5

WASTE

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5.1 CH_4 EMISSIONS FROM SOLID WASTE DISPOSAL SITES

5.1.1 Methodological issues

Methane (CH_4) is emitted during the anaerobic decomposition of organic waste disposed of in solid waste disposal sites (SWDS). Organic waste decomposes at a diminishing rate and takes many years to decompose completely.

5.1.1.1 CHOICE OF METHOD

The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (*IPCC Guidelines*) outline two methods to estimate CH_4 emissions from solid waste disposal sites, the default method (Tier 1) and the First Order Decay (FOD) method (Tier 2). The main difference between the two methods is that the FOD method produces a time-dependent emission profile that better reflects the true pattern of the degradation process over time, whereas the default method is based on the assumption that all potential CH_4 is released in the year the waste is disposed of. The default method will give a reasonable annual estimate of actual emissions if the amount and composition of deposited waste have been constant or slowly varying over a period of several decades. If the amount or composition of waste disposed of at SWDS is changing more rapidly over time, however, the IPCC default method will not provide an accurate trend. For example, if there is a reduction in the amount of carbon deposited at SWDS, the default method will underestimate emissions and overestimate reductions.

The choice of a *good practice* method will depend on national circumstances. The decision tree in Figure 5.1, Decision Tree for CH_4 Emissions from Solid Waste Disposal Sites, illustrates the process of choosing among methods. It is *good practice* to use the FOD method, if possible, because it more accurately reflects the emissions trend. The use of the FOD method requires data on current, as well as historic waste quantities, composition and disposal practices for several decades. It is *good practice* to estimate this historical data, if such data are unavailable, when this is a *key source category* (see Chapter 7, Methodological Choice and Recalculation) or if there have been significant changes in waste management practices.

The *IPCC Guidelines* do not provide default values or methods for the estimation of some key parameters needed to use the FOD method. These data are very dependent on country-specific conditions, and currently there are not enough data available to give reliable default values or methods for them. Inventory agencies are encouraged to obtain data from country-specific or regional research, because the inability of inventory agencies to use the FOD method where otherwise indicated by *good practice* would reduce comparability between national inventories. Inventory agencies selecting a method other than those described in the *IPCC Guidelines* should justify their selection based on comparable or increased accuracy and completeness of the emissions estimates.

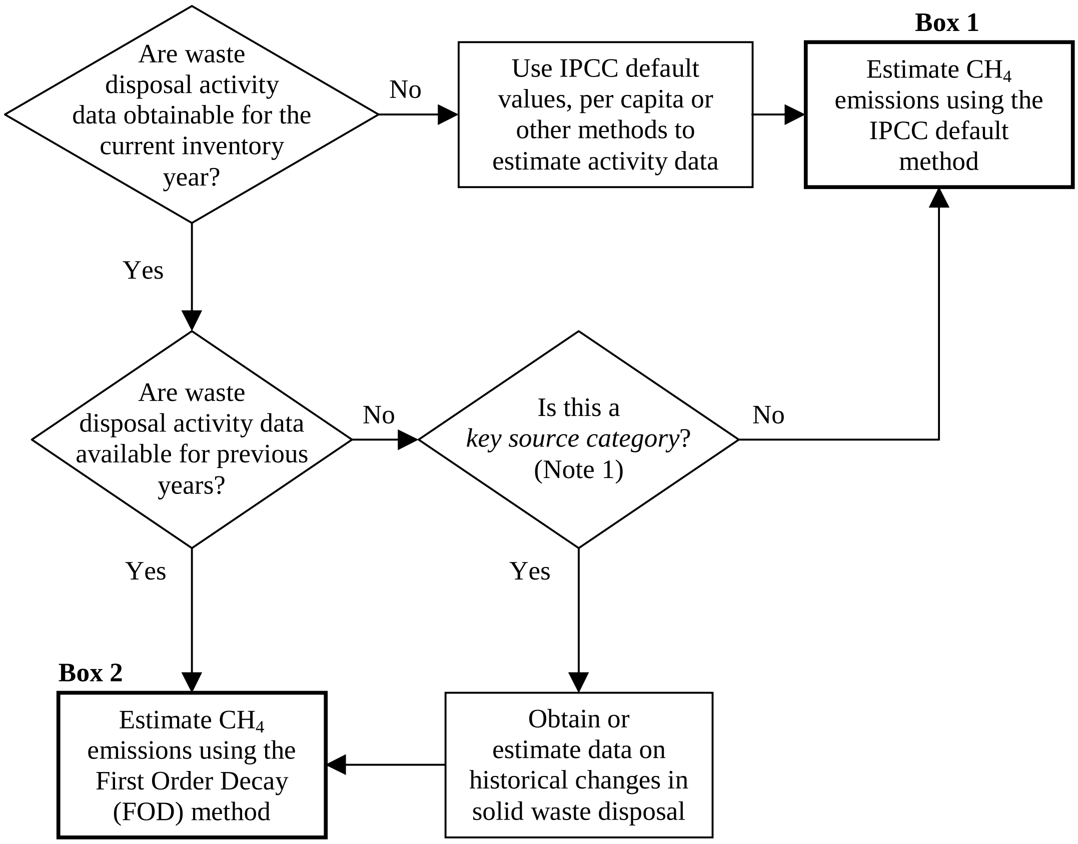
5.1.1.2 CHOICE OF EMISSION FACTORS AND ACTIVITY DATA

The discussion of *good practice* in the choice of activity data and emission factors is combined in this section, due to the unique character of the emission estimation methods.

First Order Decay (FOD) method – Tier 2

The *IPCC Guidelines* (pp 6.10-6.11, Reference Manual) present the FOD method in three equations. The first equation is to be used for an individual landfill, or possibly a group of specific landfills. A second equation, suitable for national and regional estimates, calculates emissions from all solid waste deposited in SWDS in one year. The purpose of the third equation is to estimate current annual emissions from waste disposal in current and previous years.

Figure 5.1 Decision Tree for CH_4 Emissions from Solid Waste Disposal Sites



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.)

The FOD method can be expressed equivalently by Equation 5.1 and Equation 5.2 below. Equation 5.1 is based on the derivative of the general FOD equation (see p 6.10, Reference Manual, *IPCC Guidelines*) with t replaced by t – x, representing a normalisation factor that corrects for the fact that the evaluation for a single year is a discrete time estimate rather than a continuous time estimate.

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 $[MCF(x) \bullet DOC(x) \bullet DOC_F \bullet F \bullet 16/12 \text{ (Gg } CH_4\text{/Gg waste)}]$

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)

Note that CH_4 recovered (R(t)) must be subtracted from the amount generated before applying the oxidation factor, because only landfill gas that is not captured is subject to oxidation in the upper layer of the landfill. In addition, the unit for the methane generation potential should be expressed by weight (Gg CH_4/Gg waste) and not volume (m^3/Mg waste) as currently written in the *IPCC Guidelines* in order to make the outcome of the default and FOD methods consistent.

The methane generation rate constant k that appears in the FOD method is related to the time taken for the DOC in waste to decay to half its initial mass (the 'half life' or $t_{½}$) as follows:

$$k = \ln 2 / t_{½}$$

The FOD method requires historical data on waste generation and management practices. In national inventories, it is usually necessary to include data for 3 to 5 half lives in order to achieve an acceptably accurate result. Changes in waste management practices (e.g. landfill 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 value of k 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. Measurements from SWDS in the United States, the United Kingdom and the Netherlands support values for k in the range 0.03 to 0.2 per year (Oonk and Boom, 1995). 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 = 0.03, or a half life of about 23 years) are associated with dry site conditions and slowly degradable waste such as wood or paper. Inventory agencies are encouraged to establish k values or use their own k values if available and documented. In order to estimate k values, inventory agencies should determine the composition of waste disposed in SWDS over time and study the conditions at the site(s). If no data on types of waste are available, a k value of 0.05 (a half life of about 14 years) is suggested as a default value.

Inventory agencies can estimate historical waste disposal and composition data, assuming it to be proportional to population, or urban population in cases where there has been no organised waste collection or disposal in rural areas. Inventory agencies can use other relationships if better justified, and report the reasons for those choices.

Default method – Tier 1

The default method is based on the following equation:

EQUATION 5.3

$$CH_4 \text{ emissions (Gg/yr)} = [(MSW_T \bullet MSW_F \bullet L_0) - R] \bullet (1 - OX)$$

Where:

MSW_T = Total MSW generated (Gg/yr)

MSW_F = Fraction of MSW disposed at SWDS

L_0 = Methane generation potential [MCF • DOC • DOC_F • F • 16 / 12 (Gg CH_4/Gg waste)]

MCF = Methane correction factor (fraction)

DOC = Degradable organic carbon [fraction (Gg C/Gg MSW)]

DOC_F = Fraction DOC dissimilated

F = Fraction by volume of CH_4 in landfill gas

R = Recovered CH_4 (Gg/yr)

OX = Oxidation factor (fraction)

Note that all of the model parameters can change over time, depending upon waste disposal trends and waste management practices. *Good practice* is described below for each of the above model parameters.

Total municipal solid waste (MSW_T), and the fraction of MSW sent to SWDS (MSW_F)

The use of the term municipal solid waste (MSW) may not accurately describe the types of waste disposed of in SWDS. Inventory agencies should estimate the emissions from all types of solid waste material, including industrial waste, sludge, construction and demolition waste and municipal waste, disposed of at SWDS. Data on industrial waste may be difficult to obtain in many countries, but efforts to do so should be made. (Examples of industrial waste that can produce CH_4 when disposed of include agro-food industrial waste,[1] pulp and paper waste and sludge, and waste from wood processing.) In many countries, national estimates of total waste disposal may be available. National data are preferable, provided that inventory agencies document the data collection method including the number of sites surveyed and the type of survey undertaken. If national data are not available, inventory agencies can estimate data using default assumptions provided in Table 6-1, Reference Manual of the *IPCC Guidelines*. This table provides default MSW generation and disposal rates for many regions and countries. If no default values exist, inventory agencies can use expert judgement to estimate these parameters using the values for countries with similar conditions. (Elements of comparability that inventory agencies can consider are geography, population density, national income, and type and volume of industry.)

Methane correction factor (MCF)[2]

The methane correction factor (MCF) accounts for the fact that unmanaged SWDS produce less CH_4 from a given amount of waste than managed SWDS, because a larger fraction of waste decomposes aerobically in the top layers of unmanaged 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. The term methane correction factor (MCF) in this context should not be confused with the methane conversion factor (MCF) referred to in the *IPCC Guidelines* for wastewater and livestock manure management emissions.

The *IPCC Guidelines* present default values for MCF, which are presented in Table 5.1 below.

[1] Avoid double counting with the Agriculture Sector.

[2] Unmanaged SWDS cause serious local environmental and health problems, such as fire and explosion accidents, pollution of surrounding air and waters, and outbreaks of pests and infections. However, the *IPCC Guidelines* and this report on *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (*Good Practice Report*) are intended to address greenhouse gas aspects only.

TABLE 5.1 **SWDS CLASSIFICATION AND METHANE CORRECTION FACTORS**	
Type of Site	**Methane Correction Factor (MCF) Default Values**
Managed [a]	1.0
Unmanaged – deep (≥5 m waste)	0.8
Unmanaged – shallow (<5 m waste)	0.4
Uncategorised SWDS [b]	0.6

[a] Managed SWDS 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 some of the following: cover material, mechanical compacting or levelling of waste.
[b] The default value of 0.6 for uncategorised SWDS may be inappropriate for developing countries with a high percentage of unmanaged shallow sites, as it will probably lead to overestimation of emissions. Therefore, inventory agencies in developing countries are encouraged to use 0.4 as their MCF, unless they have documented data that indicates managed landfill practices in their country.

Source: Reference Manual of the *IPCC Guidelines.*

Degradable organic carbon (DOC)

Degradable organic carbon is the organic carbon that is accessible to biochemical decomposition, and should be expressed as Gg C per Gg waste. It 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. The following equation, as presented in the *IPCC Guidelines*, estimates DOC using default carbon content values:

EQUATION 5.4

$$DOC = (0.4 \bullet A) + (0.17 \bullet B) + (0.15 \bullet C) + (0.3 \bullet D)$$

Where:

A = Fraction of MSW that is paper and textiles

B = Fraction of MSW that is garden waste, park waste or other non-food organic putrescibles

C = Fraction of MSW that is food waste

D = Fraction of MSW that is wood or straw

The default carbon content values for these fractions can be found in the *IPCC Guidelines* (Table 6-3, Reference Manual).[3] The use of national values is encouraged if data are available. National values can be obtained by performing waste generation studies and sampling of different SWDS within a country. If national values are used, survey data and sampling results should be reported. In addition, it is important that inventory agencies exclude lignin from their DOC calculations if the default value (0.77) for DOC_F is used, as discussed below.

Fraction of degradable organic carbon dissimilated (DOC_F)

DOC_F is an estimate of the fraction of carbon that is ultimately degraded and released from SWDS, and reflects the fact that some organic carbon does not degrade, or degrades very slowly, when deposited in SWDS. The *IPCC Guidelines* provide a default value of 0.77 for DOC_F. Based on a review of 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. For example, experimental values in the order of 0.5-0.6 (including lignin C) have been used in the Netherlands (Oonk and Boom, 1995) and demonstrated to give reliable estimates of landfill gas generated and recovered in the Netherlands. It is also *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.

[3] From Bingemer and Crutzen (1987).

Fraction of CH_4 in landfill gas (F)

Landfill gas consists mainly of CH_4 and carbon dioxide (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)

Methane recovery is the amount of CH_4 generated at SWDS that is recovered and burned in a flare or energy recovery device. CH_4 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[4]. Reporting based on metering of all gas recovered for energy utilisation 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)

The oxidation factor (OX) reflects the amount of CH_4 from SWDS that is oxidised 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% of CH_4 is oxidised. 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.

The default oxidation factor in the *IPCC Guidelines* is zero. Results from field and laboratory give a wide range, but values higher than 0.1 are probably too high for national inventories. Field and laboratory CH_4 and CO_2 emissions concentrations and fluxes measurements should not be used directly. In general, these field and laboratory experiments determine CH_4 oxidation from uniform and homogeneous soil layers. In reality, only a fraction of the CH_4 generated will diffuse through such a homogeneous layer. Another fraction will escape through cracks or via lateral diffusion without being oxidised. Therefore, results from field and laboratory studies may lead to overestimations of oxidation in landfill cover soils.

Currently, most industrialised countries with well-managed SWDS use 0.1 for OX, which is a reasonable assumption based on available information. In developing countries with less elaborate management practices, the average value is probably closer to zero. The use of the oxidation value of 0.1 is justified for well-managed landfills, in other cases the use of an oxidation value different than zero should be clearly documented and referenced.

It is important to remember that any CH_4 that is recovered must be subtracted from the amount generated before applying an oxidation factor.

5.1.1.3 COMPLETENESS

Inventory agencies should make efforts to include emissions from non-MSW SWDS. These include industrial waste sites and sludge disposal sites as well as construction and demolition waste sites. As with MSW, the DOC must be assessed to evaluate the potential significance of the sub-source category. Industrial waste generation or disposal data may be hard to obtain, because they may be confidential or not reported. Usually, the non-MSW SWDS are less significant contributors to national CH_4 emissions than MSW SWDS.

Closed SWDS should not be a completeness issue, because both the FOD and the default methods use yearly waste disposal. Therefore, the waste that is present in a closed landfill should also have been accounted for.

5.1.1.4 DEVELOPING A CONSISTENT TIME SERIES

Given the differences in approach and expected results between the FOD and default methods, a time series should be developed using the same method (i.e. methods should not be mixed). Thus, if an inventory agency decides to move from the default to the FOD method, they need to recalculate the base year and the entire time series with the new approach. In this situation, inventory agencies will need to derive a time series of historical waste disposal data to support the FOD approach. The method of this derivation and number of years affected must be clearly described. To ensure consistency over time, it is *good practice* to recalculate emissions estimates using past and current methods to ensure that any trends in emissions are real and not caused by changes in the

[4] CO_2 emissions from landfill gas recovery combustion are of biogenic origin and should not be included in national totals.

estimation methodologies. These recalculations should be carried out according to the guidance in Chapter 7, Methodological Choice and Recalculation, Section 7.3.2.2, Alternative Recalculation Techniques.

Given the significance of this source category in many national inventories, and the limitations of the default method, inventory agencies should collect and maintain as much historical data as possible to enable future recalculations with more accurate methods. Inventory agencies should also take into account the time dependence of several parameters related to waste composition and landfill design.

5.1.1.5 UNCERTAINTY ASSESSMENT

Uncertainty estimates for MSW_T and MSW_F and the default model parameters are given in Table 5.2. The estimates are based on expert judgement. If an inventory agency uses national values for these factors, it should evaluate the uncertainty of these values consistent with the guidance provided in Chapter 6, Quantifying Uncertainties in Practice.

Some uncertainty information is available on the methane generation potential (L_0), which equals MCF • DOC • DOC_F • F • 16 / 12, and appears as a factor in the equations for both the default and the FOD methods. In the Netherlands, where high quality data are available, the uncertainty for CH_4 generation per tonne of waste is estimated to be approximately ±15% (Oonk and Boom, 1995). In countries with similar quality data, uncertainties in quantities of CH_4 generation per tonne of waste are expected to be of the same order. For countries with poor quality data on CH_4 generation per tonne of waste, the associated uncertainties could be of the order of ±50%. The basis for the uncertainty assessment should be well documented.

The data in Table 5.2, Estimates of Uncertainties Associated with the Default Parameters in the IPCC Default and FOD Methods for CH_4 emissions from SWDS, show that the overall uncertainty associated with estimating CH_4 emissions from SWDS is likely to be high, perhaps a factor of two, even when national data are well characterised. National data should be used where possible. Chapter 6, Quantifying Uncertainties in Practice, 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.

TABLE 5.2 ESTIMATES OF UNCERTAINTIES ASSOCIATED WITH THE DEFAULT PARAMETERS IN THE IPCC DEFAULT AND FOD METHODS FOR CH_4 EMISSIONS FROM SWDS [a]	
Parameter	**Uncertainty Range** [b]
Total Municipal Solid Waste (MSW_T) and Fraction of MSW sent to SWDS (MSW_F)	Country-specific: >±10% (<–10%, >+10%. The absolute value of the uncertainty range is greater than 10%.) for countries with high quality data (e.g. weighing at all SWDS) For countries with poor quality data: more than a factor of two.
Degradable Organic Carbon (DOC) = 0.21 (maximal default value in the *IPCC Guidelines*)	–50%, +20%
Fraction of Degradable Organic Carbon Dissimilated (DOC_F) = 0.77	–30%, +0%
Methane Correction Factor (MCF) = 1 = 0.4 = 0.6	 –10%, +0% –30%, +30% –50%, +60%
Fraction of CH_4 in Landfill Gas (F) = 0.5	–0%, +20%
Methane Recovery (R)	The uncertainty range will depend on how the amounts of CH_4 recovered and flared or utilised are estimated, but the uncertainty is likely to be relatively small compared to other uncertainties if metering is 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, as specified in Section 5.1.1.2, Choice of Emission Factors and Activity Data.
Methane Generation Rate Constant (k) = 0.05	–40%, +300%

[a] The estimates are valid only for the default values given in the *IPCC Guidelines* or in the table, and are based on expert judgement.
[b] If the evaluation of additional data on the parameters provides data for the revision of the default values, the uncertainty range should also be changed. When country-specific values are used, they should be accompanied with appropriate uncertainty values.

Source*:* Judgement by Expert Group (see Co-chairs, Editors and Experts; CH_4 Emissions from Solid Waste Disposal).

5.1.2 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 8, Quality Assurance and Quality Control, Section 8.10.1, Internal Documentation and Archiving. Some examples of specific documentation and reporting relevant to this source category are provided below.

- If the FOD method is used, historical data and k values used should be documented.
- The distribution of waste to managed and unmanaged sites for the purpose of MCF should also be documented with supporting information.
- If methane 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.

5.1.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to conduct quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and an expert review of the emissions estimates. Additional quality control checks as outlined in the Tier 2 procedures in Chapter 8 as well as quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. Inventory agencies are encouraged to use higher tier QA/QC for *key source categories* as identified in Chapter 7, Methodological Choice and Recalculation.

Furthermore, transparency can be improved by the provision of clear documentation and explanations of work undertaken in the following areas:

Estimate of the emissions using different approaches

- If the emissions are estimated with the FOD method, inventory agencies should also estimate them with the IPCC default method. The results can be useful for cross-comparison with other countries. Inventory agencies should record the results of such comparisons for internal documentation, and investigate any discrepancies.

Review of emission factors

- Inventory agencies should cross-check country-specific values for estimation with the available IPCC values. The intent of this comparison is to see whether the national parameters used are considered reasonable relative to the IPCC default values, given similarities or differences between the national source category and the emission sources represented by the default.

Review of activity data

- Inventory agencies should compare country-specific data to IPCC default values for the following activity level parameters: MSW_T, MSW_F, and DOC. They should determine whether the national parameters are reasonable and ensure that errors in calculations have not occurred. If the values are very different, inventory agencies should characterise municipal solid waste separately from industrial solid waste.
- 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 they were collected and aggregated correctly. Inventory agencies 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.

Involvement of industry and government experts in review

- Inventory agencies should provide the opportunity for experts to review input parameters. For example, individuals with expertise in the country's solid waste management practices should review the characteristics of the solid waste stream and its disposal. Other experts should review the methane correction factors.

Verification of emissions

- Inventory agencies should compare national emission rates with those of similar countries that have comparable demographic and economic attributes. This comparison should be made with countries whose inventory agencies use the same landfill CH_4 estimation method. Inventory agencies should study significant discrepancies to determine if they represent errors in the calculation or actual differences.

5.2 EMISSIONS FROM WASTEWATER HANDLING

Handling of domestic and industrial wastewater under anaerobic conditions produces CH_4.[5] The methodological issues concerning CH_4 emissions from domestic and industrial wastewater handling systems are considered separately in this discussion because the types of activity data and emission factors needed for each sub-source category are different. Both wastewater systems are discussed in Section 5.2.2, Reporting and Documentation, and Section 5.2.3, Inventory Quality Assurance/Quality Control (QA/QC).

5.2.1 Methodological issues

5.2.1.1 DOMESTIC WASTEWATER

In developed countries, most domestic wastewater is handled in aerobic treatment facilities and lagoons. In developing countries, a small share of domestic wastewater is collected in sewer systems, with the remainder ending up in pits or latrines.

Some industrial wastewater may be discharged into municipal sewer lines where it combines with domestic wastewater.

CHOICE OF METHOD

The *IPCC Guidelines* describe a single method for calculating CH_4 emissions from domestic wastewater handling. Emissions are a function of the amount of waste generated and an emission factor that characterises 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 total emissions. The simplified general equation is as follows:

EQUATION 5.5

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

Depending on the available activity data and emission factors, this method can be applied at various levels of disaggregation. The decision tree in Figure 5.2, Decision Tree for CH_4 Emissions from Domestic Wastewater Handling, describes how to determine the appropriate level of disaggregation in applying the IPCC method. Regardless of the level of disaggregation, the steps in *good practice* in inventory preparation for CH_4 from wastewater are as follows:

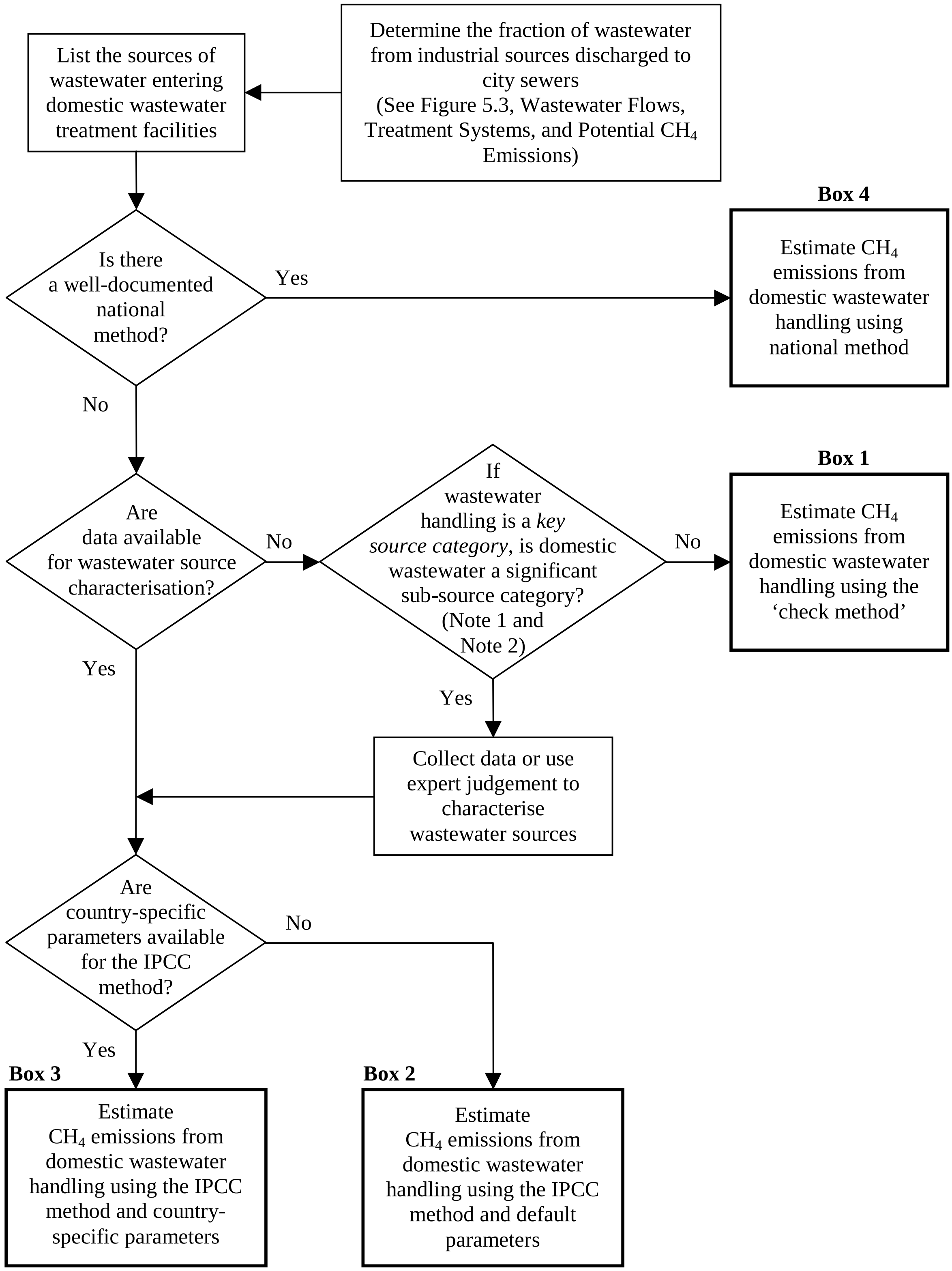
(i) Characterise the wastewater systems in the country;

(ii) Select the most suitable parameters;

(iii) Apply the IPCC method.

[5] *Good practice* methods for estimating indirect nitrous oxide (N_2O) emissions from sewage disposal were described with other indirect N_2O sources in Chapter 4, Agriculture, Section 4.8, Indirect N_2O Emissions from Nitrogen Used in Agriculture . Given the present state of data availability, the highly simplified method described in the *IPCC Guidelines* for direct N_2O emissions from wastewater disposal represents *good practice* as it stands. This is an area where future work is needed, however, to make possible the level of detail in the corresponding parts of the Agriculture Sector.

Figure 5.2 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.

BOX 5.1
CHECK METHOD

Equation 5.6 presents a quick method to check national estimates. Default parameter values are included to enable a sample calculation to be made.

EQUATION 5.6

$$WM = P \bullet D \bullet SBF \bullet EF \bullet FTA \bullet 365 \bullet 10^{-12}$$

Where:

WM = Annual CH_4 emission per country, from domestic wastewater (Tg)

P = Population of country or urban population for some developing countries (person)

D = Organic load in biochemical oxygen demand per person (g BOD/person/day), overall default = 60 g BOD/person/day

SBF = Fraction of BOD that readily settles, default = 0.5

EF = Emission factor (g CH_4/g BOD), default = 0.6

FTA = Fraction of BOD in sludge that degrades anaerobically, default = 0.8

Over 50% of the BOD in domestic wastewater is associated with non-dissolved solids, much of which rapidly settle under a wide range of conditions. For example, a conventional settling tank typically removes 33% of suspended solids, whereas a figure of 50% is more appropriate to many longer-term processes such as lagoons, septic tanks, latrines, and ungraded sewers. This is SBF in the equation above. Furthermore, it is believed that in many countries a very large fraction of this settleable BOD will degrade anaerobically, resulting in the high FTA (0.8). The remaining parameters are as defined in the *IPCC Guidelines*.

For countries that are extensively sewered, employ exclusively aerobic processes, and whose sludge is treated by non-CH_4 producing procedures or by anaerobic digestion with combustion of CH_4, the FTA would be significantly lower or zero. In these cases, the full *IPCC Guidelines* method would be more accurate. For countries where data are unavailable to determine the percentage of population connected to the various treatment types in use or, more particularly, when there is a significant unsewered population, the full IPCC procedure can miss significant emissions and its results should be reviewed with results from the check method.

This method can be used to make a rough estimate of global CH_4 emissions from domestic wastewater. Setting the global population P to 6 billion and EF to 0.6, one will arrive at total WM of 32 Tg/yr. This is in the same range as the 29 Tg/yr global estimate in Doorn and Liles (1999).

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 Equation 5.7. The MCF indicates the extent to which the methane producing potential (B_o) is realised in each type of treatment method.

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)

The derivation of each of these terms is described below.

Maximum methane producing capacity (B_o)

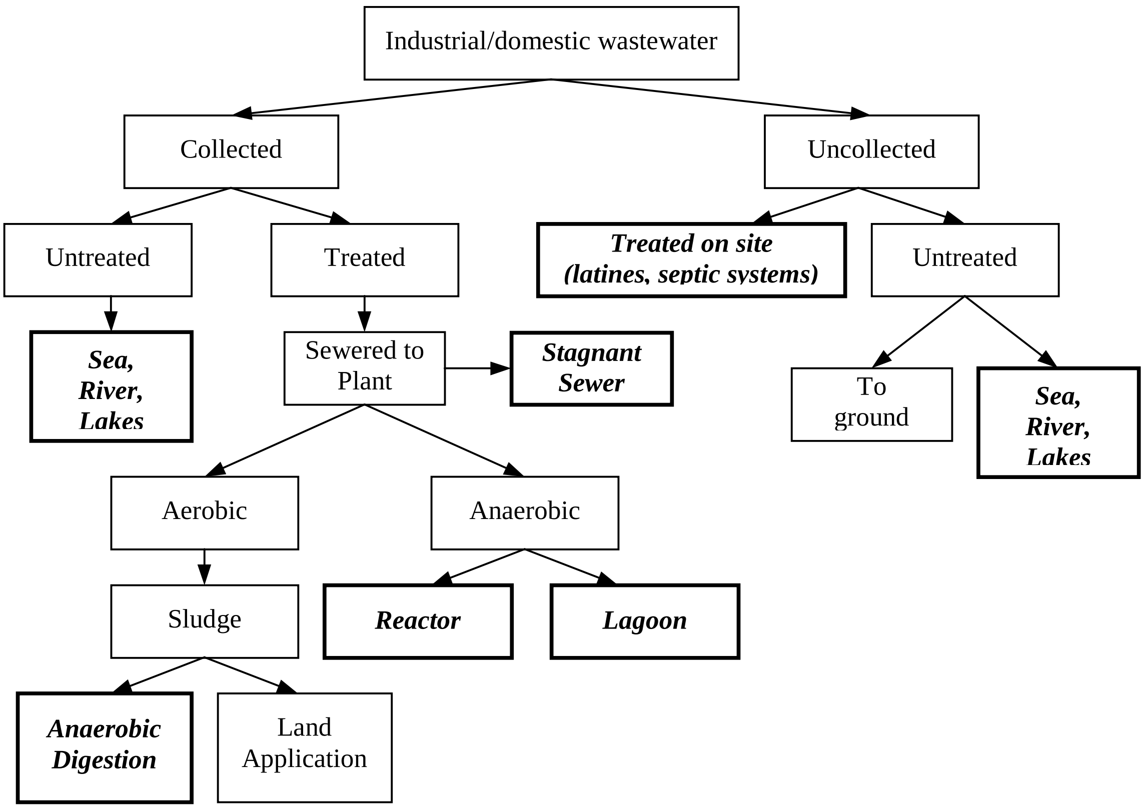
Good practice is to use country-specific data for B_o, expressed in terms of kg CH_4/kg BOD removed to be consistent with the activity data. If country-specific data are not available, a default value can be used. The *IPCC Guidelines* suggest a default value of 0.25 kg CH_4/kg COD (Chemical Oxygen Demand), based on a theoretical calculation. Comprehensive field test data (Doorn *et al*., 1997)[6] are in good agreement with the default value.

Note that degradable carbon in organic waste can be measured in terms of either BOD or 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 *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 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.

Weighted average of MCFs

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 characterise the wastewater treatment systems in the country by producing a list of CH_4 emission sources. Figure 5.3 below presents a comprehensive picture of the flow of domestic and industrial wastewater through various treatment options. Those treatment options shown in bold are potential CH_4 sources.

Figure 5.3 Wastewater Flows, Treatment Systems, and Potential CH_4 Emissions



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

6 This reference indicated a representative value of 0.21 kg CH_4/kg COD.

In the *IPCC Guidelines*, the weighted MCF value is determined according to Equation 5.8:

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

The *IPCC Guidelines* propose a separate calculation for wastewater and for sludge removed from the wastewater. The distinction is inappropriate for most countries, however, because sludge is rarely collected separately. If sludge separation is practised and appropriate statistics are available, then these sub-source categories should be separated. Such separation will not affect the overall estimate unless there are country-specific B_o measurements for sludge and wastewater. Typically, the theoretical default B_o values for sludge and wastewater are the same. If default factors are being used, emissions from wastewater and sludge can be estimated together. In this case, summing across i terms becomes unnecessary. Where a separate estimate for emissions from sewage sludge is not made, the weighted MCF for primary treatment and aerobic secondary treatment may need to be greater than zero, reflecting the typical sludge processing routes for that country. Regardless of how sludge is treated, it is important that CH_4 emissions from biosolids (sludge) sent to landfills or used in agriculture are not included in this sector.

As mentioned above, the wastewater characterisation will determine the fraction of each wastewater type treated by a particular type of system. To determine the use of each type of treatment 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 system usage. Otherwise, consultation with sanitation experts can help and expert judgement can be applied (see Chapter 6, Quantifying Uncertainties in Practice, for general guidance on eliciting expert judgement). Urbanisation statistics may provide a useful tool (e.g. city sizes and income distribution), assuming that rural populations are less likely to have access to wastewater treatment in most countries.

If no national data are available, then Equation 5.8 can be modified as follows to incorporate the expert judgement of sanitation engineers and other experts:

EQUATION 5.9

Weighted MCF = Fraction of BOD that will ultimately degrade anaerobically

The determination of weighted MCF through expert judgement should be fully documented. Default data provided by the *IPCC Guidelines* can be used as a basis for expert judgement.

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):

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)

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. For domestic wastewater, BOD data are more likely to be available. The *IPCC Guidelines* provide default values for BOD for different regions in the world (see Table 6-5, Reference Manual of the *IPCC Guidelines*).

Total population statistics should be readily available from national statistics agencies or the United Nations. If significant amounts of waste in rural areas is expected to degrade aerobically, as is the case in some developing countries, then it is *good practice* to compute the estimate using only the urban population.

COMPLETENESS

The *IPCC Guidelines* present the main wastewater handling methods in developed and developing countries (see Table 6-4, Reference Manual of the *IPCC Guidelines*). This table mentions sources such as latrines, river discharge, sewer lines and septic tanks, but the current method does not allow for their inclusion. (See Doorn and Liles, 1999 for information on emissions from these sources.) A diagram such as Figure 5.3, Wastewater Flows, Treatment Systems, and Potential CH_4 Emissions, may be more useful than Table 6-4, Reference Manual of the *IPCC Guidelines*.

DEVELOPING A CONSISTENT TIME SERIES

Emissions from domestic wastewater handling should be calculated using the same method and data sets for every year in the time series. Where consistent data are unavailable for the same method for any years in the time series, these gaps should be recalculated according to the guidance provided in Chapter 7, Methodological Choice and Recalculation, Section 7.3.2.2, Alternative Recalculation Techniques.

UNCERTAINTY ASSESSMENT

Table 5.3 presents uncertainty ranges assigned to the parameters discussed in the text above.

TABLE 5.3
DEFAULT UNCERTAINTY RANGES FOR DOMESTIC WASTEWATER

Parameter	Uncertainty Range
Human Population	–5%, +5%
BOD/person	–30%, +30%
Maximum Methane Producing Capacity (B_o)	–30%, +30%
Fraction Treated Anaerobically	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 0 to 1.

Source: Judgement by Expert Group (see Co-chairs, Editors and Experts; CH_4 and N_2O Emissions from Wastewater Handling).

Chapter 6 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.

5.2.1.2 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 should be covered there. Therefore, this discussion deals with estimating CH_4 emissions from on-site industrial wastewater treatment.

CHOICE OF METHOD

The method for calculating emissions from industrial wastewater in the *IPCC Guidelines* is similar to the one used 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.

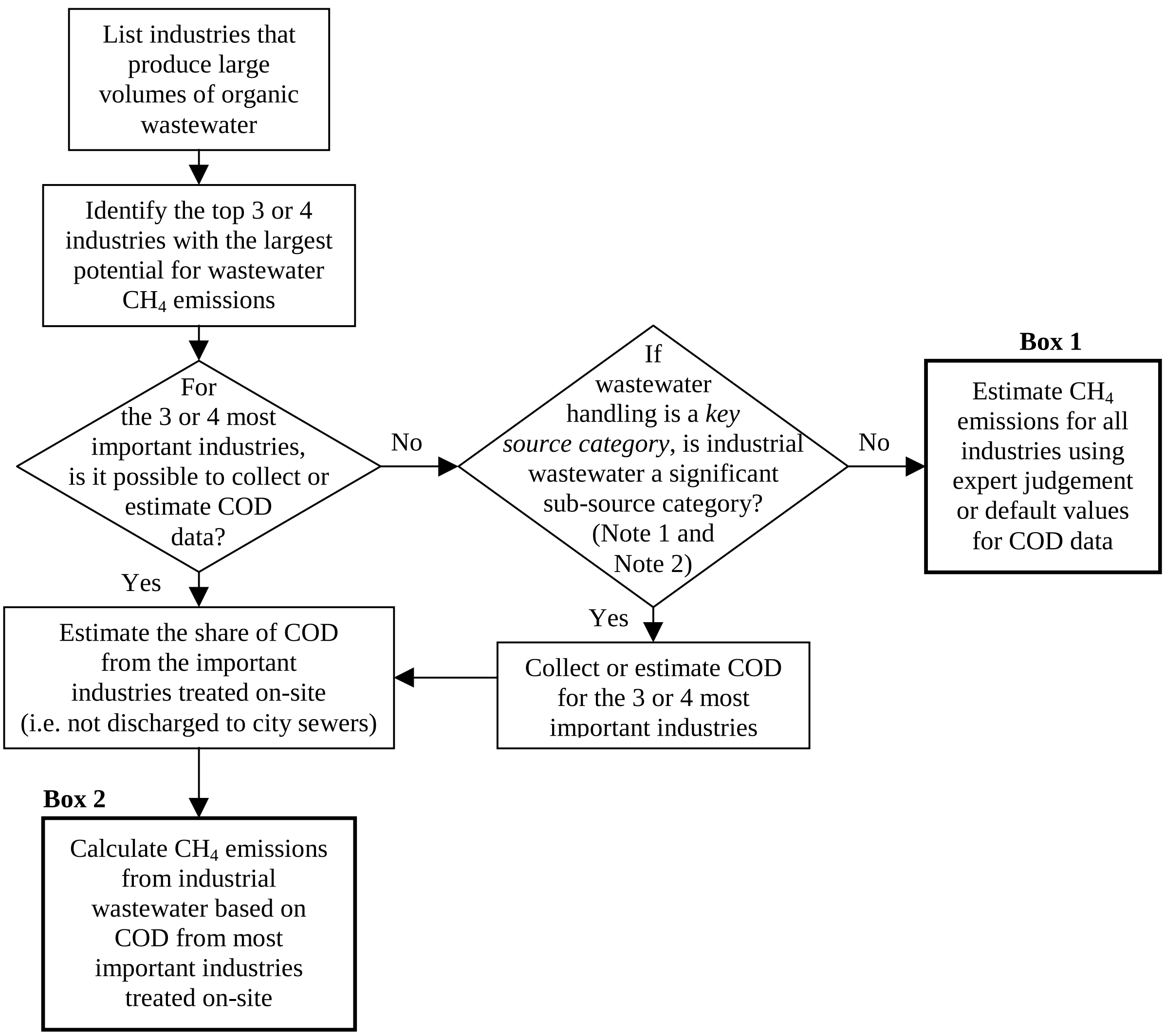
The most accurate estimates of emissions for this source category are based on measured data from point sources. Due to the high costs of measurements and the potentially large number of point sources, collecting comprehensive measurement data is very difficult. Therefore, it is suggested that inventory agencies use a top-down modified *IPCC Guidelines* approach. The decision tree in Figure 5.4 defines *good practice* in adapting the methods in the *IPCC Guidelines* to these country-specific circumstances.

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 methane producing capacity (B_o) and the fraction of waste treated anaerobically (weighted MCF) in each industry. *Good practice* is to use country- and industry sector-specific data that may be available from government authorities, industrial organisations, or industrial experts. Currently, however, most inventory agencies will find detailed industry sector-specific data unavailable or incomplete. If no national 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 fraction of waste treated anaerobically, expert judgement based on the advice of engineers and other experts should be used. 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. 3-5 years). Chapter 6, Quantifying Uncertainties in Practice, Section 6.2.5, Expert Judgement, 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.

Figure 5.4 Decision Tree for CH_4 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.

CHOICE OF ACTIVITY DATA

The first step in estimating the total industrial organic waste produced is to characterise by listing the industry sectors in the country which produce large volumes of organic wastewater. Since a limited number of industries are likely to produce most of the industrial wastewater (e.g. food processing, pulp and paper), it is *good practice* to focus on these industrial sectors. National statistics, regulatory agencies, wastewater treatment associations or industry associations can provide this information.

Next, the COD inputs for the top three or four identified major industrial sectors should be quantified. This may require some 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. The *IPCC Guidelines* present typical COD values for some industries. However, these values have been updated below (Table 5.4). Both sources are consistent with *good practice*, depending on national circumstances. For the remaining industries, an overall combined COD output should be assigned. Production data can be obtained from national statistics.

A significant fraction of industrial wastewater may be discharged into municipal sewers to be treated or disposed of with domestic wastewater. This fraction will likely have to be estimated by expert judgement and should be added to the domestic wastewater loading.

TABLE 5.4
INDUSTRIAL WASTEWATER DATA

Industry Type	Wastewater Generation (m^3/Mg)	Wastewater Generation Range (m^3/Mg)	BOD (g/l)	BOD Range (g/l)	COD (g/l)	COD Range (g/l)
Animal Feed	NA		NA		NA	
Alcohol Refining	24	16-32	NA	3-11	11	5-22
Beer & Malt	6.3	5.0-9.0	1.5	1-4	2.9	2-7
Coffee	NA		5.4	2-9	9	3-15
Coke	1.5	1.3-1.7	NA	0.1	0.1	
Dairy Products	7	3-10	2.4	1-4	2.7	1.5-5.2
Drugs & Medicines	NA		0.9		5.1	1-10
Explosives	NA		NA		NA	
Fish Processing	NA	8-18	1.5		2.5	
Meat & Poultry	13	8-18	2.5	2-3	4.1	2-7
Organic Chemicals	67	0-400	1.1	1-2	3	0.8-5
Paints	NA	1-10	NA		NA	1-10
Petroleum Refineries	0.6	0.3-1.2	0.4	1-8	1.0	0.4-1.6
Plastics & Resins	0.6	0.3-1.2	1.4	1-2	3.7	0.8-5
Pulp & Paper (combined)	162	85-240	0.4	0.3-8	9	1-15
Soap & Detergents	NA	1.0-5.0	NA	0.3-0.8	NA	0.5-1.2
Soft Drinks	NA	2.0	NA	1.0	NA	2.0
Starch Production	9	4-18	2.0	1-25	10	1.5-42
Sugar Refining	NA	4-18	NA	2-8	3.2	1-6
Textiles (natural)	172	100-185	0.4	0.3-0.8	0.9	0.8-1.6
Vegetable Oils	3.1	1.0-5.0	0.5	0.3-0.8	NA	0.5-1.2
Vegetables, Fruits & Juices	20	7-35	1.0	0.5-2	5.0	2-10
Wine & Vinegar	23	11-46	0.7	0.2-1.4	1.5	0.7-3.0

Notes: NA = Not Available.
When few data points are available, the range is assumed to be from –50 to +100%.

Source: Doorn *et al*. (1997).

COMPLETENESS

Industries may produce inventories that include emissions from on-site wastewater handling. It is *good practice* to use these estimates provided they are transparent and otherwise consistent with the QA/QC principles set out in Chapter 8, Quality Assurance and Quality Control. The national estimation method should be sufficiently disaggregated to allow recognition of the separate accounting of these emissions and hence avoid double counting.

DEVELOPING A CONSISTENT TIME SERIES

Emissions from industrial wastewater handling should be calculated using the same method and data sets for every year in the time series. Where consistent data are unavailable for the same method for any years in the time series, these gaps should be recalculated according to the guidance provided in Chapter 7, Methodological Choice and Recalculation, Section 7.3.2.2, Alternative Recalculation Techniques.

UNCERTAINTY ASSESSMENT

The uncertainty ranges in Table 5.5 were assigned to the parameters discussed in the text above.

TABLE 5.5
DEFAULT UNCERTAINTY RANGES FOR INDUSTRIAL WASTEWATER

Parameter	**Uncertainty Range**
Industrial Production	–25 %, +25%. Use expert judgement regarding the quality of data source to assign more accurate uncertainty range.
Wastewater/unit production COD/unit wastewater	These data can be very uncertain as the same sector might use different waste handling procedures in different countries. The product of the parameters should 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).
Maximum Methane Producing Capacity (B_o)	–30%, +30%
Fraction Treated Anaerobically	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 0 to 1.
Source*:* Judgement by Expert Group (see Co-chairs, Editors and Experts; CH_4 and N_2O Emissions from Wastewater Handling).	

5.2.2 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 8, Quality Assurance and Quality Control, Section 8.10.1, Internal Documentation and Archiving. Some examples of specific documentation and reporting relevant to this source category are provided below.

The existing sectoral tables accompanied with a detailed inventory report provide good transparency for this source category. The tables necessarily separate industrial from domestic wastewater treatment. The inventory report should provide the remainder of the information on activity data, assumptions made and references, as text. It is particularly important to document the use of default data in developing parameter values. Two additional columns in the worksheet, one for comments and one for references (e.g. by number), should be provided by the inventory agency.

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 (such as changes in default values for MCFs).

5.2.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to conduct quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and an expert review of the emissions estimates. Additional quality control checks as outlined in the Tier 2 procedures in Chapter 8 as well as quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. Inventory agencies are encouraged to use higher tier QA/QC for *key source categories* as identified in Chapter 7, Methodological Choice and Recalculation.

Furthermore, transparency can be improved by the provision of clear documentation and explanations of work undertaken in the following areas:

Comparison of emissions estimate using different approaches

- For domestic wastewater, inventory agencies should cross-check the national estimate, as appropriate, with emissions estimated using IPCC defaults or the ‘check method’. This cross-check should be a standard QC practice wherever non-default parameters are used in the estimation method. Inventory agencies should record the results of such comparisons for internal documentation, and investigate any unexplainable discrepancies.

Review of emission factors

- For domestic wastewater, inventory agencies should 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 waste treated anaerobically, inventory agencies are encouraged to cross-check values for MCFs against those from other countries with similar wastewater handling practices.
- Inventory agencies should confirm the agreement between the units used for degradable carbon in the waste 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 to the check method or to another country's emissions.
- For industrial wastewater, inventory agencies should cross-check values for MCFs against those from other national inventories with similar industrial wastewater characteristics.

Review of activity data

- For industrial wastewater, inventory agencies should review the secondary data sets (e.g. from national statistics, regulatory agencies, wastewater treatment associations or industry associations) 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.
- Inventory agencies should compare country-specific data (BOD in domestic wastewater or industry COD output) to IPCC default values. If inventory agencies use country-specific values, they should document why their country-specific or industry values differ from these default values.

Involvement of industry experts in the review

- In some countries, domestic wastewater treatment is highly scrutinised and regulated (especially in urban areas) and as such, there may be opportunities for expert peer review of the inputs to the emissions calculations. Peer review should involve experts that have knowledge of the particular input parameter. Expert peer review is particularly important to verify MCF values and other parameters where IPCC defaults are not available for cross-checks.
- For industrial wastewater, inventory agencies should involve industry experts that have knowledge of particular input parameters. For example, industry experts should review the characteristics of the industrial wastewater and its treatment with expertise in their specific industries. Expert peer review is particularly important to verify MCF values and other parameters where IPCC defaults are not available for cross-checks.

5.3 EMISSIONS FROM WASTE INCINERATION

5.3.1 Methodological issues

Incineration of waste produces emissions of CO_2, CH_4 and N_2O. Emissions of CH_4 are not likely to be significant because of the combustion conditions in incinerators (e.g. high temperatures and long residence times). Normally, emissions of CO_2 from waste incineration are significantly greater than N_2O emissions. Currently, waste incineration is more common in developed countries, although it is common for both developed and developing countries to incinerate clinical waste.

The methodology described here applies to 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.

Consistent with the *IPCC Guidelines*, 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 emissions estimates. The carbon fraction that is derived from biomass materials (e.g. paper, food waste, and wooden material) is not included.

5.3.1.1 CHOICE OF METHOD

The choice of a *good practice* method will depend on national circumstances. The decision trees in Figures 5.5, Decision Tree for CO_2 Emissions from Waste Incineration, and 5.6, Decision Tree for N_2O Emissions from Waste Incineration, define *good practice* in adapting the methods in the *IPCC Guidelines* to these country-specific circumstances. Figures 5.5 and 5.6 describe respectively the choice of method to estimate CO_2 emissions and N_2O emissions.

The most accurate emissions estimates can be developed by determining the emissions for each type of waste (e.g. municipal solid waste (MSW), sewage sludge, clinical waste, and hazardous waste).

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.

Estimating CO_2 emissions

The *IPCC Guidelines* describe one method for estimating CO_2 emissions from waste incineration. As shown in Equation 5.11, the activity data are the waste inputs into the incinerator, and the emission factor is based on the carbon content of the waste that is of fossil origin only. The most accurate CO_2 emissions estimates results from disaggregating the activity data into different waste types (e.g. municipal solid waste, sewage sludge, clinical waste, and hazardous waste). The burn out efficiency of combustion should also be included in the calculation.

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)

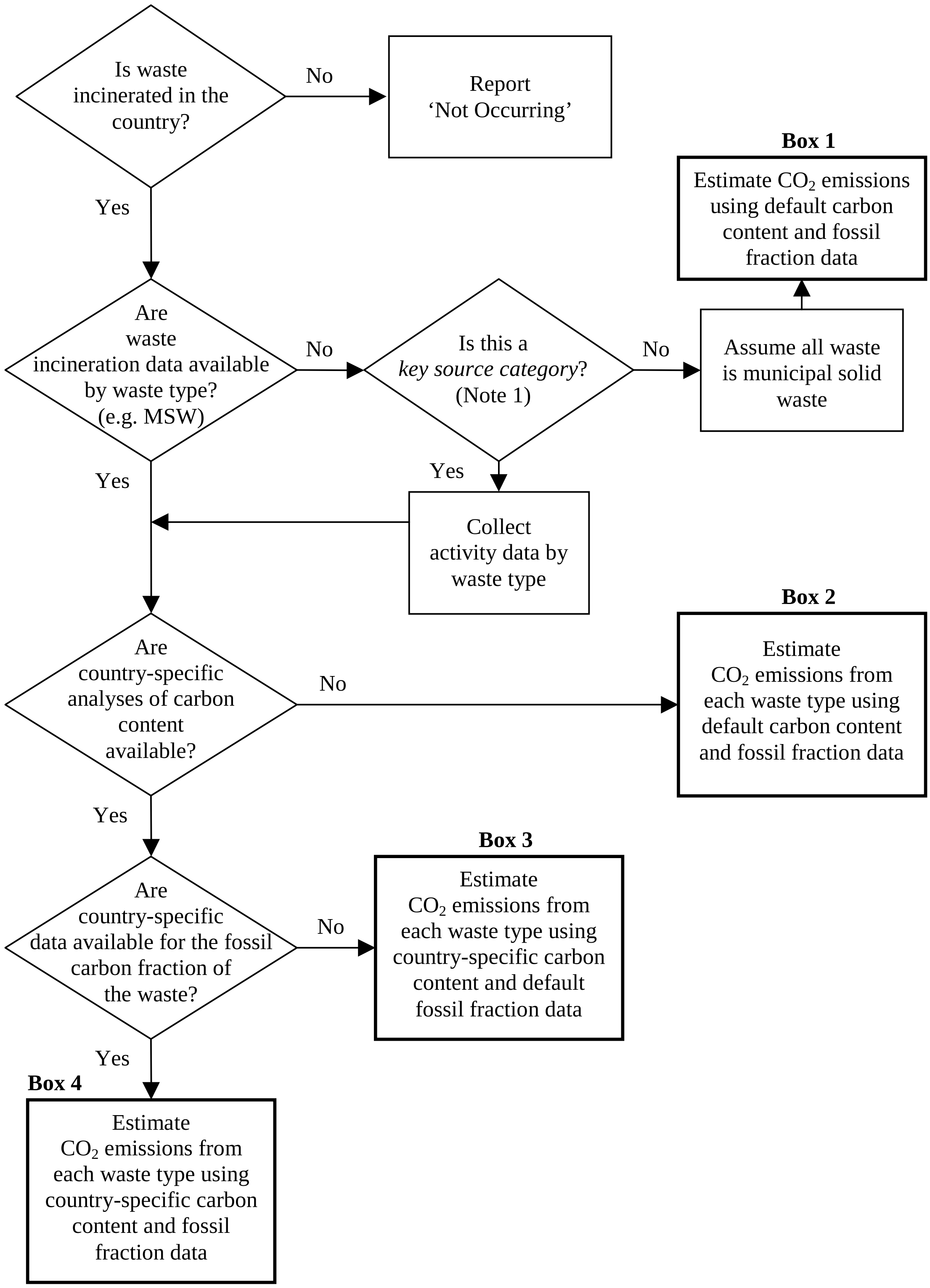
CCW_i = Fraction of carbon content in waste of type i

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)

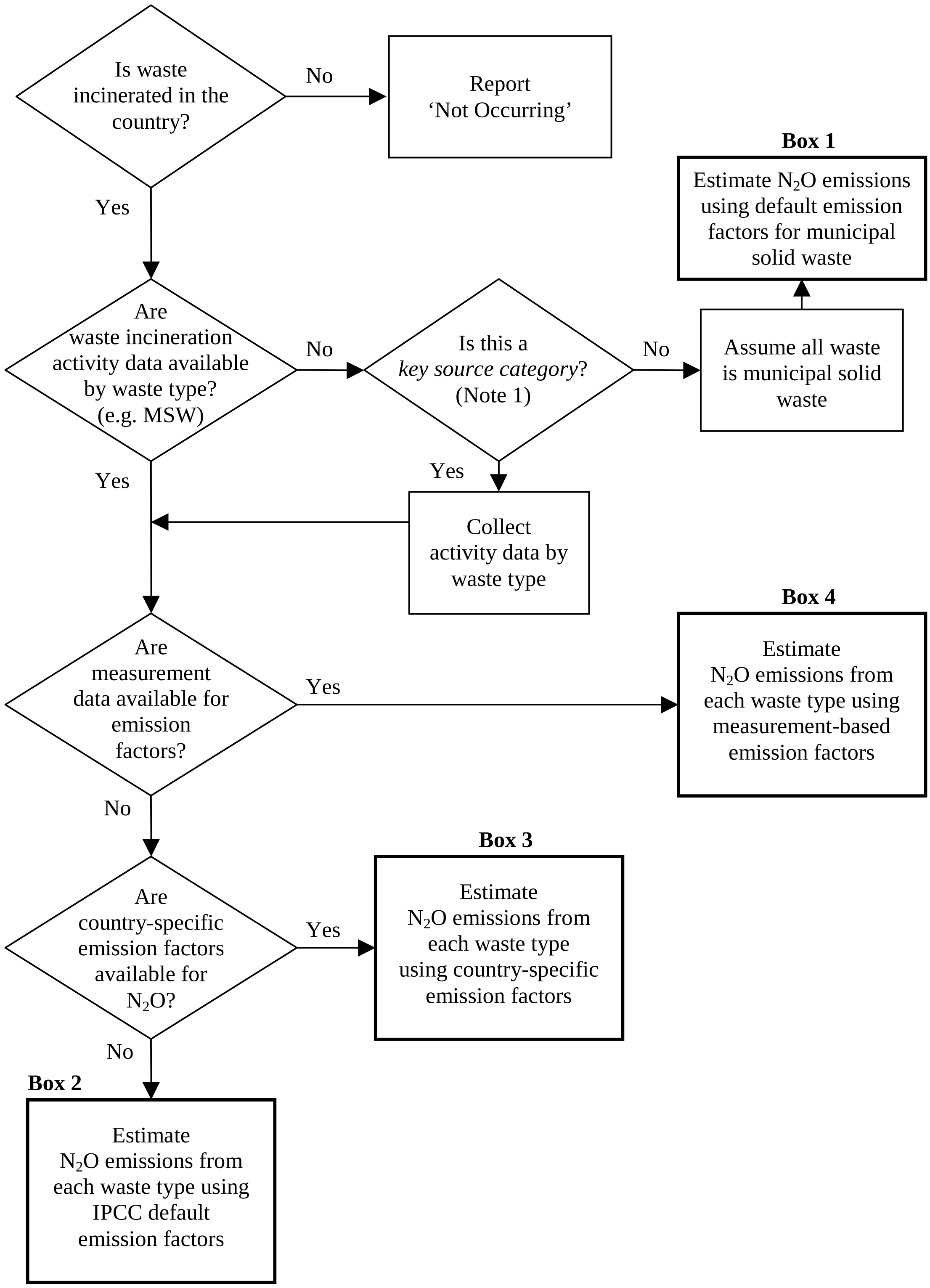
44 / 12 = Conversion from C to CO_2

Figure 5.5 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.)

Figure 5.6 Decision Tree for N_2O 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.)

The decision tree in Figure 5.5 can be used to estimate CO_2 emissions for each incineration plant as well as for estimating emissions from all plants. The best results will be obtained if emissions are determined for each plant, and then summed.

Estimating N_2O emissions

The calculation of N_2O emissions is based on waste input to the incinerators and an emission factor:

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)

Figure 5.6 provides a general decision tree for the estimation of N_2O emissions from waste incineration. The decision tree can also be used for estimation of other gases (e.g. NO_x). The best results will be obtained if N_2O emissions are determined for each plant based on the plant-specific monitoring data, and then summed.

5.3.1.2 CHOICE OF EMISSION FACTORS AND ACTIVITY DATA

CO_2 emissions

CO_2 is not normally directly monitored in exhaust gases. It can be calculated from the total carbon content of the waste. This is commonly undertaken in most countries. CO_2 emissions can also be estimated using default data for the carbon content (see Table 5.6, Default Data for Estimation of CO_2 Emissions from Waste Incineration). However, where the carbon content of the waste is not known but the inventory agency has well-documented measured data on CO_2 emissions from waste incineration, these data can be used to obtain the country-specific carbon content of the waste.

It can be difficult to differentiate between the biogenic and the fossil part of waste going for incineration. Data to determine the fractions can be gathered from the waste analysis available in many countries. However, actual data on the origin of waste is often lacking and may not be up to date.

The fractions of fossil and biogenic carbon are likely to change considerably in the future because of recent waste legislation adopted in many countries (e.g. Japan, Norway, and the USA). The legislation will influence the total waste flow incinerated as well as the fossil carbon content of the incinerated waste. It is uncertain how new legislation will influence the fossil carbon content, and limited current data are available as the changes are still occurring.

The fraction of fossil carbon will differ for different types of waste. The carbon in MSW and clinical waste is of both biogenic and fossil origin (default data are provided in Table 5.6). In sewage sludge the fossil carbon usually can be neglected (only traces of detergents and other chemicals). The carbon in hazardous waste is usually of fossil origin (default data are provided in Table 5.6).

It is *good practice* to assume that the composition of incinerated MSW is the same as the composition of MSW generated in the country. However, if a certain fraction of MSW is incinerated separately, the carbon content for these streams must be determined specifically.

TABLE 5.6
DEFAULT DATA FOR ESTIMATION OF CO_2 EMISSIONS FROM WASTE INCINERATION

	MSW	Sewage Sludge	Clinical Waste	Hazardous Waste
C Content of Waste	33-50% of waste (wet) default: 40%	10-40% of sludge (dry matter) default: 30%	50-70% of waste (dry matter) [a] default: 60%:	1-95% of waste (wet) default: 50%
Fossil Carbon as % of Total Carbon	30-50% default: 40%	0%	30-50% default: 40% more information is needed	90-100% [b] default: 90%
Efficiency of Combustion [c]	95-99% default: 95%	95%	50-99.5% default: 95%	95–99.5% default: 99.5%

[a] Clinical waste contains mainly paper and plastics. The carbon content can be estimated from the following factors: C-content of paper: 50% and C-content of plastics: 75-85%.
[b] The fossil carbon may be reduced if it includes carbon from packaging material and similar materials.
[c] Depends on plant design, maintenance and age.

Source: Judgement by Expert Group (see Co-chairs, Editors and Experts; Emissions from Waste Incineration).

N_2O emissions

Where practical, N_2O emission factors should be derived from emission measurements. Continuous emission monitoring is technically feasible, but not necessary for *good practice*. Periodic measurements should be conducted sufficiently often to account for the variability of N_2O generation (i.e. due to variable waste composition), and different types of incinerator operating conditions (e.g. combustion temperature). Chapter 8, Quality Assurance and Quality Control, Section 8.7.1.3, Direct Emission Measurements, provides further advice on representativeness. Where measurement data are not available, other reliable means of developing emission factors should be used (see Figure 5.6, Decision Tree for N_2O Emissions from Waste Incineration).

Emission factors for N_2O differ with facility type and type of waste. Emission factors for fluidised-bed plants are higher than from plants with grate firing systems. Emission factors for MSW are lower than for sewage sludge. Ranges of N_2O emission factors reflect abatement techniques (the injection of ammonia or urea as used in some NOx abatement technologies may increase emissions of N_2O), temperature, and the occupancy time of the waste in the incinerator.

If site-specific N_2O emission factors are not available, default factors can be used (see Table 5.7, Emission Factors for N_2O from Waste Incineration).

Many countries that use waste incineration should have plant-specific data for the amount of waste incinerated.

For hazardous waste and clinical waste, the activity data may be more 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, plant-specific data may not be available, but overall data for total waste incinerated may be available from waste regulators.

Categorisation of waste types varies across countries (e.g. in Japan sewage sludge is included in industrial waste) as well as within countries (e.g. on a municipal or regional level). Therefore comparability of waste types may be difficult. Where possible, waste should be categorised as above to facilitate consistency and comparability.

5.3.1.3 COMPLETENESS

Completeness depends on the reporting of waste types and amounts 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 included. Inventory agencies should make efforts to report all waste types arising in their country.

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, the emissions from such processes should be reported under ‘other fuels’ in the Energy Sector, not within the waste disposal source category.

TABLE 5.7
EMISSION FACTORS FOR N_2O FROM WASTE INCINERATION

Incineration Plant Type	MSW kg N_2O/Gg waste (dry)	Sewage Sludge kg N_2O/Gg sewage sludge (dry matter)	Clinical Waste kg N_2O/Gg waste (dry)	Hazardous Waste (from industry) kg N_2O/Gg waste (dry)
Hearth or grate	5.5-66 (Germany) average 5.5-11 highest value 30 (UK) 40-150 (Japan: wet)	400 (Japan: wet)	NA	NA
Rotating	NA	NA	NA	210-240 (Germany)
Fluidised bed	240-660 (Japan: wet)	800 (Germany) 100-1500 (UK) 300-1530 (Japan: wet)	NA	NA

Note: NA = Not Available.

Source:
Germany: Johnke (1999),
United Kingdom: Environment Agency (1999),
Japan: Yasuda (1993).

5.3.1.4 DEVELOPING A CONSISTENT TIME SERIES

Emissions from waste incineration should be calculated using the same method and data sets for every year in the time series. Where consistent data are unavailable for the same method for any years in the time series, these gaps should be recalculated according to the guidance provided in Chapter 7, Methodological Choice and Recalculation, Section 7.3.2.2, Alternative Recalculation Techniques.

5.3.1.5 UNCERTAINTY ASSESSMENT

Tables 5.6 and 5.7 provide default ranges for CO_2 and N_2O emissions estimates, but inventory agencies should assign country-specific uncertainties to the emission factors, especially if they used monitored data.

More recent information will have a lower uncertainty because it reflects changing practices, technical developments, or changing fractions (biogenic and fossil) of incinerated waste. In many developed countries, uncertainties on the amount of incinerated waste are estimated around 5%, but the uncertainty could be higher for some wastes, such as clinical waste.

The major uncertainty for CO_2 is the estimation of the fossil carbon fraction. There is a high level of uncertainty related to the separation of biogenic and fossil carbon fraction.

Direct measurement or monitoring of emissions of N_2O has less uncertainty. For continuous and periodic emission monitoring, uncertainty depends on the accuracy of measurement instruments. For periodic measurement, uncertainty will also depend on the sampling frequency.

If default values for the N_2O emission factors are used, uncertainty ranges have been estimated to be as high as 100%.

Chapter 6 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.

5.3.2 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 8, Quality Assurance and Quality Control, Section 8.10.1, Internal Documentation and Archiving. Some examples of specific documentation and reporting relevant to this source category are provided below.

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.

Some countries use different categorisation schemes for waste at the local or regional level. In this case, the inventory agency should review consistency with the IPCC categorisation scheme and provide a rationale on how it transformed the data to fit in the IPCC categories. Inventory agencies should clearly indicate the waste types included in the waste estimates.

Inventory agencies should also include information on how they obtained the carbon content, the fossil carbon fraction, and the N_2O emission factors.

Many incineration plants produce electricity and heat. Combustion of waste for energy purposes should be reported under the Energy Sector of the *IPCC Guidelines* (CO_2 from stationary combustion). Waste should be reported as 'other fuel' in the Energy Sector. These emissions should not be reported in the Waste Sector of the *IPCC Guidelines* so as to avoid double counting.

Sometimes gas, oil, or other fuels are used as support fuel to start the incineration process or maintain the temperature. Consumption of support fuel for this purpose should not be reported under waste incineration but instead included in the Energy Sector. Support fuels normally account for less than 3% of total calorific input, but they can be more important with the incineration of hazardous waste.

5.3.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to conduct quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and an expert review of the emissions estimates. Additional quality control checks as outlined in the Tier 2 procedures in Chapter 8 and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. Inventory agencies are encouraged to use higher tier QA/QC for *key source categories* as identified in Chapter 7, Methodological Choice and Recalculation.

Furthermore, transparency can be improved by the provision of clear documentation and explanations of work undertaken in the following areas:

Review of direct emission measurements

- Where direct measurement data are available, inventory agencies 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 agencies should compare plant-level factors among plants, and also to IPCC defaults. They should review any significant difference between factors.

Review of emission factors

- Inventory agencies 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 in Table 5.6.
- Inventory agencies should review the QC procedures associated with the waste incineration data and analysis used to develop site-specific emission factors. If there is insufficient QC, the uncertainty of the national estimates should be assessed and the use of those data may need to be evaluated.

Involvement of experts in the peer review

- Expert peer review should be directed at the characterisations of waste fuel and situations where default data are not used. 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.

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