The amount of waste open-burned is the most important activity data required for estimating emissions from open burning of waste. In most countries statistics may not be available. Where the data on waste amount are not available, alternative methods such as data from period surveys, research project or expert judgement can be used to estimate total amount of waste burned together with appropriate explanation and documentation. Extrapolation and interpolation can be used to obtain estimates for years for which no data are available. Population and economic data can be used as drivers.

Equation 5.7 below can be used to estimate the total amount of MSW open-burned.

EQUATION 5.7
TOTAL AMOUNT OF MUNICIPAL SOLID WASTE OPEN-BURNED

$$MSW_B = P \bullet P_{frac} \bullet MSW_P \bullet B_{frac} \bullet 365 \bullet 10^{-6}$$

Where:

MSW_B = Total amount of municipal solid waste open-burned, Gg/yr

P = population (capita)

P_{frac} = fraction of population burning waste, (fraction)

MSW_P = per capita waste generation, kg waste/capita/day

B_{frac} = fraction of the waste amount that is burned relative to the total amount of waste treated, (fraction)

365 = number of days by year

10^{-6} = conversion factor from kilogram to gigagram

Fraction of population burning waste (P_{frac})

Open burning includes regularly burning and sporadically burning. Regularly burning means that this is the only practice used to eliminate waste. Sporadically burning means that this practice is used in addition to other practices and therefore open burning is not the only practice used to eliminate waste. For example, when waste is not collected or is burned for other reasons such as cost avoidance.

For countries that have well functioning waste collection systems in place, it is *good practice* to investigate whether any fossil carbon is open-burned. In a developed country, P_{frac} can be assumed to be the rural population for a rough estimate. In a region where urban population exceeds 80 percent of total population, one can assume no open burning of waste occurs.

In a developing country, mainly in urban areas, P_{frac} can be roughly estimated as being the sum of population whose waste is not collected by collection structures and population whose waste is collected and disposed in open dumps that are burned. In general, it is preferable to apply country- and regional-specific data on waste handling practices and waste streams.

Fraction of waste amount open-burned (B_{frac})

B_{frac} means the fraction of waste for which carbon content is converted to CO_2 and other gases. When all the amount of waste is burned B_{frac} could be considered equal to 1 (an oxidation factor related to the combustion efficiency is applied later to estimate emissions using Equation 5.1 or 5.2). However, in some cases, mainly when a substantial quantity of waste in open dumps is burned, a relatively large part of waste is left unburned (in open dumps the fraction not compacted often burns). In this situation B_{frac} should be estimated using survey or research data available, or expert judgement, and applied in the Equation 5.7 (here also an oxidation factor is applied later to estimate emissions using Equation 5.1 or 5.2).

When open burning is practiced, countries are encouraged to undertake surveys in order to estimate P_{frac} and B_{frac} and then MSW_B using the Equation 5.7.

Box 5.1 gives an example of estimating MSW_B .

BOX 5.1
EXAMPLE OF ESTIMATING MSW_B

In a country of population P inhabitants, 15 percent of the population burns waste in the backyard (barrels or on the ground) and 20 percent sends waste to open-dumps that are burned. Therefore, P_{frac} = 35 percent. The remainder 65percent are eliminated through other waste treatment systems. The example calculation is as follows:

MSW_P = 0.57 kg waste/capita/day

B_{frac} = 0.6 (default value suggested for burning of open dumps based on expert judgment considering the fact that 0.4 is suggested as default value for MCF of unmanaged shallow SWDS).

For P = 1 500 000 inhabitants, the total amount of waste open-burned is:

MSW_B = 65.54 Gg/yr

National statistics on population and per capita waste generation exist in many countries and can be used. Data on population, per capita waste generation and waste composition used should be consistent with those reported under the categories of Solid Waste Disposal and Biological Treatment of Solid Waste. Population data are usually available from national statistics, international databases such as those of United Nations also provide international population statistics (UN, 2002) can be used where national statistics are not available (see Section 3.2.2). The amount of fossil liquid waste combusted can include both by incineration and by open burning (see Section 5.2.1.4). The amount does not need to be differentiated by type of management practice, as the default methodology is applicable to both practices (see also Chapter 2).

5.3.3 Dry matter content

An important distinction needs to be made between dry weight and wet weight of waste, because the water content of waste can be substantial. Therefore, the dry matter content of the waste or waste fraction is an important parameter to be determined.

The weight of waste incinerated should be converted from wet weight to dry weight, if the related emission factors refer to dry weight. The dry matter content of waste can range from below 50 percent in countries with a higher percentage of food waste to 60 percent in countries with higher fractions of paper-based and fossil carbon-based wastes. Detailed procedures for determination of the dry matter content are being developed in the document PrEN (2001).

Table 2.4 in Section 2.3 provides default data on dry matter content for different waste types/material that can be used to estimate dry matter content in MSW. This can be done using Equation 5.8.

EQUATION 5.8
DRY MATTER CONTENT IN MSW

$$dm = \sum_i \left(WF_i \bullet dm_i \right)$$

Where:

dm = total dry matter content in the MSW

WF_i = fraction of component *i* in the MSW

dm_i = dry matter content in the component *i*.

It is important to notice that Equation 5.8 is a part of Equation 5.2.

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. Each of these factors is discussed in detail in the sections below[3].

TABLE 5.2
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	40 – 50	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)	58	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: When waste is open-burned, refuse weight is reduced by approximately 49 to 67 percent (US-EPA, 1997, p.79). A default value of 58 percent is suggested.

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 Guidelines*, Expert judgement.

5.4.1.1 TOTAL CARBON CONTENT

While a fraction of the carbon in waste incinerated or open-burned is derived from biomass raw materials (e.g., paper, and food waste), part of the total carbon is plastics or other products made from fossil fuel. Table 5.2 in this section and Section 2.3 in Chapter 2 provide default carbon fractions for waste types and MSW waste fractions respectively. Further details on the fraction of fossil carbon are provided below.

Inventory compilers can use data on composition of MSW and the default data on total carbon content for different waste types/material of MSW provided in Section 2.3 of Chapter 2 to estimate the total carbon content in MSW (see Equation 5.9).

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[3] 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.

EQUATION 5.9
TOTAL CARBON CONTENT IN MSW

$$CF = \sum_i (WF_i \bullet CF_i)$$

Where:

CF = total carbon content in MSW

WF_i = fraction of component *i* in the MSW

CF_i = carbon content in the waste type/material *i* in MSW

This is also reflected in Equation 5.2.

5.4.1.2 FOSSIL CARBON FRACTION

In estimating emissions from incineration and open burning of waste, the desired approach is to separate carbon in the waste into biomass and fossil fuel based fractions. For the purposes of calculating anthropogenic CO_2 emissions from incineration and open burning of waste, the amount of fossil carbon in the waste should be determined. The fraction of fossil carbon will differ for different waste categories and types of waste. The carbon in MSW and clinical waste is of both biogenic and fossil origin. In sewage sludge the fossil carbon usually can be neglected while the carbon in hazardous waste is usually of fossil origin. Default data for these waste categories and different waste types/materials included in MSW are provided in Table 5.2 and in Chapter 2, Section 2.3.

Where plant-specific data are available, the exact composition of the waste being incinerated should be collected and used in CO_2 emission calculations. If such data are not readily available, country-specific data may be used. This type of data will most likely be in the form of general surveys of the country-specific waste stream. The survey should contain not only the composition, but also the fate of the waste streams (i.e., the percentage of a particular waste type, which is incinerated/open-burned).

Different fossil fuel-based waste products will contain different percentages of fossil carbon. For each waste stream, an analysis should be performed for each waste type. In general, plastics will represent the waste type being incinerated with the highest fossil carbon fraction. In addition, the fossil carbon content of toxics, synthetic fibres and synthetic rubbers is particularly relevant. A certain amount of tire waste is also considered as source of fossil carbon, since tires can be composed of synthetic rubbers or carbon black.

If neither plant-specific waste types nor country-specific waste stream information are available, Section 2.3 in Chapter 2 provides default fossil carbon fractions for the most relevant waste fractions in MSW as well as for specific types of industrial waste and other waste (including hazardous waste and clinical waste).

The fractions of fossil and biogenic carbon are likely to change considerably in the future because of recent waste legislation adopted in some countries. Such programmes will influence the total waste flow incinerated, as well as the fossil carbon content of the waste incinerated/open-burned.

It is *good practice*, under Tier 2a, that inventory compilers use country-specific data on composition of MSW and default values provided in Chapter 2, Section 2.3, to estimate fossil carbon fraction (FCF) in MSW using Equation 5.10.

EQUATION 5.10
FOSSIL CARBON FRACTION (FCF) IN MSW

$$FCF = \sum_i (WF_i \bullet FCF_i)$$

Where:

FCF = total fossil carbon in the MSW

WF_i = fraction of waste type *i* in the MSW

FCF_i = fraction of fossil carbon in the waste type *i* of the MSW

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 presents default oxidation factors by management practices and waste types.

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.

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 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.

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.

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.

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 NO_x 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
N_2O 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	Stoker	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.

Table 5.5 shows the example of N_2O emission factors used for estimate emissions from incineration of sludge and industrial waste.

TABLE 5.5
N_2O EMISSION FACTORS FOR INCINERATION OF SLUDGE AND INDUSTRIAL WASTE

Country	Type of Waste	Type of Incineration / Technology	Emission factor for Industrial Waste (g N_2O / t waste)	Weight basis
Japan[1]	Waste paper, waste wood		10	wet weight
	waste oil		9.8	wet weight
	waste plastics		170	wet weight
	sludge (except sewage sludge)		450	wet weight
	dehydrated sewage sludge		900	wet weight
	high molecular weight flocculant	fluidised bed incinerator at normal temperature	1 508	wet weight
	high molecular weight flocculant	fluidised bed incinerator at high temperature	645	wet weight
	high molecular weight flocculant	multiple hearth	882	wet weight
	other flocculant		882	wet weight
	lime sludge		294	wet weight
Germany[2]	sewage sludge		990	dry weight
	industrial waste		420	wet weight

[1] GIO 2005.
[2] Johnke 2003.

It is *good practice* to apply these if no country-specific information is available.

For open burning of waste, only information on emissions from burning of agricultural residues is available. The approach for agricultural residues is outlined in Volume 4, Section 2.4 in Chapter 2 Non CO_2 emissions, and Section 11.2 (N_2O emissions from managed soils) in Chapter 11. Assuming an N/C ratio of 0.01 (Crutzen and Andrea, 1990), an emission factor of up to 0.15 g N_2O / kg dry matter is obtained as N_2O emission factor for agricultural residues. Because it is expected that the nitrogen content of household waste is towards the higher end of the nitrogen content of agricultural wastes, this emission factor for agricultural wastes is suggested here to be used as default value for N_2O emissions from open-burning of waste.

Based on the current information available and the emission factors provided in Table 5.4 and 5.5, Table 5.6 provides N_2O default emission factors for different types of waste and management practices.

TABLE 5.6
DEFAULT N_2O EMISSION FACTORS FOR DIFFERENT TYPES OF WASTE AND MANAGEMENT PRACTICES

Type of waste	Technology / Management practice	Emission factor (g N_2O / t waste)	weight basis
MSW	continuous and semi-continuous incinerators	50	wet weight
MSW	batch-type incinerators	60	wet weight
MSW	open burning	150	dry weight
Industrial waste	all types of incineration	100	wet weight
Sludge (except sewage sludge)	all types of incineration	450	wet weight
Sewage sludge	incineration	990	dry weight
		900	wet weight

Source: Expert judgement by lead authors of this chapter of *2006 Guidelines*

It is *good practice* to apply these if no country-specific information is available.

NO_x can be transformed to N_2O in the atmosphere. Therefore, NO_x emissions from incineration and open burning of waste can be relevant sources of indirect N_2O emissions. When the country has information on NO_x emissions, it is *good practice* to estimate the indirect N_2O emissions using the guidance in Chapter 7 Ozone Precursors, SO_2 and Indirect Emissions of Volume 1.

5.5 COMPLETENESS

Completeness depends on the reporting of types and amounts of waste incinerated or open-burned. If the method is implemented at the facility-level and then summed across facilities, it is *good practice* to ensure that all waste incineration plants are covered.

Inventory compilers should make efforts to report all waste types arising in their country as well as associated management practices. When different types of waste are incinerated together, it is *good practice* to estimate emissions from each type of waste separately and report them following guidance provided in this chapter.

It should be noted that there are possibilities of double counting CO_2 emissions because waste is often incinerated in facilities with energy recovery capabilities. Also, waste can be used as substitute fuel in industrial plants other than waste incineration plants (e.g., in cement and brick kilns, and blast furnaces). In order to avoid double counting or misallocation, guidance provided in this chapter for estimating and reporting emissions from incineration between Waste and Energy Sectors should be followed.

For open burning of waste, it could be difficult to determine the total amount of waste burned because reliable statistics are often unavailable. Inventory compilers should consider data that fall outside the official statistics in order to avoid underestimation of emissions. If household waste is open-burned in rural areas (villages, etc.) this should be considered.

Open-burning on solid waste disposal sites has an effect to reduce degradable organic carbon (DOC). The reduction in the DOC available for decay, and hence the reduction in future CH_4 emissions, can be roughly estimated, at Tier 1, as the product of the amount of waste burned on landfills and the corresponding average DOC. Actually, open burning on landfills is a more complex issue since it would affect some important parameters such as humidity, availability of nutrients, and availability of micro organisms (likely killed by fire or change in their metabolism) to some extent and this would influence subsequent CH_4 emissions from landfill at least for a given period. At higher tiers (e.g., Tier 2) countries should strive for improving estimate of emissions arising from this practice as well as its effect on DOC.

To check whether completeness has been achieved, a diagram showing waste stream and distribution between management practices could be drawn. This could also facilitate the process of QA/QC.

5.6 DEVELOPING A CONSISTENT TIME SERIES

Emissions of greenhouse gas from incineration and open-burning of waste should be calculated using the same method and data sets consistently for every year in the time series, at the same level of disaggregation. Where country-specific data are used, it is *good practice* to use the same coefficients and methods for equivalent calculations at all points in the time series. Where consistent data are not available for the same method for any years in the time series, these gaps should be filled according to the guidance provided in Volume 1, Chapter 5 Time Series Consistency, Section 5.3, Resolving data gaps.

Activity data may only be available every few years. To achieve time series consistency, various methods such as interpolation, extrapolation from longer time series or trends should be used. (See Chapter 5 of Volume 1.)

5.7 UNCERTAINTY ASSESSMENT

Section 2.3 in Chapter 2, Table 2.4 provides typical ranges as well as single values for parameters relevant for the calculation of CO_2 emissions from incineration and open burning of waste. Examples of CH_4 and N_2O emission factors of some countries are outlined in Section 5.4.2 and Section 5.4.3 respectively. It is *good practice* that inventory compilers calculate the uncertainty as 95 percent confidence interval for country-defined parameters. Also uncertainty estimates based on expert judgement or the default uncertainty estimates can be used. More recent information could have a lower uncertainty because it reflects changing practices, technical developments, or changing fractions (biogenic and fossil) of incinerated waste. This should form the basis of the inventory uncertainty assessment.

Volume 1, Chapter 3, Uncertainties, provides advice on quantifying uncertainties in practice. It includes eliciting and using expert judgements, which in combination with empirical data can provide overall uncertainty estimates. Estimates of emissions from open burning can be highly uncertain due to lack of information mainly in developing countries.

The use of country-specific data may introduce additional uncertainty in the following areas:

- If surveys on waste composition are used, the interpretation of definitions of solid waste and surveys may differ, which due to a variety of sources of varying reliability and accuracy.
- Emission factors for N_2O and CH_4 for solid waste combustion facilities may span an order of magnitude, reflecting considerable variability in the processes from site to site. Control/removal efficiency can also be uncertain, e.g., due to controls in place to reduce NO_x.

5.7.1 Emission factor uncertainties

There is a high level of uncertainty related to the separation of biogenic and fossil carbon fractions in the waste. This uncertainty is mainly related to the uncertainties in waste composition. The major uncertainty associated with CO_2 emissions estimate is related to the estimation of the fossil carbon fraction (see Section 3.7 on uncertainty assessment in Chapter 3 of this Volume).

Uncertainties associated with CO_2 emission factors for open burning depend on uncertainties related to fraction of dry matter in waste open-burned, fraction of carbon in the dry matter, fraction of fossil carbon in the total carbon, combustion efficiency, and fraction of carbon oxidised and emitted as CO_2. A default value of ± 40 percent is proposed for countries relying on default data on the composition in their calculations.

Direct measurement or monitoring of emissions of N_2O and CH_4 has less uncertainty. For continuous and periodic emission monitoring, uncertainty depends on the accuracy of measurement instruments and methods used. These are likely to be in order of ± 10 percent. For periodic measurement, uncertainty will also depend on the sampling strategy and frequency, and the uncertainties will be much higher. If default values for N_2O and CH_4 emission factors are used, uncertainty ranges have been estimated to be ± 100 percent or more.

5.7.2 Activity data uncertainties

In many developed countries where the amount of waste incinerated is based on waste statistics or plant specific data, uncertainties on the amount of incinerated waste are estimated around ± 5 percent on a wet weight basis. The uncertainty could be higher for some waste types, such as clinical waste.

The conversion of waste amounts from wet weight to dry weight adds additional uncertainty. Depending on the frequency and the accuracy of the dry weight determination, this uncertainty varies substantially. The uncertainty of the dry matter content may therefore range between ± 10 percent up to ± 50 percent and even more.

When waste statistics are insufficient, population, per capita waste generation, and fraction of waste burned are parameters to be considered for estimating amount of waste open-burned. Uncertainties can be particularly high for the amount of waste generated per capita and the fraction of waste burned. For the countries using the default values for waste generation and management data given in the Section 2.2 in Chapter 2, the uncertainty values for activity data provided in Table 3.5 in Chapter 3 can be used also for incineration. Estimates on the total carbon content and fraction of fossil carbon can be estimated using the ranges given in Table 2.4 in Chapter 2, Section 2.3.

5.8 QA/QC, REPORTING AND DOCUMENTATION

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

Quality assurance and quality control checks as outlined in Chapter 6 of Volume 1 should be used when estimating emissions from incineration and open burning of waste. Furthermore, transparency can be improved by the provision of clear documentation and explanations of work undertaken in the following areas.

Review of activity data

- Inventories compilers should review data collection methods, check data and compare them with other data sources. Data should also be checked with previous year to ensure consistency over time. This includes mainly amount of waste incinerated/open-burned and dry matter content.
- Diagram of distribution of waste according to management practices should be developed to ensure that the total amount of waste generated is the same as the sum of waste recycled and treated under different management practices.

Review of emission factors

- Inventory compilers should compare country-specific or plant-specific values of the carbon content of waste, the fossil carbon as fraction of total carbon, and the efficiency of combustion for the incinerator to the default values provided. When there is difference, they should check whether sound explanation is provided.

Review of direct emission measurements

- Where direct measurement data are available, inventory compilers should confirm that internationally recognised standard methods were used for measurements. If the measurement practices fail this criterion, then the use of these emissions data should be carefully evaluated.
- Where emissions are measured directly, inventory compilers should compare plant-level factors among plants, and also with IPCC defaults. They should review any significant differences between factors. This is particularly true for hazardous and clinical waste, because these wastes are often not quantified on a plant basis and can vary significantly from plant to plant.

Consistency of activity data and emissions factors

- The activity data, the emission factors and related factors need to be related to the quantity of waste in a consistent manner: e.g., wet weight or dry weight. Otherwise conversion factors (e.g., dry matter content) need to be applied.
- The applied data and factors should preferably refer to the same or similar system boundaries. For example, if one component in an equation relates to rural waste, another to waste in large cities, these should be used in a consistent manner.

5.8.2 Reporting and Documentation

It is *good practice* to document and archive all information required to produce the national greenhouse gas inventory as outlined in Section 6.11 of Chapter 6 in Volume 1. A few examples of specific documentation and reporting relevant to this category are outlined in the following paragraphs.

While documentation is important, it is not practical or necessary to include all documentation in a greenhouse gas inventory report. However, the inventory should include summaries of methods used and references for data sources such that the reported estimates are transparent and steps included in their calculations may be traced and verified.

Some countries use different categorisations for waste at local or regional levels. In such instances, the inventory compiler should pay special attention to the consistency with the IPCC categorisation and explain how the data were manipulated to fit the IPCC categories.

Inventory compilers should also include information on how they obtained the dry matter content, the carbon content, the fossil carbon fraction and the N_2O and CH_4 emission factors or any other relevant information.

In some countries, incineration plants are used to produce both heat and electricity. In such cases, emissions from incineration of waste for energy purposes should be reported under Energy Sector (fossil CO_2, N_2O and CH_4 from Stationary Combustion, and biogenic CO_2 as an information item). Resulting emissions should not be reported in the Waste Sector in order to avoid double counting.

In cases where gas, oil or other fuels are used as support fuel to start the incineration process or to maintain the required temperature, consumption of this fuel should not be reported under waste incineration but under the Energy Sector (see Chapter 2, Stationary Combustion, in Volume 2, Energy). Such fuels, normally, account for less than 3 percent of total calorific input of MSW incineration but could be more important with the incineration of hazardous waste.

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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

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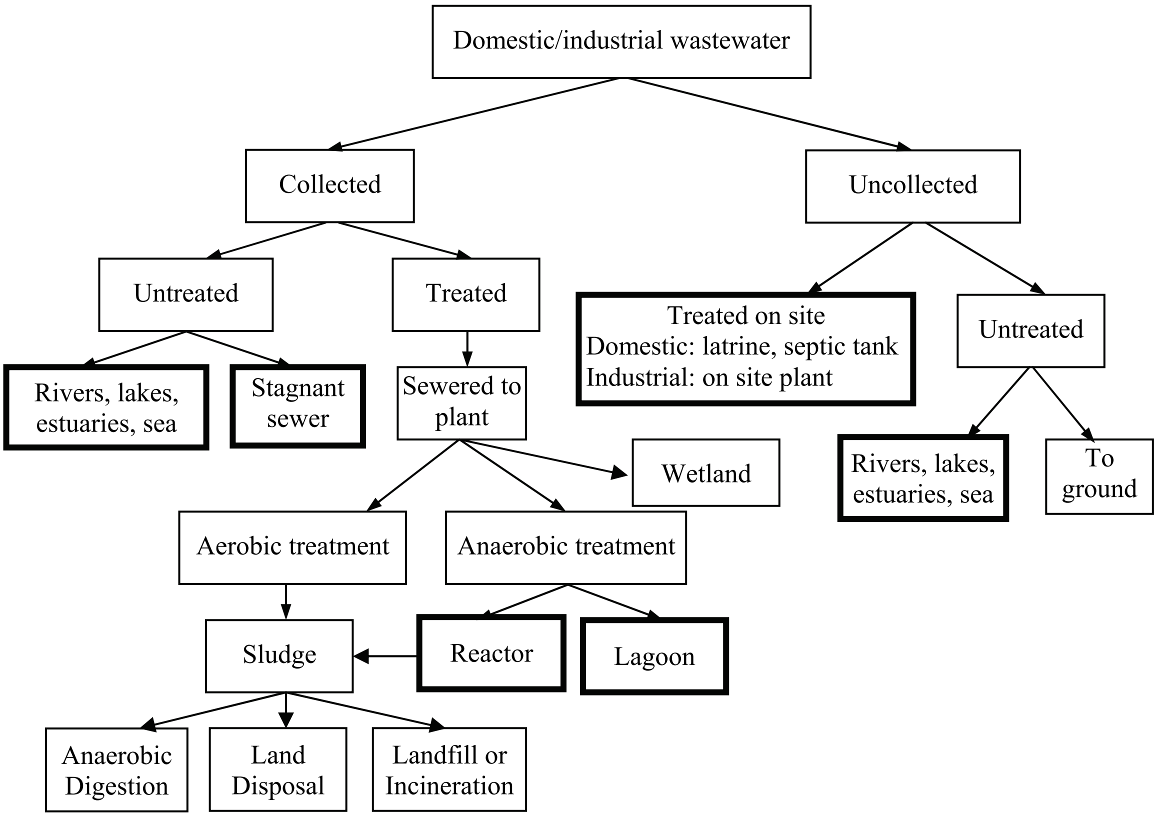
[1] Because the methodology is on a per person basis, emissions from commercial wastewater are estimated as part of domestic wastewater. To avoid confusion, the term municipal wastewater is not used in this text. Municipal wastewater is a mix of household, commercial and non-hazardous industrial wastewater,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

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[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.
		Sewers (closed and under ground)		Not a source of CH_4/N_2O.
		Sewers (open)		Stagnant, overloaded open collection sewers or ditches/canals are likely significant sources of CH_4.
	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.
			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.
			Aerobic shallow ponds	Unlikely source of CH_4/N_2O. Poorly designed or managed aerobic systems produce CH_4.
		Anaerobic treatment	Anaerobic lagoons	Likely source of CH_4. Not a source of N_2O.
			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.
	Open pits/Latrines			Pits/latrines are likely to produce CH_4 when temperature and retention time are favourable.
	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.

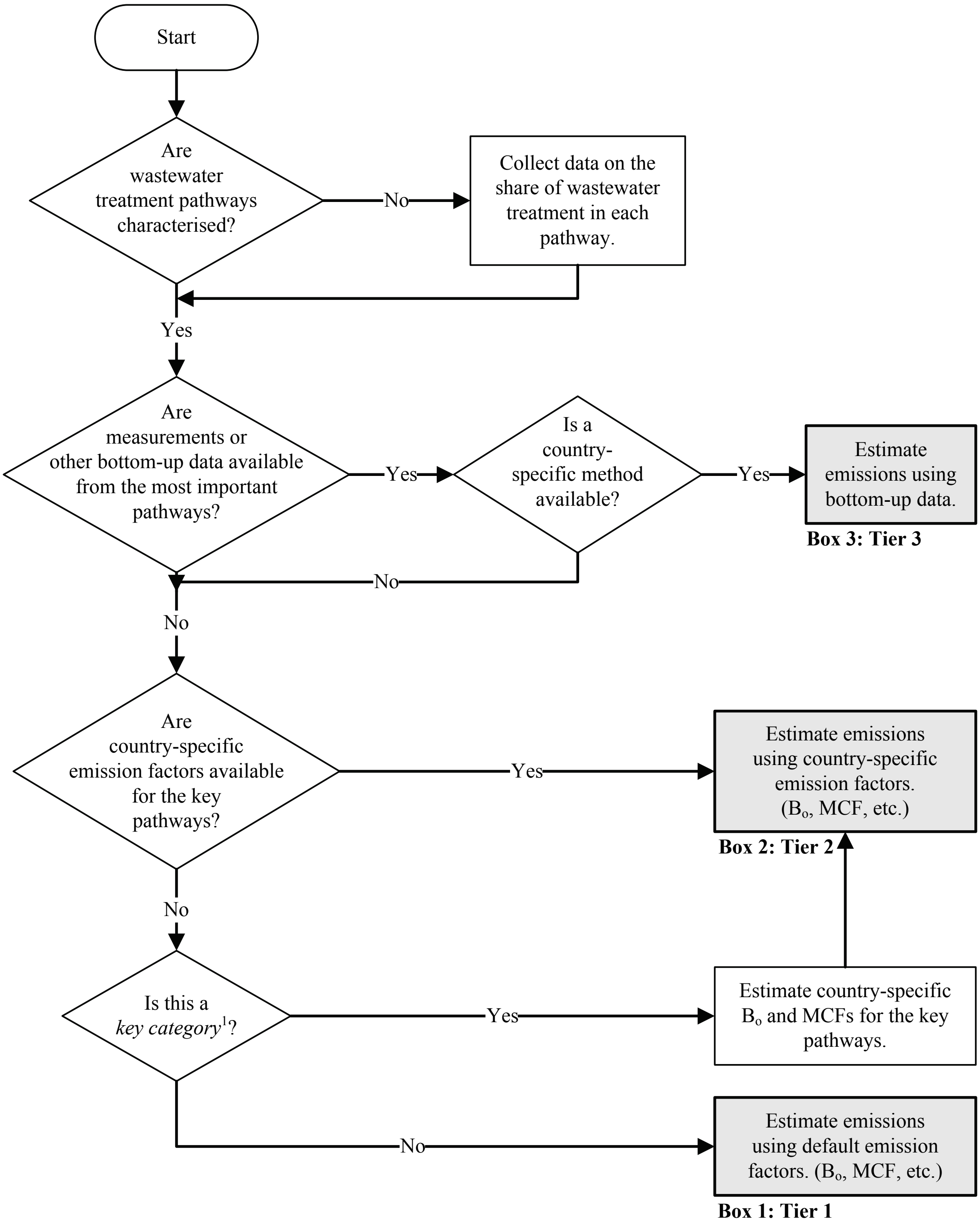
Emissions from flaring are not significant, as the CO_2 emissions are of biogenic origin, and the CH_4 and N_2O emissions are very small so *good practice* in the Waste Sector does not require their estimation. However, if it is wished to do so these emissions should be reported under the Waste Sector.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

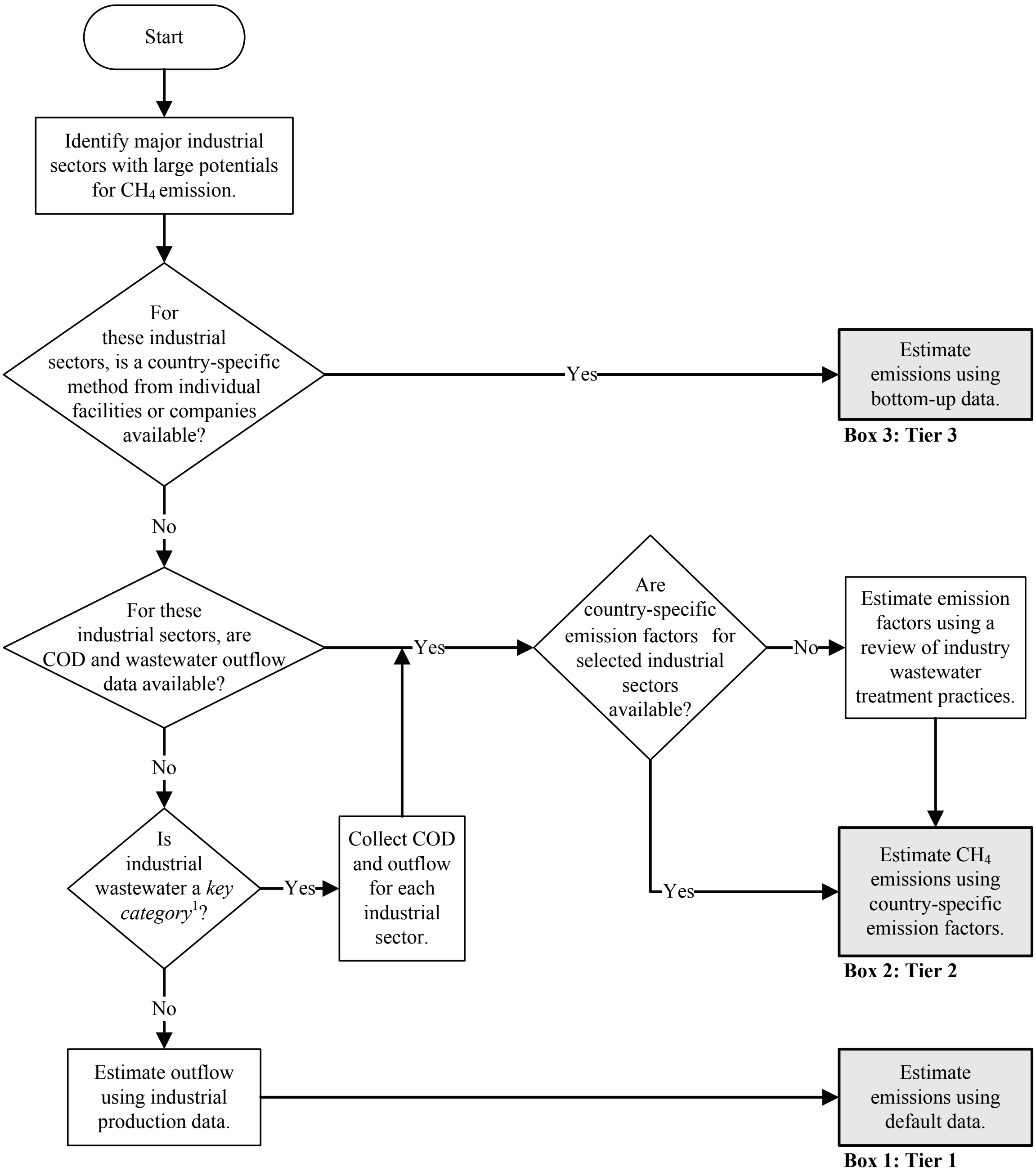
6.2.3 Industrial wastewater

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 %
$F_{NON-CON}$	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
$F_{IND-COM}$	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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ANNEX 1

WORKSHEETS

Contents

Annex 1 Worksheets

Note: For 4A Category Solid Waste Disposal, see spreadsheet IPCC Waste Model.

Sector		**Waste**				
Category		**Biological Treatment of Solid Waste**				
Category Code		**4B**				
Sheet		**1 of 1 Estimation of CH_4 emissions from Biological Treatment of Solid Waste**				
		STEP 1	**STEP 2**		**STEP 3**	
Biological Treatment System	**Waste Category/ Types of Waste[1]**	A	B	C	D	E
		Total Annual amount treated by biological treatment facilities[3] (Gg)	Emission Factor (g CH_4/kg waste treated)	Gross Annual Methane Generation (Gg CH_4)	Recovered/flared Methane per Year (Gg CH_4)	Net Annual Methane Emissions (Gg CH_4)
				$C = (A \times B) \times 10^{-3}$		$E = (C - D)$
Composting						
Anaerobic digestion at biogas facilities[2]						
					Total	

1 Information on the waste category should include information of the origin of the waste (MSW, Industrial, Sludge or Other) and type of waste (Food waste or Garden and Park Waste).

2 If anaerobic digestion involves recovery and energy use of the gas, the emissions should be reported in the Energy Sector.

3 Information on whether the amount treated is given as wet or dry weight should be given.

Sector		**Waste**		
Category		**Biological Treatment of Solid Waste**		
Category Code		**4B**		
Sheet		**1 of 1 Estimation of N_2O emissions from Biological Treatment of Solid Waste**		
		STEP 1	**STEP 2**	
		A	B	C
Biological Treatment System	**Waste Category /Types of Waste[1]**	Total Annual amount treated by biological treatment facilities[3] (Gg)	Emission Factor (g N_2O/kg waste treated)	Net Annual Nitrous Oxide Emissions (Gg N_2O)
				$E = (C - D) x10^{-3}$
Composting				
Anaerobic digestion at biogas facilities[2]				
			Total	

1 Information on the waste category should include information of the origin of the waste (MSW, Industrial, Sludge or Other) and type of waste (Food waste or Garden and Park Waste).

2 If anaerobic digestion involves recovery and energy use of the gas, the emissions should be reported in the Energy Sector.

3 Information on whether the amount treated is given as wet or dry weight should be given.

Sector	**Waste**
Category	**Incineration and Open Burning of Waste**
Category Code	**4C1**
Sheet	**I of I Estimation of CO_2 emissions from Incineration of Waste**

Type of Waste		A	B	C	D	E	F	G
		Total Amount of Waste Incinerated (Wet Weight) (Gg Waste)	Dry Matter Content[1] dm (fraction)	Fraction of Carbon in Dry Matter[2] CF (fraction)	Fraction of Fossil Carbon in Total Carbon[3] FCF (fraction)	Oxidation Factor OF (fraction)	Conversion Factor 44/12	Fossil CO_2 Emissions (Gg CO_2)
								G= A x B x C x D x E x F
Municipal Solid Waste (MSW)[4, 5]								
Composition[4,5]	Plastics							
	Textiles							
	Rubber							
	Nappies							
Industrial solid waste								
Hazardous waste								
Clinical waste								
Sewage sludge								
Other (specify)								
							Total	

1 For default data and relevant equations on the dry matter content in MSW and other types of waste, see Section 5.3.3 in Chapter 5.

2 For default data and relevant equations on the fraction of carbon, see Section 5.4.1.1 in Chapter 5.

3 For default data and relevant equations on the fraction of fossil carbon, see Section 5.4.1.2 in Chapter 5.

4 Users may either enter all MSW incinerated in the MSW row or the amount of waste by composition by adding the appropriate rows.

5 All relevant fractions of fossil C should be included. For consistency with the CH_4 and N_2O sheets, the total amount incinerated should be reported here. However the fossil CO_2 emissions from MSW should be reported only once (either for total MSW or the components).

Sector	**Waste**					
Category	**Incineration and Open Burning of Waste**					
Category Code	**4C1**					
Sheet	**1 of 1 Estimation of total amount of waste open-burned**					
STEP 1						
Region, city, etc.	A	B	C	D	E	F
	Population	Fraction of Population Burning Waste	Per Capita Waste Generation	Fraction of the waste amount burned relative to the total amount of waste treated	Number of days by year 365	Total Amount of MSW Open-burned
	P	P_{frac}	MSW_P	B_{frac} [1]		MSW_B
	(Capita)	(fraction)	(kg waste/capita/day)	(fraction)	(day)	(Gg/yr)
						F = A x B x C x D x E
Sum of regions, cities, etc. (Total amount of MSW open-burned in the country)						
					Total	

[1] When all the amount of waste is burned B_{frac} could be considered equal 1. When a substantial quantity of waste in open dumps is burned, a relatively large part of waste is left unburned. In this situation, B_{frac} should be estimated using survey or research data available or expert judgement.

Sector	**Waste**
Category	**Incineration and Open Burning of Waste**
Category Code	**4C2**
Sheet	**1 of 1 Estimation of CO_2 emissions from Open Burning of Waste**

STEP 1		**STEP 2**						
		F	G	H	I	J	K	L
Type of Waste		Total Amount of Waste open-burned (Wet Weight) (Gg Waste)	Dry Matter Content [1] dm (fraction)	Fraction of Carbon in Dry Matter [2] CF (fraction)	Fraction of Fossil Carbon in Total Carbon [3] FCF (fraction)	Oxidation Factor OF (fraction)	Conversion Factor 44/12	Fossil CO_2 Emissions (Gg CO_2)
		F = (A x B x C x D) [4]						L= F x G x H x I x J x K
Municipal Solid Waste (MSW) [5,6]		This comes from previous table						
Composition [5,6]	Plastics							
	Textiles							
	Rubber							
	Nappies							
	etc							
	add as needed							
Other (specify)								
							Total	

1 For default data and relevant equations on the dry matter content in MSW and other types of waste, see Section 5.3.3 in Chapter 5.

2 For default data and relevant equations on the fraction of carbon, see Section 5.4.1.1 in Chapter 5.

3 For default data and relevant equations on the fraction of fossil carbon, see Section 5.4.1.2 in Chapter 5.

4 The amount MSW can be calculated in the previous sheet "Estimation of Total Amount of Waste Open-burned". See also Equation 5.7.

5 Users may either enter all MSW incinerated in the MSW row or the amount of waste by composition by adding the appropriate rows.

6 All relevant fractions of fossil C should be included. For consistency with the CH_4 and N_2O sheets, the total amount open-burned should be reported here. However, the fossil CO_2 emissions from MSW should be reported only once (either for total MSW or the components).

Sector	**Waste**				
Category	**Incineration and Open Burning of Waste**				
Category Code	**4C1**				
Sheet	**I of I Estimation of CO_2 emissions from incineration of fossil liquid waste**				
Type of Waste	A	B	C	D	E
	Total Amount of Fossil Liquid Waste Incinerated (Weight) Gg Waste	Fossil Carbon Content of Fossil Liquid Waste CL (fraction)	Oxidation Factor for Fossil Liquid Waste of type i OF (fraction)	Conversion Factor 44/12	Fossil CO_2 Emissions (Gg CO_2)
					E= A x B x C x D
Lubricants					
Solvents					
Waste oil					
Other (specify)					
				Total	

Sector	**Waste**
Category	**Incineration and Open Burning of Waste**
Category Code	**4C1**
Sheet	**I of I Estimation of CH_4 emissions from Incineration of Waste**

	A	B	C
Type of Waste	Amount of Waste Incinerated (Wet Weight) [1] (Gg Waste)	Methane Emission Factor (kg CH_4/Gg Wet Waste) [1]	Methane Emissions (Gg CH_4)
			$C= A \times B \times 10^{-6}$ [2]
Municipal Solid Waste			
Industrial solid waste			
Hazardous waste			
Clinical waste			
Sewage sludge			
Other (specify)			
		Total	

1 If the total amount of waste is expressed in terms of dry waste, the CH_4 emission factor needs to refer to dry weight instead.

2 Factor of 10^{-6} as emission factor is given in kg /Gg waste incinerated on a wet weight basis.

Sector	**Waste**		
Category	**Incineration and Open Burning of Waste**		
Category Code	**4C2**		
Sheet	**I of I Estimation of CH_4 emissions from Open Burning of Waste**		
Type of Waste	F	G	H
	Total Amount of Waste Open-burned (Wet Weight) [1,2] (Gg Waste)	Methane Emission Factor (kg CH_4/Gg Wet Waste) [2]	Methane Emissions (Gg CH_4)
			$H= F \times G \times 10^{-6}$ [3]
Municipal Solid Waste			
Other (specify)			
		Total	

1 Total amount of MSW open-burned is obtained by estimates in the Worksheet “Total amount of waste open-burned”.

2 If the total amount of waste is expressed in term of dry waste, the CH_4 emission factor needs to refer to dry weight instead.

3 Factor of 10^{-6} as emission factor is given in kg /Gg waste incinerated on a wet weight basis.

Sector	**Waste**		
Category	**Incineration and Open Burning of Waste**		
Category Code	**4C1**		
Sheet	**I of I Estimation of N_2O emissions from Incineration of Waste**		
Type of Waste	A	B	C
	Total Amount of Waste Incinerated (Wet Weight [1]) (Gg Waste)	Nitrous Oxide Emission Factor (kg N_2O/Gg Wet Waste) [1]	Nitrous Oxide Emissions (Gg N_2O)
			$C= A \times B \times 10^{-6}$ [2]
Municipal Solid Waste			
Industrial solid waste			
Hazardous waste			
Clinical waste			
Sewage sludge			
Other (specify)			
		Total	

1 If the total amount of waste is expressed in terms of dry waste, the CH_4 emission factor needs to refer to dry weight instead.

2 Factor of 10^{-6} as emission factor is given in kg /Gg waste incinerated on a wet weight basis.

Sector	**Waste**		
Category	**Incineration and Open Burning of Waste**		
Category Code	**4C2**		
Sheet	**I of I Estimation of N_2O emissions from Open Burning of Waste**		
Type of Waste	F	G	H
	Total Amount of Waste Open-burned (Wet Weight) [1,2] (Gg Waste)	Nitrous Oxide Emission Factor (kg N_2O/Gg Dry Waste) [2]	Nitrous Oxide Emissions ($Gg\ N_2O$)
			$H = F \times G \times 10^{-6}$ [3]
Municipal Solid Waste			
Other (specify)			
		Total	

1 Total amount of MSW open-burned is obtained by estimates in the Worksheet "Total amount of waste open-burned".

2 If the total amount of waste is expressed in terms of dry waste, a fraction of dry matter should not be applied.

3 Factor of 10^{-6} as emission factor is given in kg /Gg waste incinerated on a wet weight basis.

Sector	**Waste**			
Category	**Domestic Wastewater Treatment and Discharge**			
Category Code	**4D1**			
Sheet	**1 of 3 Estimation of Organically Degradable Material in Domestic Wastewater**			
	STEP 1			
Region or City	A	B	C	D
	Population (P) cap	Degradable organic component (BOD) (kg BOD/cap.yr) [1]	Correction factor for industrial BOD discharged in sewers (I) [2]	Organically degradable material in wastewater (TOW) (kg BOD/yr)
				D = A x B x C
			Total	

1 g BOD/cap.day *x* 0.001 *x* 365 = kg BOD/cap.yr

2 Correction factor for additional industrial BOD discharged into sewers, (for collected the default is 1.25, for uncollected the default is 1.00).

Sector	**Waste**		
Category	**Domestic Wastewater Treatment and Discharge**		
Category Code	**4D1**		
Sheet	**2 of 3 Estimation of CH_4 emission factor for Domestic Wastewater**		
STEP 2			
Type of treatment or discharge	A	B	C
	Maximum methane producing capacity (B_0) (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	**3 of 3 Estimation of CH_4 emissions from Domestic Wastewater**

STEP 3

Income group	**Type of treatment or discharge pathway**	A	B	C	D	E	F	G
		Fraction of population income group (U_i) (fraction)	Degree of utilization (T_{ij}) (fraction)	Emission Factor (EF_j) (kg CH_4/kg BOD)	Organically degradable material in wastewater (TOW) (kg BOD/yr)	Sludge removed (S) (kg BOD/yr)	Methane recovered and flared (R) (kg CH_4/yr)	Net methane emissions (CH_4) (kg CH_4/yr)
				Sheet 2 of 3	Sheet 1 of 3			G = [(A x B x C) x (D -E)] - F
Rural								
Urban high income								
Urban low income								
							Total	

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				
Industry Sectors	A	B	C	D
	Total industry product (P_i) $(t_{product}/yr)$	Wastewater generated (W_i) $(m^3/t_{product})$	Chemical Oxygen Demand (COD_i) $(kgCOD/m^3)$	Total organic degradable material in wastewater for each industry sector (TOW_i) $(kgCOD/yr)$
				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			
Type of treatment or discharge	A	B	C
	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 BOD)
			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
Industrial sector	Type of treatment or discharge pathway	Total organic degradable material in wastewater for each industry sector (TOW_i)	Sludge removed in each industry sector (S_i)	Emission factor for each treatment system (EF_i)	Recovered CH_4 in each industry sector (R_i)	Net methane emissions (CH_4)
Units		(kg COD/yr)	(kg COD/yr)	(kg CH_4/kgBOD)	(kg CH_4/yr)	(kg CH_4/yr)
		Sheet 1 of 3		Sheet 2 of 3		E = [(A – B) x C] – D
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 2 Estimation of nitrogen in effluent**

	A	B	C	D	E	F	H
	Population (P)	Per capita protein consumption (Protein)	Fraction of nitrogen in protein (F_{NPR})	Fraction of non-consumption protein ($F_{NON-CON}$)	Fraction of industrial and commercial co-discharged protein ($F_{IND-COM}$)	Nitrogen removed with sludge (default is zero) (N_{SLUDGE})	Total nitrogen in effluent ($N_{EFFLUENT}$)
units	(people)	(kg/person/ year)	(kg N/kg protein)	(-)	(-)	(kg)	kg N/year)
							H = (A x B x C x D x E) – F
						Total	

Sector	**Waste**				
Category	**Domestic Wastewater Treatment and Discharge**				
Category Code	**4D1**				
Sheet	**2 of 2 Estimation of emission factor and emissions of indirect N_2O from Wastewater**				
	A	B	C	D	E
	Nitrogen in effluent ($N_{EFFLUENT}$) (kg N/year)	Emission factor (kg N_2O-N/kg N)	Conversion factor of kg N_2O-N into kg N_2O 44/28	Emissions from Wastewater plants (default = zero) (kg N_2O-N/year)	Total N_2O emissions (kg N_2O-N/year)
					E= A x B x C – D