CGE SUPPLEMENTARY TRAINING MATERIAL FOR THE TEAM OF TECHNICAL EXPERTS

Module 2.2e

Background material:
National greenhouse gas inventories – waste sector

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ABBREVIATIONS

AD	activity data
BOD	biological oxygen demand
CH_4	methane
CO_2	carbon dioxide
COD	chemical oxygen demand
DOC	degradable organic compound
FOD	first order decay
GHG	greenhouse gas
GPG 2000	Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
IPCC	Intergovernmental Panel on Climate Change
MCF	methane conversion factor, methane correction factor
MSW	municipal solid waste
N_2O	nitrous oxide
NH_3	ammonia
NO_X	nitrogen oxides
SWDS	solid waste disposal sites

1. BACKGROUND AND COURSE OBJECTIVES

This material was developed within the context of the process for international consultation and analysis to further support the training for the team of technical experts and to provide additional background knowledge and context.

This module, prepared as supplementary training material to module 2.2 on technical analysis of greenhouse gas (GHG) inventories, aims to provide an overview of the methods and science involved in estimating emissions from the waste sector. This is intended for **those experts nominated to the UNFCCC roster of experts with no or limited prior knowledge and wishing to enhance their technical knowledge on national GHG inventories**.

It is drawn from the most recent Consultative Group of Experts (CGE) training materials on national GHG inventories for Parties not included in Annex I to the Convention (non-Annex I Parties), which are based on the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (hereinafter referred to as the Revised 1996 IPCC Guidelines), and *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (herein referred to as GPG 2000).

The information presented here should be further supplemented with that from the Revised 1996 IPCC Guidelines and GPG 2000 in order to address the complete length and breadth of science and methods involved in estimating GHG emissions from the waste sector.

2. SECTOR OVERVIEW

The Revised 1996 IPCC Guidelines and the GPG 2000 provide guidance on categories of the waste sector. They are the following: solid waste disposal on land (6.A), wastewater handling (6.B) and waste incineration (6.C).

Table 1
Greenhouse gas source and sink categories

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
A. Solid Waste Disposal on Land							
1. Managed Waste Disposal on Land							
2. Unmanaged Waste Disposal Sites							
3. Other *(as specified in table 6.A)*							
Other non-specified							
B. Waste Water Handling							
1. Industrial Wastewater							
2. Domestic and Commercial Waste Water							
3. Other *(as specified in table 6.B)*							
Other non-specified							
Unsewered wastewater treatment							
C. Waste Incineration							
D. Other *(please specify)*							
Other non-specified							

Note: The grey cells indicate categories where emissions do not occur.

3. WASTE SECTOR EMISSION PROCESSES

3.1. CARBON DIOXIDE EMISSION PROCESSES

Waste incineration and open burning of waste containing fossil carbon, such as plastics, are the most important sources of carbon dioxide (CO_2) emissions from the waste sector. CO_2 emissions from open burning of fossil carbon are accounted for under the waste sector. However, CO_2 is estimated and reported under the energy sector when the waste material is incinerated with energy recovery, where the waste is used directly as fuel or converted into a fuel. Open burning and combustion (technology-based controlled burning) converts the carbon stored in waste by chemical decomposition reaction into CO_2 released into the atmosphere.

CO_2 is associated with the biogas generated in solid waste disposal sites (SWDS), anaerobic treatment of wastewater and burning of non-fossil waste; but this CO_2 is treated as of biogenic origin and is therefore not included in the national total from the waste sector. CO_2 emissions resulting from the combustion of biogenic materials, including CO_2 from waste-to-energy applications, are documented and reported in the energy sector, as memo/information items, and are not included in the national total emissions.

3.2. NON-CARBON DIOXIDE EMISSION PROCESSES

3.2.1. METHANE EMISSIONS

The most significant GHG produced from the waste sector for most countries is methane (CH_4). Methane emissions are generated from the methanogenesis of biodegradable solid waste, wastewater and its sludge under anaerobic conditions. Anaerobic bacteria break down organic matter into substances such as cellulose, amino acids and sugars, which are further broken down by fermentation processes that support growth of methanogenic bacteria. The methane-producing anaerobic bacteria convert the fermentation products into biogas consisting of approximately 50 per cent CO_2 and 50 per cent CH_4 by volume. Methane production typically begins one or two years after the waste disposal in a modern landfill, and may last for 10–60 years.

Wastewater sludge handling can also be a source of CH_4 when treated or disposed of under anaerobic conditions. The extent of CH_4 generation depends on the quantity of degradable organic material in the wastewater (measured as biological oxygen demand (BOD) load), temperature and the type of treatment system. For instance, below 15°C, significant CH_4 production is unlikely, because methanogens are not active.

3.2.2. NITROUS OXIDE

Nitrous oxide (N_2O) is produced in most wastewater treatment systems. The significance of the N_2O emissions varies considerably depending on the type of treatment and operating conditions during the treatment. Direct emissions of N_2O may be generated when wastewater is subject to nitrification, and denitrification processes without biological nutrient reduction systems. 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 in the wastewater, such as urea, nitrate and protein in human sewage mixed with other household wastewater into nitrate (NO_3), while denitrification occurs under anoxic conditions and involves the biological conversion of nitrate into dinitrogen gas (N_2). N_2O can be an intermediate product of both processes, but is more often associated with denitrification.

3.2.3. CARBON MONOXIDE, AMMONIA, NITROGEN OXIDES AND NON-METHANE VOLATILE ORGANIC COMPOUNDS

Waste and wastewater treatment and discharge can also produce emissions of non-methane volatile organic compounds, nitrogen oxides (NO_X), and carbon monoxide (CO), as well as of ammonia (NH_3). The NO_X and NH_3 emissions from the waste sector can cause indirect N_2O emissions. NO_X is produced mainly in the burning of waste, while NH_3 occurs during composting and anaerobic digestion without nutrient reduction.

4. METHODS TO ESTIMATE GREENHOUSE GAS EMISSIONS FROM THE WASTE SECTOR

4.1. INTRODUCTION

In the Revised 1996 IPCC Guidelines and GPG 2000, methods are generally referred to as 'tiers', with higher tier methods being more advanced. The GPG 2000 provides decision trees to help Parties in the selection of data and methods (i.e. tiers) for each individual category. These decision trees are intended to direct the Party to use the best method and data possible, given its national circumstances. In general, it is **good practice** for Parties to utilize higher tier methods, with their associated more detailed data, in particular for key categories. Parties are, however, permitted some flexibility in applying these decision trees as long as the choices they make result in estimates that are of equivalent quality to those described in the GPG 2000.

This flexibility is an important characteristic of the Revised 1996 IPCC Guidelines and the GPG 2000, because it recognizes that Parties have different national circumstances (e.g. availability of historical data). Although **good practice** is meant to direct Parties to use more rigorous methods and more detailed data, what is defined as 'good practice' can vary from Party to Party, depending on the national circumstances.

This section provides background on the steps for estimating emissions from the waste sector, using the decision tree approach to select methods (appropriate tier level) consistent with national circumstances, emission factors and activity data (AD). It also outlines consistent approaches to avoid double counting between categories within the waste sector, and also from categories in other sectors, such as the energy sector (accounting for non-CO_2 emissions from burning of waste for energy purposes).

4.2. SOLID WASTE DISPOSAL SITES

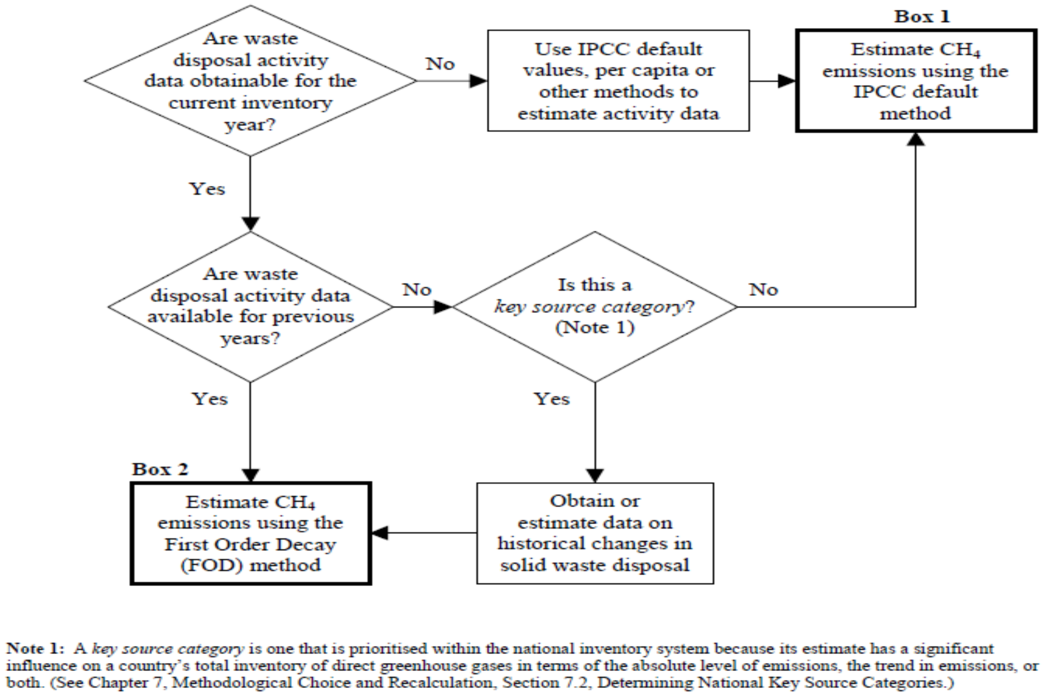
Methane is emitted during the anaerobic decomposition of organic waste disposed of in SWDS. Organic waste decomposes at a diminishing rate and takes many years to decompose completely.

Landfill gas is known to be produced both in managed 'landfill' and 'open dump' sites. Both are considered here as SWDSs. Gas can migrate from SWDSs either laterally or by venting to the atmosphere, causing vegetation damage and unpleasant odours at low concentrations, while at concentrations of 5–15 per cent in the air, the gas may form an explosive mixture.

4.2.1. DECISION TREE FOR METHANE FROM SOLID WASTE DISPOSAL SITES

Figure 1

Decision Tree for CH_4 Emissions from Solid Waste Disposal Sites



Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 5.6.

4.2.2. TIER 1 METHOD

Box 1
Methane emissions from solid waste disposal sites

EQUATION 1

Methane emissions (Gg/yr)

$$= (MSW_T \times MSW_F \times MCF \times DOC \times DOC_F \times F \times 16/12 - R) \times (1-OX)$$

where:

MSW_T	=	total MSW generated (Gg/yr)
MSW_F	=	fraction of MSW disposed to solid waste disposal sites
MCF	=	methane correction factor (fraction)
DOC	=	degradable organic carbon (fraction)
DOC_F	=	fraction DOC dissimilated
F	=	fraction of CH_4 in landfill gas (default is 0.5)
R	=	recovered CH_4 (Gg/yr)
OX	=	oxidation factor (fraction - default is 0)

Source: Revised 1996 IPCC Guidelines for National Greenhouse gas Inventories, Reference Manual, p. 6.5.

The parameters used in the tier 1 method are described below.

Total municipal solid waste (MSW_T)

This can be calculated from the population (thousand people) x annual MSW generation rate (Gg/thousand people/year). Per capita MSW generation rates are provided for many countries and regions in the Revised 1996 IPCC Guidelines, Reference Manual, table 6-1. The components of MSW may vary from country to country. These differences can play an important role in the resulting emissions estimate, as each waste stream may have a different degradable organic compound (DOC) content and hence a different CH_4 generation potential.

The fraction of MSW disposed of in SWDSs (MSW_F)

The MSW_F and the methane correction factor (MCF) reflect the way in which MSW is managed and the effect of 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 the three categories of solid waste disposal sites (managed, unmanaged-deep and unmanaged-shallow).

Methane correction factor (MCF)

A MCF is assigned to each type of solid waste disposal site: managed, unmanaged-deep and unmanaged-shallow. The MCF reflects the lower methane-generating potential of unmanaged sites. The classification recognizes that some developing countries, or countries with economies in transition, may have a small number of well-managed waste disposal sites, with the majority of sites less well-managed or unmanaged, often shallow and with lower methane-generating potential. A default value is also 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 as national waste management policies are implemented over a number of years.

Degradable organic carbon (DOC)

This is the organic carbon that is accessible to biochemical decomposition, and should be expressed as gigagrams of carbon per gigagram of waste. DOC content is based on the composition of waste, and can be calculated from a weighted average of the carbon content of various components of the waste stream. Country and/or region default data for DOC, where available, is presented in the Revised 1996 IPCC Guidelines, Reference Manual, table 6-1. It is highly recommended, however, for countries where the composition of the fractions in the waste stream are known, that these be combined with a knowledge of the carbon content of these various fractions, to produce a country-specific value for DOC. It is critical that the DOC value corresponds to the waste generation and disposal rate on which the CH_4 estimate is based. For example, a country that includes industrial waste in its MSW estimate should ensure that the DOC value used reflects this component of the waste stream.

The fraction of dissimilated DOC (DOC_F)

This is an estimate of the fraction of carbon that is ultimately degraded and released from SWDS. It reflects the fact that some organic carbon does not degrade, or degrades very slowly, when deposited in SWDS. The Revised 1996 IPCC Guidelines provide a default value of 0.77 for DOC_F, but based on recent literature, it appears that this default value may be an overestimate. It should only be used if lignin C is excluded from the DOC value. It is also a good practice to use a value of 0.5–0.6 (including lignin C) as the default. 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.

Fraction of CH_4 in landfill gas (F)

Landfill gas consists mainly of CH_4 and CO_2. The CH_4 fraction F is usually taken to be 0.5, but can vary between 0.4 and 0.6, depending on several factors including waste composition (e.g. carbohydrate and cellulose). 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)

This is the amount of CH_4 generated at SWDS that is recovered and burned in a flare or energy recovery device. Methane recovered and subsequently vented should not be subtracted from gross emissions. The default value for methane recovery is zero.

This default should only be changed when references documenting the amount of methane recovery are available. Recovered gas volumes should be reported as CH_4, not as landfill gas, as landfill gas contains only a fraction of CH_4. Reporting based on metering of all gas recovered for energy utilization and flaring is consistent with good practice. The use of undocumented estimates of landfill gas recovery potential is not appropriate, as such estimates tend to overestimate the amount of recovery.

Oxidation factor (OX)

This reflects the amount of CH_4 from SWDS that is oxidized in the soil or other material covering the waste. If the oxidation factor is zero, no oxidation takes place, and if OX is 1 then 100 per cent of CH_4 is oxidized. Studies show that sanitary landfills tend to have higher oxidation results than unmanaged dump sites. For example, 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 in the cover.

4.2.3. HIGHER TIER METHODS

The tier 2 method, or the first order decay (FOD) model can be used to model the rate of CH_4 generation over time. This approach has been used extensively to model landfill gas generation rate curves for individual landfills. It can also be used to model gas generation for a set of SWDSs to develop country emission estimates, or can be applied in a more general way to entire regions.

It is good practice to use the FOD method. The FOD method produces a time-dependent emission profile that better reflects the true pattern of the degradation process over time in solid waste disposal sites. It is good practice to use the FOD method, or a validated country-specific method, in order to account for time dependence of the emissions. This is because the GPG 2000 tier 1 default method will generally underestimate emissions. It overestimates them if there is a reduction in the amount of carbon deposited at SWDS with changing organic fraction, which is influenced by several factors, including policy.

The FOD approach uses some default parameters; but requires good-quality country-specific AD on current and historical waste disposal at SWDSs. Historical waste disposal data for 10 years or more should be based on country-specific statistics, surveys or other similar sources. Data is needed on the amounts disposed at the SWDS.

The key activity data required for the application of the GPG 2000 FOD approach includes total waste generation and waste streams by fraction of waste collected and disposed to SWDSs. Where waste composition and per capita waste generation are still not available, default activity data values for MSW are provided in the Revised 1996 IPCC Guidelines, Reference Manual, tables 6.1 and 6.3.[1]

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[1] For more information, see GPG 2000, p. 5.5.

Box 2

Methane generated in solid waste disposal sites

EQUATION 5.1

$$CH_4 \text{ generated in year t (Gg/yr)} = \sum_x [(A \bullet k \bullet MSW_T(x) \bullet MSW_F(x) \bullet L_0(x)) \bullet e^{-k(t-x)}]$$

for x = initial year to t

Where:

t = year of inventory

x = years for which input data should be added

$A = (1 - e^{-k}) / k$; normalisation factor which corrects the summation

k = Methane generation rate constant (1/yr)

$MSW_T(x)$ = Total municipal solid waste (MSW) generated in year x (Gg/yr)

$MSW_F(x)$ = Fraction of MSW disposed at SWDS in year x

$L_0(x)$ = Methane generation potential $[MCF(x) \bullet DOC(x) \bullet DOC_F \bullet F \bullet 16/12$ (Gg CH_4/Gg waste)]

MCF (x) = Methane correction factor in year x (fraction)

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

DOC_F = Fraction of DOC dissimilated

F = Fraction by volume of CH_4 in landfill gas

16 / 12 = Conversion from C to CH_4

Sum the obtained results for all years (x).

EQUATION 5.2

$$CH_4 \text{ emitted in year t (Gg/yr)} = [CH_4 \text{ generated in year t} - R(t)] \bullet (1 - OX)$$

Where:

R(t) = Recovered CH_4 in inventory year t (Gg/yr)

OX = Oxidation factor (fraction)

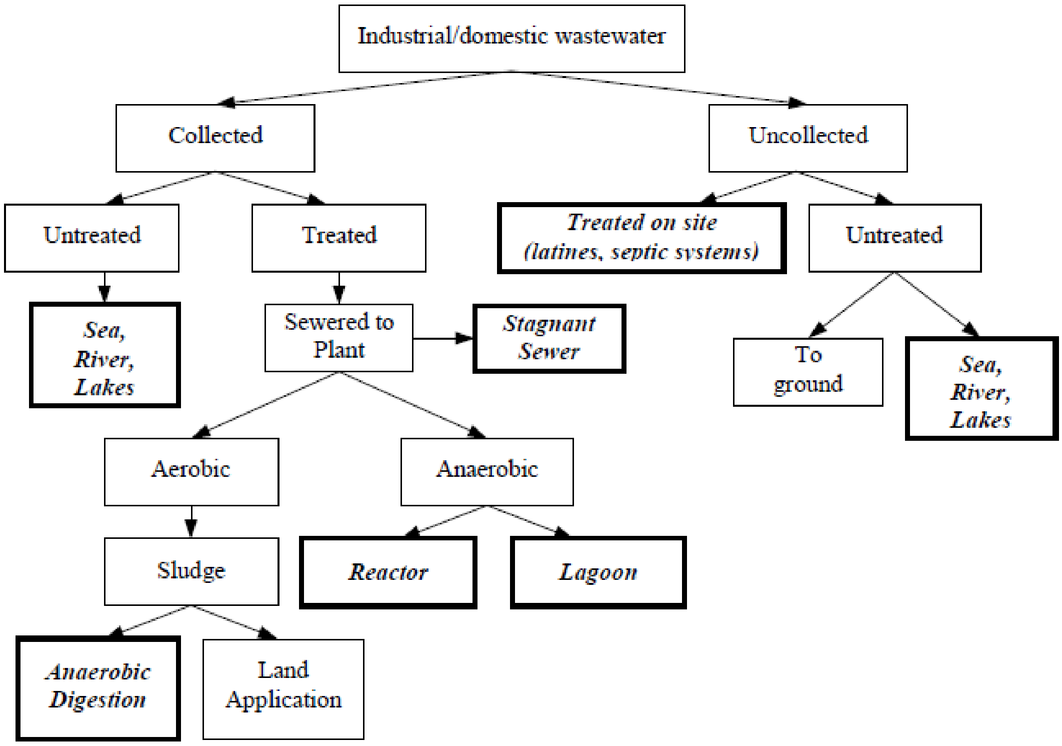
Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 5.6–5.7.

4.3. DOMESTIC WASTEWATER HANDLING

Handling of domestic and industrial wastewater under anaerobic conditions produces CH_4. The methodological issues concerning CH_4 emissions from domestic and industrial wastewater handling systems are considered separately, because the types of activity data and emission factors needed for each sub-source category are different.

The GPG 2000 elaborates the wastewater pathways, presented in figure 2. The waste water pathways offer guidance for the disaggregation of wastewater categories to improve the completeness of the wastewater inventory.

Figure 2
Wastewater flows, treatment systems and potential methane emissions

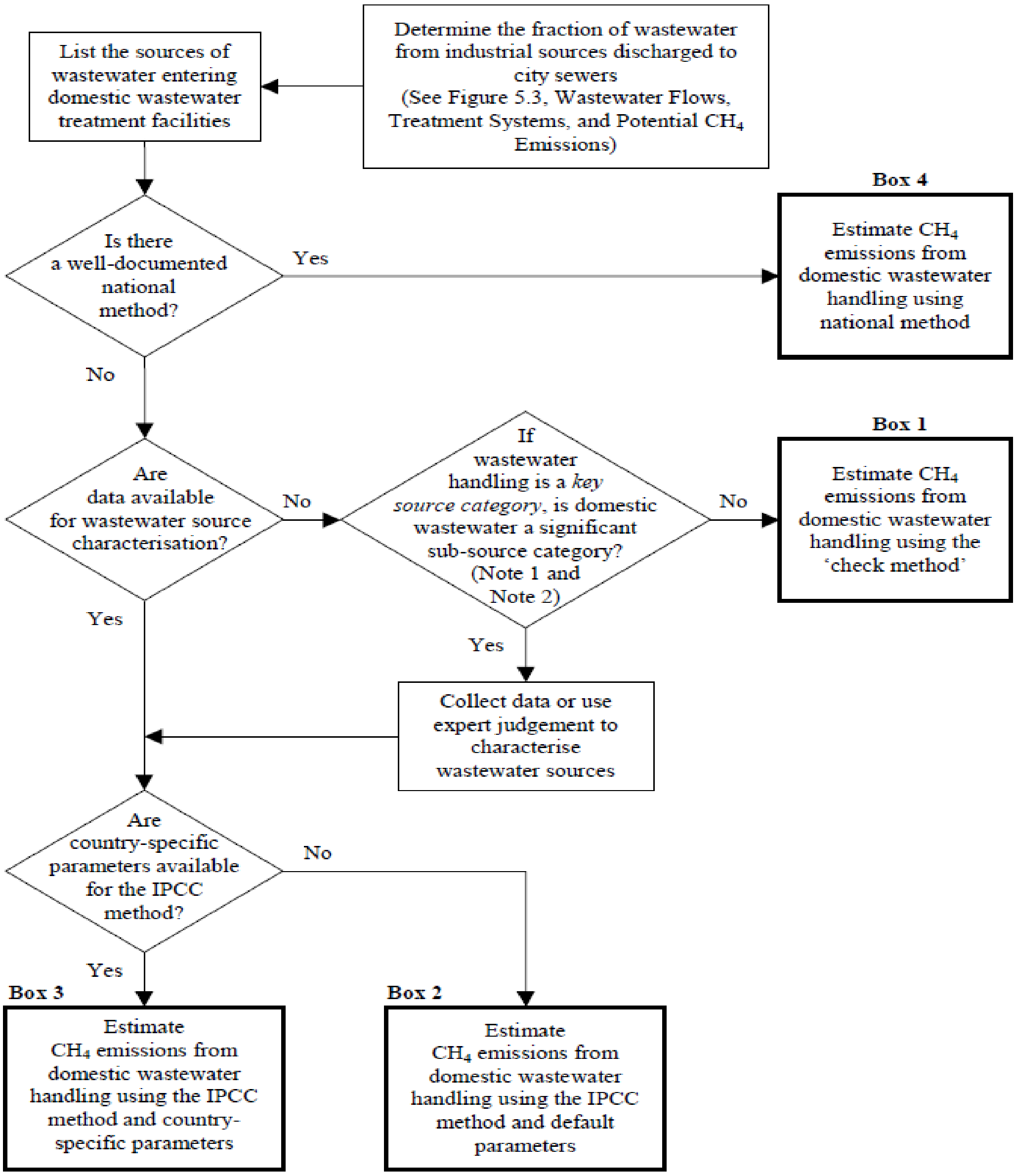


Note: Italic text in a bold frame box indicates areas with the potential for CH_4 emissions.

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 5.17.

4.3.1. DECISION TREE FOR METHANE EMISSIONS FROM DOMESTIC WASTEWATER HANDLING

Figure 3
Decision Tree for CH_4 Emissions from Domestic Wastewater Handling



Note 1: A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

Note 2: As a rule of thumb, a sub-source category would be significant if it accounts for 25-30% of emissions from the source category.

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 5.15.

4.3.2. TIER 1 METHOD

CH_4 emissions from domestic wastewater handling are a function of the amount of waste generated, and of an emission factor that characterizes the extent to which this waste generates CH_4. Any CH_4 that is recovered and flared, or used for energy, should be subtracted from the total emissions.

Box 3
Methane emissions from wastewater handling

EQUATION 5.5

$$\text{Emissions} = (\text{Total Organic Waste} \bullet \text{Emission Factor}) - \text{Methane Recovery}$$

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 5.14.

4.3.2.1. Choice of emission factors

The emission factor for each waste type is a function of the maximum methane producing potential of each waste type (B_O), and the weighted average of the methane conversion factors (MCFs) for the different wastewater treatment systems used in the country, as shown in the equation in Box 4. The MCF indicates the extent to which the methane producing potential (B_O) is realized in each type of treatment method.

Box 4
Emission factor for wastewater handling

EQUATION 5.7

$$\text{Emission Factor} = B_o \bullet \text{Weighted Average of MCFs}$$

Where:

B_o = Maximum methane producing capacity (kg CH_4/kg BOD or kg CH_4/kg COD)

MCF = Methane conversion factor (fraction)

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 5.16.

4.3.2.2. Maximum methane producing capacity

Good practice is to use country-specific data for B_O, expressed in terms of kilograms of CH_4 per kilogram of biological oxygen demand (BOD) removed (kg CH_4/kg BOD) to be consistent with the activity data. Note that degradable carbon in organic waste can be measured in terms of either BOD or chemical oxygen demand (COD). For typical domestic raw sewage, COD (mg/l) is 2 to 2.5 times higher than BOD (mg/l). Therefore, it is important to use emission factors that are consistent with the measure of degradable carbon being used. The Revised 1996 IPCC Guidelines provide only one default value of B_O that has to be applied to both COD and BOD. This is not consistent with the observed differences between BOD and COD levels in raw sewage. Given the differences in the amount of BOD and COD in wastewater this can result in estimates of different emissions levels from the same amount of wastewater depending on which measure is used. To ensure that the resulting emission estimate from a given amount of wastewater is the same regardless of the measure of organic carbon that is used, the COD-based value of B_O should be converted into a BOD-based value via up-scaling with a default factor of 2.5. Thus, it is good practice to use a default value of 0.25 kg CH_4/kg COD or a default value of 0.6 kg CH_4/kg BOD.

4.3.2.3. Weighted average of methane conversion factors

The MCF is an estimate of the fraction of BOD or COD that will ultimately degrade anaerobically. The first step in determining the weighted MCF is to characterize the wastewater treatment systems in the country by producing a list of CH_4 emission sources.

Box 5
Weighted methane conversion factors (default)

EQUATION 5.8

$$\text{Weighted MCF}_i = \sum_x (WS_{ix} \bullet MCF_x)$$

Where:

WS_{ix} = Fraction of wastewater type i treated using wastewater handling system x

MCF_x = Methane conversion factors of each wastewater handling system x

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 5.18.

If no national data are available, then the equation in Box 5 can be modified as follows to incorporate the expert judgment of sanitation engineers and other experts (equation in Box 6).

Box 6
Weighted methane conversion factors (country specific)

EQUATION 5.9

$$\text{Weighted MCF} = \text{Fraction of BOD that will ultimately degrade anaerobically}$$

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 5.18.

4.3.2.4. Choice of activity data

The activity data for this source category is the amount of organic waste in a country. Total organic waste (TOW) is a function of human population and waste generation per person, and is expressed in terms of biochemical oxygen demand (kg BOD/year):

Box 7
Total organic waste

EQUATION 5.10

$$TOW = P \bullet D_{dom}$$

Where:

TOW = Total organic waste (kg BOD/yr)

P = Human population (1000 persons)

D_{dom} = Degradable organic component (kg BOD/1000 persons/yr)

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 5.18.

As mentioned previously, the degradable carbon in organic waste can be measured either as BOD or COD, and the COD-based value should be converted into a BOD-based value by multiplying by a default factor of 2.5. The Revised 1996 IPCC Guidelines provide default values for BOD for different regions in the world.[2]

4.3.3. HIGHER TIER METHODS

Higher tier methodologies are not described in the Revised 1996 IPCC Guidelines or GPG 2000. Measurement data may be considered a higher tier method.

4.4. INDUSTRIAL WASTEWATER HANDLING

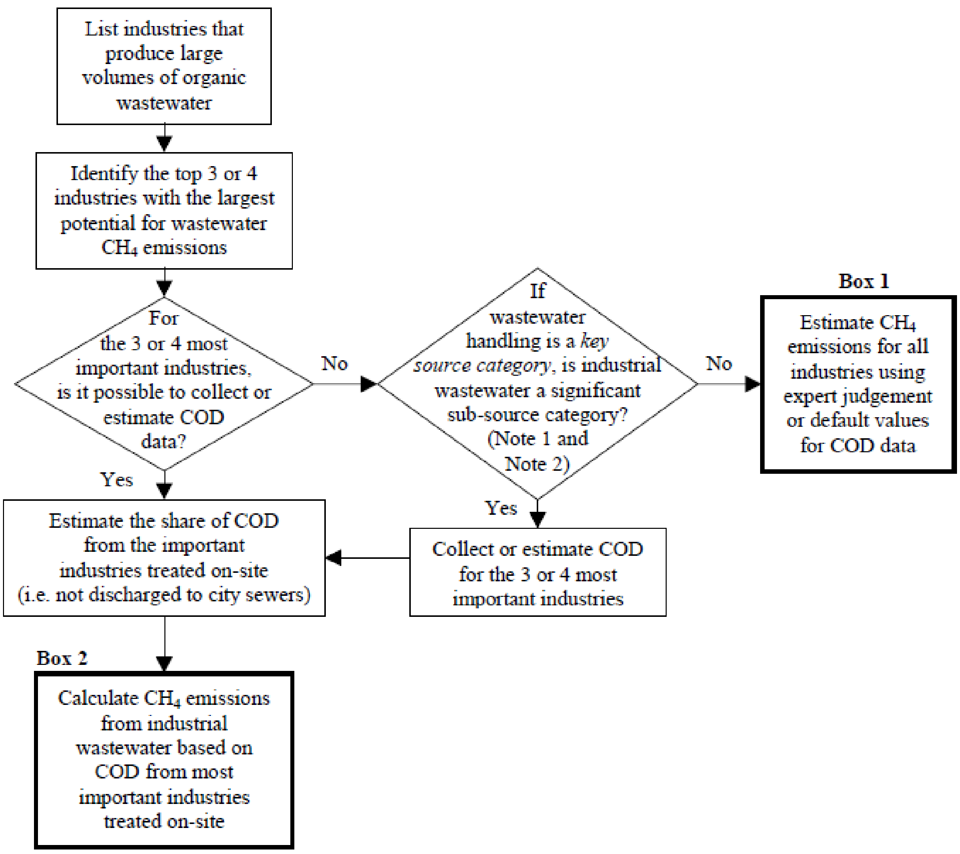
Industrial wastewater may be treated on site or released into the domestic sewer systems. If it is released into the domestic sewer system, the emissions should be covered there. Therefore, this discussion deals with estimating CH_4 emissions from on-site industrial wastewater treatment.

The method for calculating emissions from industrial wastewater is similar to that for domestic wastewater. The development of emission factors and activity data is more complex, because there are many types of wastewater and many different industries to track.

[2] Revised 1996 IPCC Guidelines, Reference Manual, table 6-5.

4.4.1. DECISION TREE FOR METHANE EMISSIONS FROM INDUSTRIAL WASTE WATER HANDLING

Figure 4
Decision tree for methane emissions from industrial wastewater handling



Note 1: A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

Note 2: As a rule of thumb, a sub-source category would be significant if it accounts for 25-30% of emissions from the source category.

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 5.20.

4.4.2. TIER 1 METHOD

The total CH_4 emissions from industrial wastewater is calculated as a sum of emissions from wastewater and sludge, assuming that there is no methane recovery. If there is methane recovery, and thus CH_4 is not emitted into the atmosphere, the amount of CH_4 recovered should be subtracted from the total. If no data is readily available, the default assumption is that this amount is zero. The total CH_4 emissions from wastewater and sludge are estimated from the equations in Boxes 8 and 9.

Box 8

Methane emissions from industrial wastewater

EQUATION 12

$$WM = \Sigma_i (TOW_i \times EF_i - MR_i)$$

where:

WM	=	total methane emissions from wastewater in kg CH_4
TOW_i	=	total organic waste for wastewater type i in kg DC/yr. For domestic streams, the DC is BOD; for industrial streams it is the COD (Step 1)
EF_i	=	emission factor for wastewater type i in kg CH_4/kg DC (Step 2)
MR_i	=	total amount of methane recovered or flared from wastewater type i in kg CH_4. If no data are available, use the default value of zero

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 6.22.

Box 9

Methane emissions from sludge

EQUATION 13

$$SM = \Sigma_j (TOS_j \times EF_j - MR_j)$$

where:

SM	=	total methane emissions from sludge in kg CH_4
TOS_j	=	total organic waste for sludge type j in kg DC/yr. For domestic streams, the DC is BOD; for industrial streams it is COD (Step 1)
EF_j	=	emission factor for sludge type j in kg CH_4/kg DC (Step 2)
MR_j	=	total amount of methane recovered or flared from sludge type j in kg CH_4. If no data are available, the default is zero

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 6.22.

The emission factors for wastewater and sludge from a particular industry are estimated from the equation in Box 10.

Box 10
Emission factor for wastewater

EQUATION 10

$$EF_i = B_{oi} \times \sum (WS_{ix} \times MCF_x)$$

where:

EF_i = emission factor (kg CH_4 /kg DC) for wastewater type (e.g., fertiliser industry, domestic, etc.)

B_{oi} = maximum methane producing capacity (kg CH_4/kg DC) for wastewater type i

WS_{ix} = fraction of wastewater type i treated using wastewater handling system x

MCF_x = methane conversion factors of each wastewater system x

Equation 11 presents the emission factor calculation for sludge:

EQUATION 11

$$EF_j = B_{oj} \times \sum (SS_{jy} \times MCF_y)$$

where:

EF_j = emission factor (kg CH_4 /kg DC) for sludge type j (e.g., fertiliser industry wastewater, domestic wastewater, etc.)

B_{oj} = maximum methane producing capacity (kg CH_4/kg DC) for sludge type j

SS_{jy} = fraction of sludge type j treated using sludge handling system y

MCF_y = methane conversion factors of each sludge handling system y (See footnote 4)

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 6.21.

The AD, or total organic wastewater (TO_{Wind}) and total organic sludge (TO_{Sind}) from a particular industry are calculated from the equations in Boxes 11 and 12.

Box 11
Total organic wastewater

EQUATION 8

$$TOW_{ind} \text{ (kg COD/yr)} = W \times O \times D_{ind} \times (1 - DS_{ind})$$

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 6.19.

Box 12
Total organic sludge

EQUATION 9

$$TOS_{ind} \text{ (kg COD/yr)} = W \times O \times D_{ind} \times DS_{ind}$$

where:

TOW_{ind}	=	total industrial organic wastewater in kg COD/yr
TOS_{ind}	=	total industrial organic sludge in kg COD/yr
W	=	wastewater consumed in m^3/tonne of product
O	=	total output by selected industry in tonnes/yr
D_{ind}	=	industrial degradable organic component in kg COD/m^3 wastewater
DS_{ind}	=	fraction of industrial degradable organic component removed as sludge

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 6.20.

4.4.3. HIGHER TIER METHODS

Higher tier methodologies are not described in the Revised 1996 IPCC Guidelines or GPG 2000. Measurement data may be considered a higher tier method.

4.5. NITROUS OXIDE EMISSIONS FROM HUMAN SEWAGE

Nitrous oxide 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. It is good practice to estimate N_2O from domestic wastewater effluent.

4.5.1. DECISION TREE FOR NITROUS OXIDE EMISSIONS FROM HUMAN SEWAGE

No decision tree is provided in the GPG 2000 for this category.

4.5.2. TIER 1 METHOD

Box 13
Nitrous oxide emissions from human sewage

EQUATION 15

$$N_2O_{(S)} = Protein \times Frac_{NPR} \times NR_{PEOPLE} \times EF_6$$

where:

$N_2O_{(s)}$	=	N_2O emissions from human sewage (kg N_2O-N/yr)
Protein	=	annual per capita protein intake (kg/person/yr)
NR_{PEOPLE}	=	number of people in country
EF_6	=	emissions factor (default 0.01 (0.002-0.12) kg N_2O-N/kg sewage-N produced) (See Table 4-18 in Agriculture Chapter)
$Frac_{NPR}$	=	fraction of nitrogen in protein (default = 0.16 kg N/kg protein) (See Table 4-19 in Agriculture Chapter)

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 6.28.

4.5.3. HIGHER TIER METHODS

Higher tier methodologies are neither described in the Revised 1996 IPCC Guidelines nor in the GPG 2000.

4.6. WASTE INCINERATION

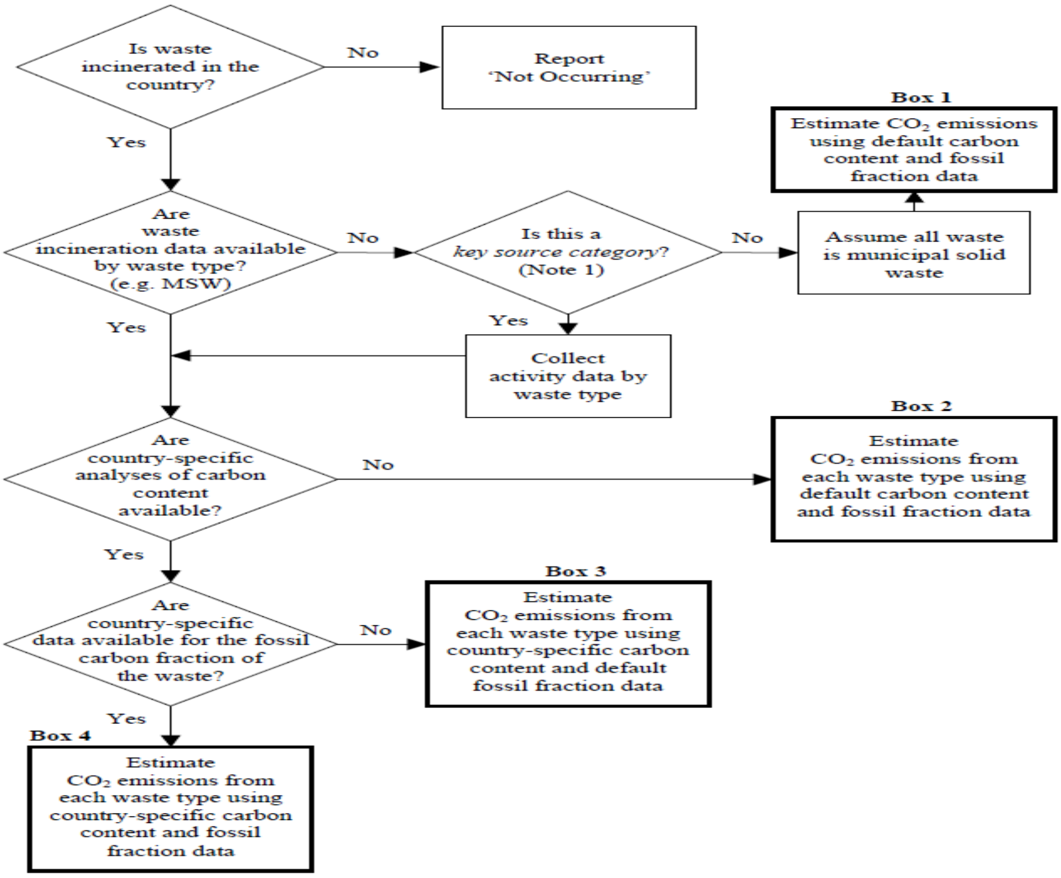
Incineration of waste produces emissions of CO_2, CH_4 and N_2O.Waste incineration is more frequent in developed countries, although it is common for both developed and developing countries to incinerate clinical waste.

The methodology describes incineration with and without energy recovery. Emissions from waste incineration without energy recovery have to be reported in the waste sector, while emissions from incineration with energy recovery should be reported in the energy sector.

Only CO_2 emissions resulting from the incineration of carbon in waste of fossil origin (e.g. plastics, certain textiles, rubber, liquid solvents, and waste oil) should be included in emission estimates. The carbon fraction that is derived from biomass materials (e.g. paper, food waste and wooden material) is not included.

4.6.1. DECISION TREES FOR EMISSIONS FROM WASTE INCINERATION

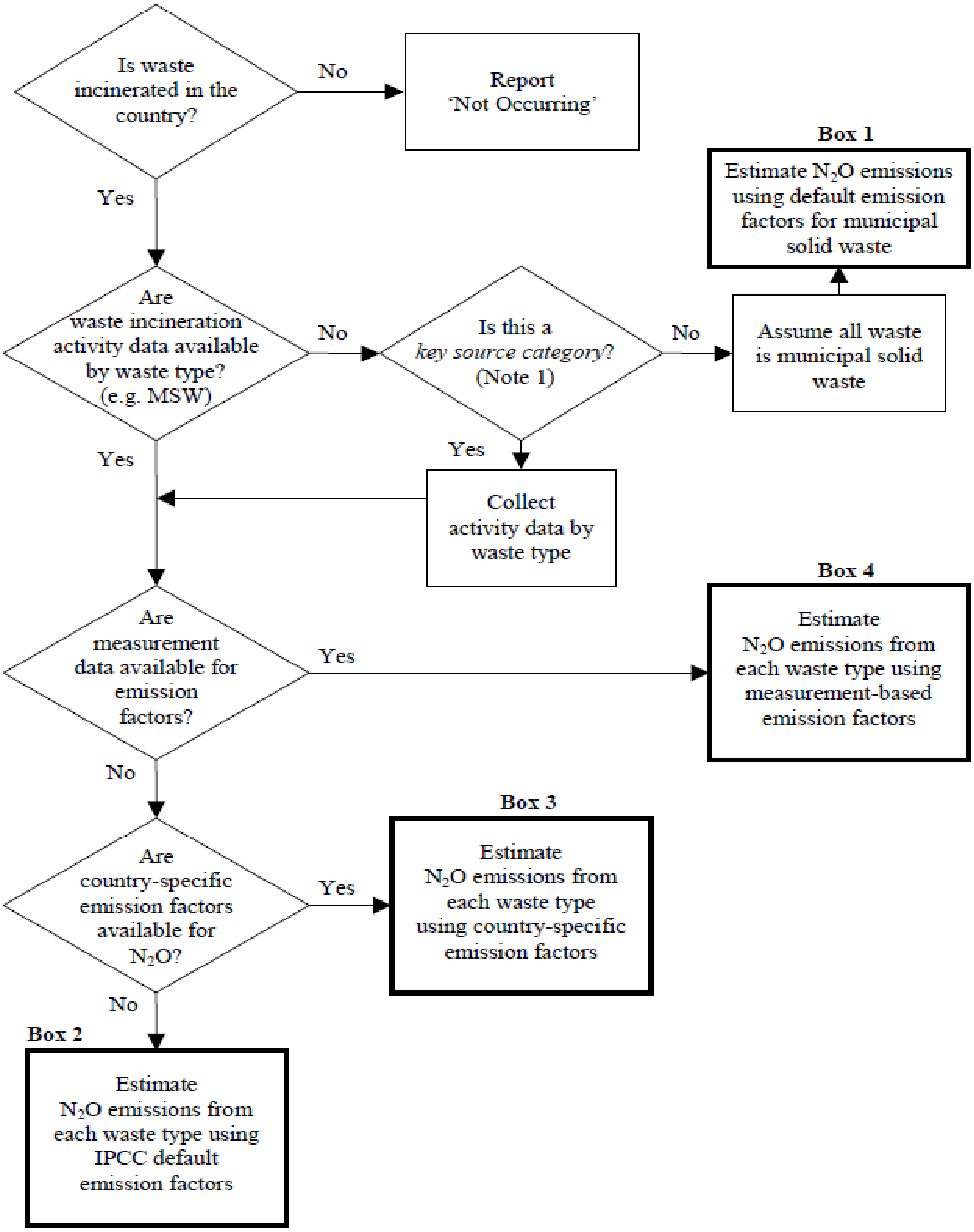
Figure 5
Decision Tree for CO_2 Emissions from Waste Incineration



Note 1: A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 5.26.

Figure 6
Decision tree for nitrous oxide emissions from waste incineration



Note 1: A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 5.27.

The GPG 2000 describes one method for estimating CO_2 emissions from waste incineration. The key activity data are the waste inputs into the incinerator, and the emission factor is based on the carbon content of each of the types of waste that is of fossil origin only. The most accurate CO_2 emission estimates result from disaggregating the activity data into different waste types (e.g. municipal solid waste, sewage sludge, clinical waste and hazardous waste).

4.6.2. TIER 1 METHOD

The methods for estimating CO_2 and N_2O from waste incineration differ because of the different factors that influence emission levels. For this reason, they are discussed separately below.

4.6.2.1. Carbon dioxide emissions

Box 14
Carbon dioxide emissions from waste incineration

EQUATION 5.11

$$CO_2 \text{ emissions (Gg/yr)} = \sum_i (IW_i \bullet CCW_i \bullet FCF_i \bullet EF_i \bullet 44 / 12)$$

Where:

i = MSW: municipal solid waste
HW: hazardous waste
CW: clinical waste
SS: sewage sludge

IW_i = Amount of incinerated waste of type i (Gg/yr)

CCW_i = Fraction of carbon content in waste of type i

FCF_i = Fraction of fossil carbon in waste of type i

EF_i = Burn out efficiency of combustion of incinerators for waste of type i (fraction)

44 / 12 = Conversion from C to CO_2

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 5.25.

4.6.2.2. Nitrous oxide emissions

Box 15
Nitrous oxide emissions from waste incineration

EQUATION 5.12

$$N_2O \text{ emissions (Gg/yr)} = \sum_i (IW_i \bullet EF_i) \bullet 10^{-6}$$

Where:

IW_i = Amount of incinerated waste of type i (Gg/yr)

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

Or

EQUATION 5.13

$$N_2O \text{ emissions (Gg/yr)} = \sum_i (IW_i \bullet EC_i \bullet FGV_i) \bullet 10^{-9}$$

Where:

IW_i = Amount of incinerated waste of type i (Gg/yr)

EC_i = N_2O emission concentration in flue gas from waste of type i (mg N_2O/m^3)

FGV_i = Flue gas volume by amount of incinerated waste of type i (m^3/Mg)

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 5.28.

4.6.3. HIGHER TIER METHODS

Higher tier methods are described neither in the Revised 1996 IPCC Guidelines nor in the GPG 2000. Measurement data may be considered a higher tier method.

5. SECTOR SPECIFIC ISSUES (ALLOCATION ISSUES)

It should be noted that double counting CO_2 emissions is possible, because waste is often incinerated in facilities with energy recovery capabilities. Also, waste can be used as a 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, the emissions from such processes should be reported under 'other fuels' in the energy sector, not within the waste disposal source category. 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 the energy sector (fossil CO_2, N_2O and CH_4 from stationary combustion), and biogenic CO_2 as an information item.

The amount of organic matter removed from wastewater treatment as sludge, for disposal into SWDS, composting, incineration or use in agriculture, should be consistent with the total amount reported in the applications. If sludge separation is practiced 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. Some waste from the agriculture or food industries may be accounted for under the agriculture sector (e.g. agricultural residue burning). Some industries may have their own landfills or on-site wastewater handling facilities. Emissions from such operations should be recognized and accounted for in a Party's national GHG inventory.