CH_4 EMISSIONS FROM SOLID WASTE DISPOSAL

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ABSTRACT

The purpose of this paper is to support the development of so-called good practice guidelines for the estimation of methane (CH_4) emissions from solid waste (SW) disposal for national greenhouse gas inventories. The paper reviews and discusses the emission estimation methods given in the IPCC 1996 Revised Guidelines (IPCC Guidelines), and uncertainty and quality management issues related to the emission estimation.

At solid waste disposal sites (SWDS) the degradable organic carbon in waste is decomposed by bacteria under anaerobic conditions into methane (CH_4) and other compounds. The CH_4 emissions from SWDS are important contributors of global anthropogenic CH_4 emissions.

The IPCC Guidelines give two methods for estimation CH_4 emissions from solid waste disposal. The IPCC default method is a simple mass balance calculation which estimates the amount of CH_4 emitted from the SWDS assuming that all CH_4 is released the same year the waste is disposed of. The other method outlined in the IPCC Guidelines is the so-called First Order Decay (FOD) method. The FOD method takes the time factors of the degradation process into account, and produces annual emission estimates that reflect this process, which can take years, even decades. The estimates on annual emissions produced by the two methods are therefore not comparable. The FOD method produces better estimates on annual emissions, whereas the IPCC default method has merits e.g. in studies comparing the potential to reduce the CH_4 emissions by alternative waste treatment methods.

The use of the IPCC default method and FOD method require as input annual SW disposal data including information on the composition of the waste and on the conditions at the SWDS. The IPCC default method requires this data only for the inventory years, whereas the FOD method requires data for also the past 20-25 or more years. In addition, the rate of degradation for waste disposed at SWDS needs to be determined in the FOD method. The IPCC Guidelines contain default values for most of the data needed in the use of the default method, whereas the guidance and default values needed in the use of the FOD method are insufficient.

The uncertainties in the emission estimates produced by both the IPCC method and the FOD method are large in most countries. Even few industrialised countries have good SW disposal data based on weighing of amounts disposed and frequent sampling to determine the composition of waste at the SWDS. The SW disposal data in many developing countries is especially poor and some concern is expressed also on the suitability of some of the default parameters in their conditions. More frequent aerobic decomposition, scavenging and fires in the conditions prevailing in many developing countries may cause much lower emissions from SW disposal than in industrialised countries. Improvements in activity data collection and emission factors (parameters used in the calculation) are needed in many countries. Also some of the IPCC default values should be reviewed and updated.

1 INTRODUCTION

When solid waste (SW) is disposed in waste dumps and landfills, most of the organic material will be degraded over a longer or shorter period, ranging in a wide span from less than one year to 100 years or more. The majority of this process will be bio-degradation. Strongly depending on conditions in the site where the SW is disposed, this biodegradation will be aerobic or anaerobic. The main degradation products are carbon dioxide (CO_2), water and heat for the aerobic process and methane (CH_4) and CO_2 for the anaerobic process. The CH_4 produced and released to the atmosphere contributes to global warming and the emissions need to be estimated and reported in national greenhouse gas inventories under the United Nations' Framework Convention of Climate Change (UNFCCC). The CO_2 produced originates from biogenic sources (e.g., food, garden, paper and wood waste) and the emissions need therefore not be considered in national inventories.

The estimated global annual emissions from solid waste disposal sites (SWDS) are in the range of 20 - 40 million tonnes of CH_4, of which the most comes from industrialised countries (so-called Annex I countries of the UNFCCC). This contribution is estimated to be approximately 5-20 percent of the global anthropogenic CH_4, which is equal to about 1 to 4 percent of the total anthropogenic greenhouse gas (GHG) emissions. The emissions from developing countries and countries with economies-in-transition will increase in the near future due to increased urban population, increased specific (pro capita) municipal solid waste (MSW) generation due to improved economy and improved SW management practices. From the Annex I countries, the emissions are estimated to remain stable or decline over the next 10 - 20 years. A recent compilation of reported emissions to the UNFCCC (UNFCC, 2000) indicate emissions of 24 million tonnes CH_4 from Annex I countries in 1990. In the year 1998 these emissions had been reduced to about 20 million tonnes. The reduction is due to increased recycling and alternative treatments and increasing implementation of landfill gas extraction and recovery systems.

This document is prepared for the IPCC National Greenhouse Gas Inventories Programme to support the development of *good practice guidelines* for estimation of greenhouse gas emissions from the Waste sector and to manage associated uncertainties. The document is a background paper for the IPCC expert meeting on Waste in Sao Paulo. The document concentrates on the anaerobic degradation process generating landfill gas (LFG). The existing *IPCC Guidelines* for national Greenhouse Gas Inventories are reviewed, and an upgraded basis for a worldwide good practice framework to carry out as accurately as possible national inventories of emissions of CH_4 is proposed.

2 METHODOLOGICAL ISSUES

2.1 Choice of method

The *IPCC Guidelines* describe two main methods:
(A): The default IPCC methodology that is based on the theoretical gas yield (a mass balance equation).

(B): Theoretical first order kinetic methodologies, through which the *IPCC Guidelines* introduces the "First order decay model" (FOD).

The main difference between the two methods is that method A does not reflect the time variation in SW disposal and the degradation process as it assumes that all potential methane is released the year the SW is disposed. The timing of the actual emissions is reflected in method B. Only if the yearly amounts and composition of waste disposed as well as disposal practices have been nearly constant for long periods, the method A will produce fairly good estimates of the yearly emissions. Increasing amounts of waste disposed will lead to an overestimation, and decreasing amounts correspondingly to underestimation, of yearly emissions.

Method B gives a more accurate estimate of the yearly emissions. Many countries may, however, have problems getting the necessary data and information (historical data on SW disposal, rate constant for the decay) to establish the proper basis for emission inventories with acceptable accuracy.

The two methods are explained in further detail below.

2.1.1 IPCC default method

The default method is based on the main equation 1:

EQUATION 1

$$\text{Methane emissions (Gg/yr)} = (MSW_T \bullet MSW_F \bullet MCF \bullet DOC \bullet DOC_F \bullet F \bullet 16/12\text{-}R) \bullet (1\text{-}OX)$$

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) (kg C/ kg SW)
DOC_F :	fraction DOC dissimilated
F :	fraction of CH_4 in landfill gas (IPCC default is 0.5)
16/12 :	conversion of C to CH_4
R :	recovered CH_4 (Gg/yr)
OX :	oxidation factor (fraction – IPCC default is 0)

The method assumes that all the potential CH4 emissions are released during the same year the waste is disposed of. The method is simple and emission calculations require only input of a limited set of parameters, for which the IPCC Guidelines provide default values, where country-specific quantities and data are not available.

The IPCC Guidelines introduce various specific default values and recommendations, (particularly for use in countries with lack of SW statistics):

MSW_T :	A selection of national specific MSW generation (in kg/capita/day) figures are provided, but information appropriate for many low and medium income countries and regions is missing
MSW_F :	A selection of national specific MSW disposal figures (in kg/capita/day) are provided (to be used instead of MSW_T)
MCF :	Three default values ranging from 1.0 to 0.4 are included, depending on the site management and with 0.6 as general default value
DOC :	A selection of national values for DOC in MSW are provided, although a more limited selection than for MSW_T and MSW_F. In addition, an equation is provided together with default values related to MSW fractions to estimate country specific figures based on national MSW composition.
DOC_F :	Tabasaran's (1981) theoretical equation $DOC_F = 0.014T + 0.28$, where T = temperature is used to determine the value. The IPCC default value is 0.77 as suggested by Bingemer and Crutzen (1987).
F :	0.5 is the IPCC default value
OX :	0 is the IPCC default value

The minimum national figures required are:

- National MSW quantities ending up at SWDS, eventually (in lack of SW statistics) based on the number of urban inhabitants in the country multiplied with a specific national MSW disposal rate figure, and
- National quantities of landfill gas recovered.

In most developing countries there is no gas extraction and recovery; hence the only figure needed in the calculation is the number of inhabitants in the country, with clear focus on the urban population.

2.1.2 Theoretical first order decay methodologies

IPCC Guidelines

This model is presented through three equations. The first equation is applicable for one or a selection of specific landfills:

EQUATION 2

$$Q = L_o \bullet R \bullet (e^{-kc} - e^{-kt})$$

Where:

Q : methane generated in current year (m^3/yr) -

L_o : methane generation potential (m^3/Mg of refuse)

R : average annual waste acceptance rate during active life (Mg/yr)

k : methane generation rate constant (l/yr)

c : time since SWDS closure (yr)

t : time since SWDS opened (yr)

When estimating regional or national figures, the following equation for CH_4 generation in year T from all solid waste landfilled in one specific year x (R_x) may be used:

EQUATION 3

$$Q_{T,x} = k \bullet R_x \bullet L_o \bullet e^{-k(T-x)}$$

Where:

$Q_{T,x}$: the amount of methane generated in year T by the waste R_x (Mg)

x : the year of waste input

R_x : the amount of waste disposed in year x (Mg)

T : current year

In order to estimate all emissions in the year T from waste disposed of in previous years, Equation 3 can be solved for all values of R_x and the results summed using the following equation:

EQUATION 4

$$Q_T = \sum Q_{T,x}$$

for x = initial year to T

Where:

Q_T : total emissions in year T from waste disposed of in previous years (including year T)

No specific recommendations of default values for variable factors like L_o and k are given, only a very wide range of values: L_o <100 - >200 Nm^3/Mg; k = 0,005 – 0,4. Limited information of units involved is provided in the guidelines. Furthermore, no reduction due to recovery of gas or oxidation factor is introduced. Although the IPCC encourages the use of this model (equations 3 and 4) it does not supply sufficient material for use of this method directly in national inventories.

Nationally Adjusted FOD-model

Several countries have made adjustments to the presented FOD-model by including supplementary information of the factors L_o and k, and are in the process of using these in their national inventories.

A model implemented in Norway in 1998 (Bartness, et al, no date) is proposed as follows:

EQUATION 5

$$Q_{T,x} = k \bullet MSW_{T(x)} \bullet MSW_{F(x)} \bullet MCF_{(X)} \bullet Lo_{(X)} \bullet e^{-k(T-x)} \bullet F$$

Where:

$Q_{T,x}$: the amount of methane generated in the current year from waste disposed in the year x

T : the current year (year of the emission estimate) (Gg/yr)

x : the historical year of the disposal of the relevant national MSW quantities

$L_{o(X)}$: DOC x DOC_F for the year x (Gg CH_4/Gg waste)

k : ln (2)/$t_{½.}$ (1/yr)

$t_{½}$: half-life period for the degradation process (yr)

$MSW_{T(x)}$, $MSWF_{(x)}$ and $MCF_{(x)}$ and F are the same factors as in the default method (equation 1), but estimated for the year x.

This is for the year x and when doing the same calculation for each year back in time from T until a point of time when the majority of the MSW is degraded in year T; total emissions in year T will be the result (equations 4 applies). From this total figure (Q_T), LFG extracted and flared and/or recovered in year T (R_T) must be subtracted together with the oxidation effect to obtain the total net emission in the year T ($Q_{Net,T}$):

EQUATION 6

$$Q_{Net,T} = (Q_T - R_T) \bullet (1 - OX)$$

In addition to the necessary input to the IPCC default model, this model will require information on:

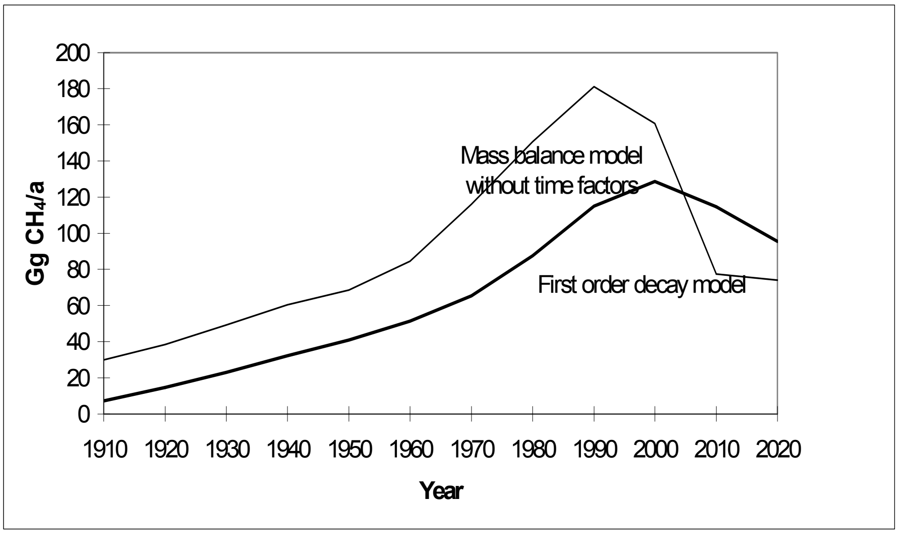
- historical $MSW_{T(x)}$, $MSW_{F\,(x)}$, $MCF_{(x)}$ values or assumptions of the rates of changes over time;
- historical DOC or assumptions of the rates of changes over time, and
- a choice of half-life period for bio-degradation in the country.

Guidelines for estimating historical figures and/or default values may be established. The mathematical calculation and data input is simple when set up in a spreadsheet.

2.1.3 Comparisons between the Methods

The IPCC default method (A) and first order decay model (B) do not provide comparable estimates of yearly emissions. The IPCC default methodology provides estimates on potential CH_4 emissions without incorporating any time factors. The first order decay model on the other hand estimates actual yearly emissions. The differences in the results provided by the two models are illustrated in Figure1, where emission estimates for MSW disposal in Finland are given (Pipatti et al. 1996). Method A predicts up to approximately 60 % (in 1990) more methane emissions than method B.

Figure 1 Emissions with the default (A) and FOD (B) models with growth and then reduction in SW disposal



Source: Pipatte et al., 1996

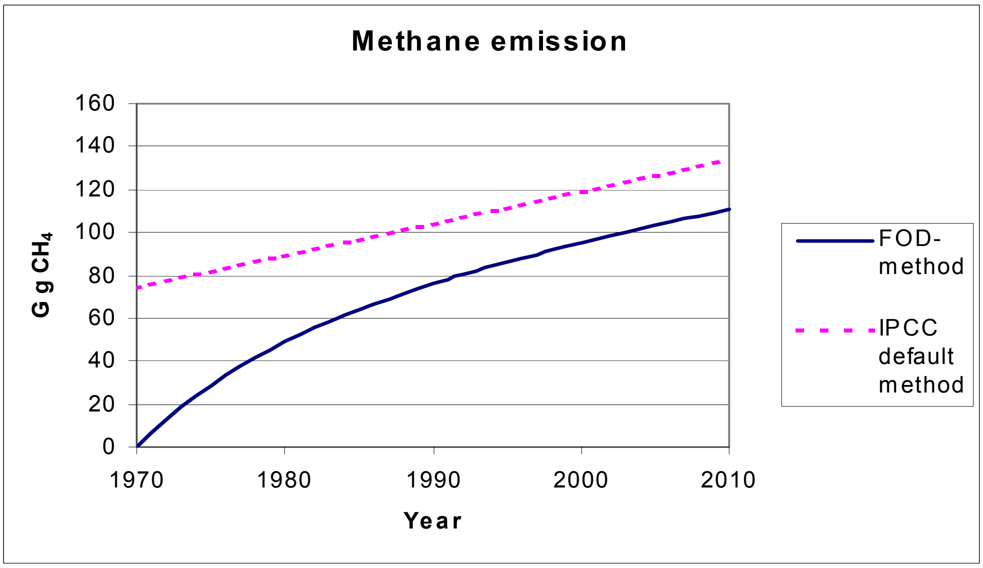
The curves given in Figure 1 are based on the following assumptions:

- MSW disposal in Finland is assumed to have grown steadily since the beginning of the century. Since1990's waste reduction, recycling and alternative waste treatment methods have been utilised increasingly, and
- More stringent restriction in SW disposal will take place in the coming years. The changes in the amount of MSW disposal are reflected immediately in the emissions calculated with the IPCC default method whereas the first order decay model responds more slowly to the changes.

Figure 2 presents an illustration of a simulation with the default and FOD method of emission estimates from the same SW amounts disposed of during 1970 to 2010 with a continuous annual growth of 2 percent in the quantities. The parameters used in the calculations differ from those used in Figure 1. As indicated, the difference between the methods will be reduced as the simulation period increases.

Box 1 presents some test calculations with the Norwegian national model (Barrett et al, no date) of the effect from varying factors like SW quantities and composition (DOC) and disposal practices over time in the FOD method and compares these to results with the default method.

Figure 2 Emissions with default and FOD models with continuous growth in SW disposal



In the long run the total emissions calculated with the two models should be similar even though yearly estimates may differ substantially. A test calculation was made for a very long period (60 years) for the FOD model, and the total amount of CH_4 estimated with the IPCC Default method was only approximately 5 percent higher than the emissions estimated with the FOD model, being within an acceptable margin.

Box 1

Test calculations made using the IPCC default method and the first order decay model (FOD) indicate that the IPCC default method may give inaccurate estimates of actual annual emissions when the input factors like SW quantities, composition and/or disposal site practices change over time (1.5 percent growth, 7 years as $t_{½}$, increased paper content etc.). Assuming changes in these factors for the last 25 years, a situation realistic for many developing countries, calculations indicate that up to 66 percent higher emissions are estimated for the present year with the default method.

This is in correspondence with the main conclusions of the paper that the IPCC default method can be used only to estimate potential emissions caused by SW disposal in the inventory years. Estimation of actual annual emissions would require the use of a kinetic model (e.g. FOD model) or introducing/proposing a time correction factor to the default method. The FOD model or a time correction factor may give emission estimates which are lower than 50 percent of the figures based on the default model in cases with steadily increasing waste disposal.

Calculations have also been made to check the contribution to this difference from various changes assumed. They indicate that:

by keeping the other historical factors similar to existing and assuming approximately 1.5 percent growth in MSW quantities, the IPCC default method gave 30 percent higher figures (the IPCC Guidelines indicate 20-25 percent higher estimates using 2 percent growth in SW quantities)

by keeping the other historical factors similar to existing and assuming a substantial change in MSW composition, the IPCC default method gave 21 percent higher figures

by keeping the other historical factors similar to existing and assuming change in SWDS conditions through the MCF of 0.7 on average compared to 0.8 as default, the IPCC default method gave 30 percent higher figures

2.1.4 Recommendations - future methods

The IPCC default method can produce relatively good estimates of the potential future emissions. It is simple, transparent and easy to use. The use of the method could therefore be recommended as a reference methodology in national inventories. It is also suitable for simple and illustrative calculations of the effect of various policies and measures to reduce the emissions from SW disposal (Pipatti and Wihersaari, 1998)

The calculation of the actual yearly emissions from SW disposal is, however, the target in the national inventories. The actual yearly emissions can be estimated with the FOD method. More information on the use of the method and default values for the input data would, however, need to be included in the *IPCC Guidelines*.
Other possibilities for the estimation of the actual yearly emissions put forward are the use of correction factors that account for changes in the SW disposal to the IPCC default methodology with the aim of achieving results based on a simplified first order decay model. (See p.11 "correction factor for SW changes over time).

2.2 Choice of emission factors

2.2.1 Emission factors in the default method (mass balance)

The default method introduces the following emission factors:

MCF-Methane correction factor
MSW can be disposed of in a wide range of site conditions. Modern sanitary landfills are characterised by conditions favourable for anaerobic degradation:

- sufficient depth (minimum 10 m, preferably more);
- high compaction with suitable equipment;
- properly designed and well-operated leachate and storm water systems;
- proper site management with no scavenging at the operational area;
- control of incoming waste types and quantities and environmental monitoring schemes established;
- frequent surface covering;
- prevention of landfill fires, litter and scavenging animals, and
- gas control and extraction/recovery.

Open dumps are more favourable for aerobic degradation and are characterised by conditions like:

- shallow sites (<5 m) (favourable for aerobic degradation);
- poor and light operational equipment, for instance bulldozers (being in widespread use) have in general a low area pressure, resulting in limited compaction effect (favourable for aerobic degradation);
- no or limited coverage (favourable for aerobic degradation);
- scavenging by people and animals;
- aerobic degradation conditions in substantial or all parts of the sites,and
- frequent fires, often used deliberately and systematically mainly to reduce volumes and to "get rid of " the SW.

Most sites will have conditions between these two extremes. The *IPCC Guidelines* present the following default values for the site conditions factor:

- Managed sites MCF = 1.0;
- Unmanaged, deep sites (≥ 5m) MCF = 0.8;
- Unmanaged, shallow sites (<5m) MCF = 0.4, and
- Unspecified SWDS – default value: MCF = 0.6

To estimate a country-specific MCF, the national SW quantities should be divided in these SWDS categories to end up with a weighted average. However, probably even countries with relatively good data on SW disposal may have problems splitting the SW quantities in these site groups. For countries without sufficient data and information to do this split, the default value of 0.6 is proposed.

The reduction implied by the MCF is normally caused by two conditions:

- SWDS conditions allowing aerobic degradation resulting in other emissions than CH_4. This may be caused by loose compacting, shallow site or lack of cover material, normally a combination of all these ,and

- Fires in the landfill instantly reduce the organic matter with very limited emissions of CH_4.

Thus the MCF may be split in sub-factors. As an illustration, Table 1 presents proposals for sub-factors for Norwegian site conditions, which probably to some extent are similar to many other western countries.

TABLE 1
ESTIMATES OF NORWEGIAN MCF HISTORICAL SUB-FACTORS

Period	Reduction caused by				
	Loose/inproper compactinG	Shallow SWDS areas	Inproper top coverage (aerobic top zones)	Fires	Summarised MCF
2000-2009	0.99	0.97	0.98	1.0	0.94
1990-1999	0.98	0.96	0.96	1.0	0.90
1980-1989	0.96	0.93	0.94	0.97	0.82
1970-1979	0.92	0.88	0.90	0.90	0.66
1960-1969	0.85	0.82	0.87	0.80	0.49
1945-1959	0.80	0.78	0.85	0.72	0.38

According to this, questions may be raised if a MCF factor equals 1 is correct even for managed, modern sites and if perhaps 0.95 as MCF would be a more realistic figure. Even a managed site will have brink zones, top layers etc., where aerobic conditions occur.

A more substantial concern is, however, which MCF to use for many developing countries in the tropical and sub-tropical climatic zone. Numerous site observations from countries like Thailand, Philippines, China and Jamaica indicate that almost all the organic material in an unmanaged or poorly-managed SWDS under tropical or sub-tropical conditions is more or less degraded in 2 up to 7 years after disposal. When excavated, the remaining material is soil, plastics, metals and inert material. The speed of the process and registered site conditions indicate that most of the process probably is aerobic. Thus, the MCF for such site conditions may be 0.3 and even lower. Site observations show also that burning is a widespread practice in many countries. Normally, this can be explained by accidental fires or fires started by scavengers. Some of the fires may also be set by the operational staff to reduce the volume of waste and problems with smell, rodents, etc. Whatever causes the fires, reduces the CH_4 emission potential to almost nothing in the areas/zones, and the MCF for the whole site may be low.

One consequence of this is that the default value of 0.6 may be too high for many developing countries. Default values for the MCF in the range between 0.3 and 0.8 could therefore be more relevant.

In general, the choice of MCF values and the given default values should be further assessed and adjusted in the proposed guidelines, based on agreed decisions at the expert meeting.

DOC - Content (fraction) of degradable organic carbon
The *IPCC Guidelines* provide the following equation:

EQUATION 7

$$DOC = 0.4 \bullet (A) + 0.17 \bullet (B) + 0.15 \bullet (C) + 0.30 \bullet (D)$$

Where default values for DOC related to A, B, C and D are as presented in Table 2:

TABLE 2
DEFAULT DOC VALUES FOR MAJOR WASTE STREAMS

	Waste Stream	Per cent DOC (by weight) in wet (fresh) SW
A.	Paper and textiles (% portion in SW)	40
B.	Garden and park waste, and other (non-food) organic putrescibles (% portion in SW)	17
C.	Food waste (% portion in SW)	15
D.	Wood and straw waste[a] (% portion in SW)	30

[a] excluding lignin C
Source: IPCC Guidelines

This provides a good basis for estimating a DOC value for the specific country. However, some elements should be commented on:

- A+B+C+D should not sum to 1.0 (100 %), as other materials like metals, plastics, rock/dust etc. are also included in the indicated MSW generation figures listed in the guidelines;
- In many countries, the composition figures are not related to mixed MSW but to, for example, household waste and non-household waste, for example. A supplementary calculation of weighted DOC for mixed MSW should be carried out, and
- Questions may be raised if some plastics should be included. Plastics are usually considered non-degradable in SWDS. Some, especially new types of plastics may behave differently, for instance polyethylene (PE) plastics have a high content of organic carbon and may bio-degrade, though over a very long period. As plastics are of fossil origin (oil), the CO_2 emissions produced should in theory also be accounted for, although their importance in the national inventories is probably negligible. In some countries, plastics have been included to some extent in the estimated DOC value.

The default values for DOC in various countries show some variations within rather similar regions that may seem strange. In general, a developing country normally should have a higher total DOC, because of higher content of paper, textile and wood with relatively high DOC. The variations may be caused by different definitions of waste included in the inventory.

The emissions from disposal of industrial, construction and demolition waste and sludge should also be included in the inventory. The DOC content of these wastes differ much from that of average MSW and guidance how to estimate this is needed.

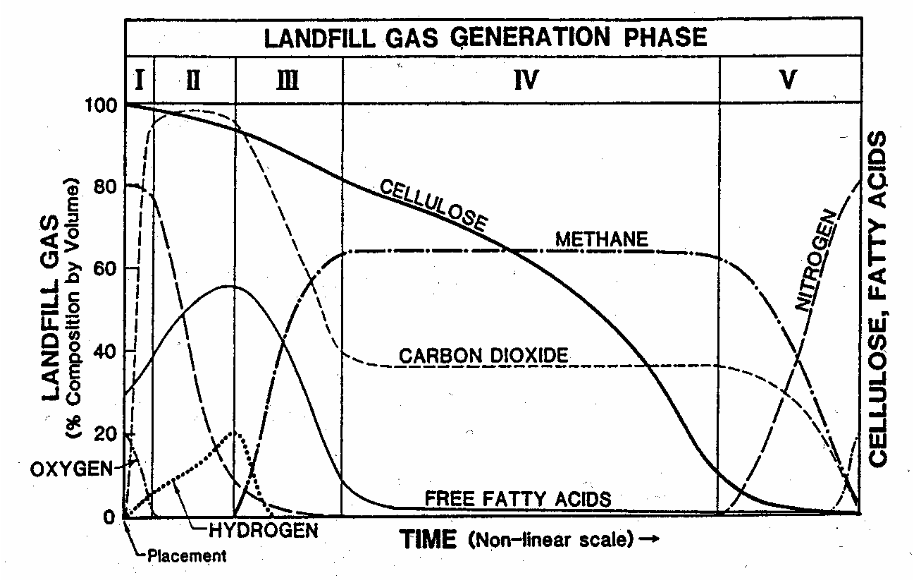
DOC_F - fraction of DOC dissimilated
This factor is based on a theoretical model where the variation depends on the temperature in the anaerobic zone of the landfill: $DOC_F = 0.014 \bullet T + 0.28$ where T is the temperature. This factor may vary from 0.42 for 10°C to 0.98 for 50°C. In fact, in many deep landfills (>20 m) temperatures of more than 50°C have been registered in gas streams from highly productive (thus clearly anaerobic) gas wells.

This theoretical factor is currently under review. An IPCC workshop in Washington in 1995 recommended the use of 0.5 as a new default factor on the basis of several experimental studies. It is, however, unclear to what extent the temperature in the strictly anaerobic zone influences the fraction of the total DOC being converted to CH_4 during the degradation process. The temperature clearly influences the speed of the process, which in the FOD model is mainly reflected in the choice of half-life period for the degradation ($t_{½}$).

For the default mass balance model, it must be further discussed how realistic this substantial influence of temperature is. If only 56 percent of the DOC is converted to CH_4 and CO_2 during the process (under e.g. 20°C conditions), then 44 percent should be stored in the SWDS (as stable organic matter), or be degraded through other unspecified and probably non-biological processes, or be degraded over a longer period than reflected in the DOC_F equation.

F - fraction of CH_4 in landfill gas (LFG)
LFG from undisturbed SWDS zones in the main anaerobic phase has a composition of mainly CH_4, CO_2 and a large number of trace components, normally accounting for less than 1 percent of volume. As indicated in the Figures 3 and 4, the composition of the gas produced and emitted may vary during the bio-degradation process.

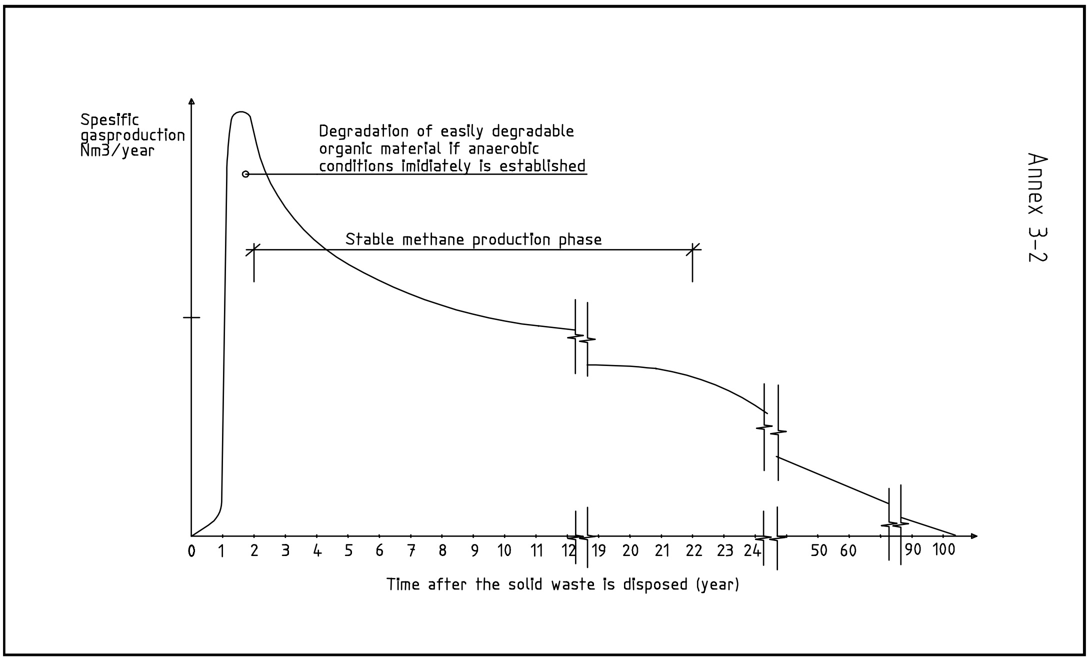
Figure 3 Composition of landfill gas in different phases of the degradation process



Source: Tasaran, 1981

Phase I : Oxygen- and nitrate-reducing phase – Duration range: Hours – 1 week
Phase II: Acidic phase – Duration range: 1 – 6 months
Phase III: Instable methane generating phase – Duration range: 3 months – 3 years
Phase IV: Long term stable methane generating phase – Duration range: 5 – 50 years
Phase V: Humus-generating and/or sulphide oxidation phase – Duration: 1 – min. 40 years
TOTAL Duration range: 10 – min. 90 years

Figure 4 Schematic presentation of the degradation process at landfills



Various sources operate with a CH_4-content in LFG between 50 and 60 percent, and the default value in the *IPCC Guidelines* is 50 percent. Experiences from a number of pumping tests are indicating that composition of undisturbed LFG very often is in the order 55 percent CH_4 and 45 percent CO_2. The adjustment of the default value to e.g., 55 percent CH_4 for F may be relevant and may be discussed further.

OX – oxidation factor
The default value for this is 0, although an increasing focus is being put on this factor. Numerous field tests including flux measurements clearly indicate that there is an oxidation effect, but the results are not systematic or consistent. It is, though, registered that the oxidation effect increases with rising temperature. The oxidation effect is also highly dependent on the type and thickness of cover at the SWDS.

At the IPCC workshop in Washington in 1995 and at an international seminar in Chicago in 1997 there was an agreement of using 10 percent as a standard value, which later on has been subsequently implemented in several national inventories. More recent studies on oxidation have not changed the basis for this value substantially, and it is proposed to introduce this as a default value in the *IPCC Guidelines.* The possibility to have a variable range depending on the temperature/climate may be discussed.Correction factor for SW changes over time

The emissions estimated with the default mass balance method do not reflect the changes over time in SW composition and quantities or disposal practices. A recent paper (Irwing et al., 1999) proposes to add a correction factor, aiming to include changes over time of disposed SW quantities and to introduce effects of degradation time for the process.

The mathematical expression for the factor introduced is:

EQUATION 8

$$\text{CORRECTION FACTOR} = [1 / (1 + R)^T] \bullet \{1- 1/[T \bullet \ln(1 + R)]\}$$

Where:

R: national annual growth rate of waste to disposal for a certain period

T: duration of methane generation

For a high growth rate for SW disposal, this correction factor may be down to 0.4, changing the emissions estimates dramatically compared to estimates by using the default model.

A comparison of estimates of US emissions (an increasing trend in the emissions) based on the FOD model indicate figures approximately 10-12 percent higher for the default IPCC model with added correction factor compared to the FOD model. This is a promising similarity in light of the simplicity in adding this factor.

Two sub-factors for potential changes over time are still not included in the correction factor: changes in MSW composition and changes in SWDS management and practices. The possibility to incorporate these in the factor may be assessed. The use of the correction factors in situations where the amounts of SW disposal fluctuate from year to year may, however, not apply.

2.2.2 Emission factors connected to IPCC's FOD method

There are two factors in IPCC FOD model (see equation 3) that have not been discussed yet: the methane generation potential Lo and methane generation rate constant k.

L_o- methane generation potential
A range between less than 100 m^3/Mg SW and more than 200 m^3/Mg SW is presented in the *IPCC Guidelines*. No basis for this range is presented, no default values given or the conditions that influence the factor mentioned. However, this factor depends on the DOC and DOC_F and the conditions at the SWDS as in the default method (L_o corresponds to MCF ● DOC ● DOC_F ● F ● 16/12 in the default method).

k - methane generation rate constant
This factor is depending on waste composition and site conditions, and describes the rate of the degradation process. A very wide range of values between 0.005 and 0.4 is given for k in the *IPCC Guidelines.*

2.2.3 Emission factors connected to an adjusted FOD model

The main equations of the Adjusted FOD model are given in 2.1.2.

k – methane generation rate constant
The formula for k = ln(2)/$t_{½}$, where $t_{½}$ is the average time for 50 percent degradation. The half life $t_{½}$ ranges usually between 4 and 10 years for MSW disposal, where warmer climate results in shorter time. The degradation time is different for various types of waste. Organic material like food waste degrades rapidly, whereas material in paper and wood degrades slowly. Thus household waste normally has a shorter degradation time than

non-household waste and industrial waste. Furthermore, the choice of degradation time also may reflect how optimised the physical and chemical conditions are inside the landfill (chemical composition, humidity etc.). If for instance the landfill is partly filled with water, this will increase the degradation time substantially.

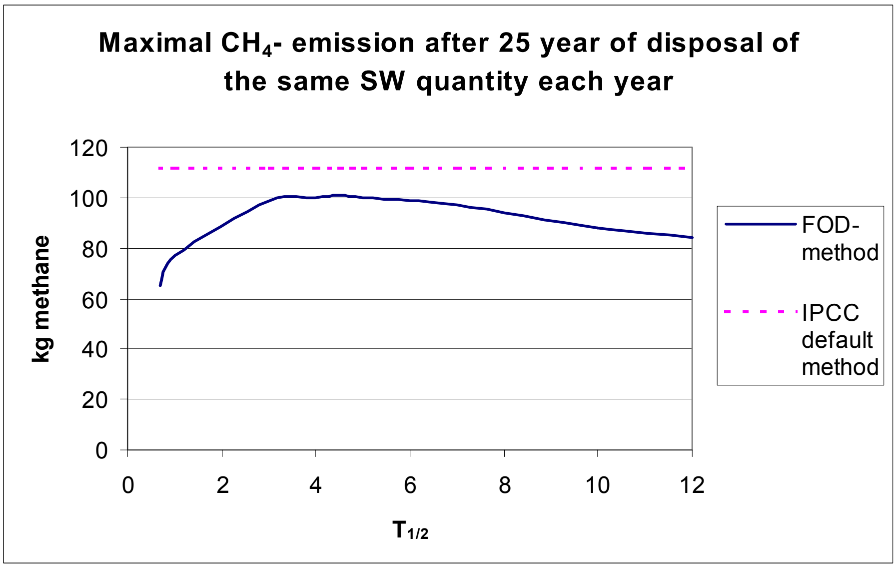
When sufficient data material is available, a weighted average for $t_{½}$ for mixed MSW may be calculated. Alternatively, a set of default values depending on climate and MSW composition may be provided.

Test calculations with various $t_{½}$ values have been carried out and the results have been compared to results based on the default IPCC method. The results are presented in Figure 5 and the main conclusion is that the difference between the two methods is at a minimum when assuming approximately 4.5 years as an average $t_{½}$ for the SW. At this point the difference is approx. 12 percent. Both through increasing and decreasing the $t_{½}$ from this value, the difference will increase.

A default value in the range between 4 and 7 years could be realistic for most developing countries (in a tropical or sub-tropical climate) and countries with economies-in-transition. Values for k should be further discussed.

To estimate total emissions in year T from all historically disposed MSW, the equation $Q_T = \sum Q_{Tx,}$ is used. The relevant total time (t_{tot}) that includes all historical years that have an impact on the emissions in year T can be indicated by $t_{tot} = 5 \text{ x } t_{½}$. Mathematically, when repeating the 50 percent reduction 5 times, only approx. 3 percent is left for degradation. This t_{tot} is typically in the range of 20-25 years in a tropical climate, and 50 years or more for a cold climate. The historical assumptions may be based on data registered over time or trends, growth rates etc., either specific for the country or the region. The net emissions of CH_4 can be established by the equation 6:

Figure 5 Comparison of emissions estimated with the IPCC Default and the FOD method



2.2.4 Emission factors with associated uncertainties

The guidelines mention potential uncertainty, in factors like DOC, MCF and OX, but without any further instructions or guidance. Uncertainty related to DOC_F or any factors related to the FOD-model are not mentioned. The use of the factor DOC_F introduces uncertainty particularly for lower temperatures. Questions can be raised whether this factor should be fully implemented, for example the DOC available for degradation is reduced by 0.56 when the temperature is 20°C. A substantial portion of the DOC is excluded without a proper basis.

The *IPCC Gu*idelines indicate that the uncertainties in the various factors in equation 1 will partly overlap, and thus must not be summarised directly, but by using the equation 9:

EQUATION 9

$$U_T = \pm \sqrt{}(U_E + U_A)$$

Where:

U_T: total uncertainty

U_E: uncertainty connected to source E

U_A: uncertainty connected to source A

Equation 9 is applicable only when U_E and U_A both are less than 60 percent.

For instance, if uncertainty is $\pm$ 10 percent for two factors, the total uncertainty would be $\pm$ 14 percent. The equation may be similarly extended, if more uncertainty factors are included.

In Table 3, default values and ranges from the *IPCC Guidelines* and ranges estimated by the authors of this paper are summarised. The actual uncertainty ranges can differ much by country depending on the level of information available. Table 4 presents how the uncertainties in the Norwegian inventory were broken down and summarised.

TABLE 3

DEFAULT UNCERTAINTIES GIVEN IN IPCC GUIDELINES AND ESTIMATED BY THE AUTHORS

Method	Default EF	Default range	Estimated range	Cause of uncertainty and comments
Default IPCC mass balance method	MCF	Default range 1 - 0.4 Default value 0.6	0.3 – 0.95 (or 1?)	Normally not 100% optimal Real average condition may vary.
	DOC_F	0.77	10 °C - 0.42 50 °C - 0.98	Unclear what happens to the DOC in low temperatures (alternative degradation processes or carbon storage in SWDS).
	F	50% default value	40 - 60%	Not sufficient in situ testing. LFG analysis world-wide
	OX	0 - default value 10% recommended	0 - 30%	No systematic and reliable survey has been presented.
FOD method introduced in the IPCC Guidelines	Lo	< 100 m^3/Mg - > 200 m^3/Mg		Same uncertainty as for DOC and DOC_F above.
	k	0.005 - 0.4		No further explanation of the basis for k is provided.
Adjusted FOD method	(k) with $t_{½}$	$t_{½}$: 4-10 yrs 7 yrs realistic as default value for tropical and 10 years for tempered climate		See Table 4 (Note: In the EPA model the range 14-17 years was chosen)
	Historical DOC_F and MCF			As for default method

TABLE 4

UNCERTAINTY ASSESSMENT IN THE NORWEGIAN CH_4 INVENTORY

Component	**Cause**	**Used value**	**Variation range**	**Uncertainty in component**	**Effect of uncertainty in total emissions in 1995**	**Comments**
Quantities of organic industrial waste outside MSW	Lack of information on portion of organic material in industrial waste. Inaccurate historic data	~ 100.000 ton in 1995 and onwards	1998 and onwards: 0-150.000	÷ 100 - +50%	÷ 10 % - +5%	Substantial uncertainty in how large portion have been disposed in larger SWDS
LFG production from organic industrial waste	Substantial uncertainty in the extent of anaerobic conditions in disposed industrial waste		~ 200 - 425 Nm^3/ton		÷ 5 % - 0 %	Mainly loose compacted landfills for waste from wood/tree processing and working
Quantities of construction/demolition waste not included in MSW	Uncertainty in the extent of anaerobic conditions and the portion of organic material in disposed construction/demolition waste	0	0 - 200.000 ton/yr generating LFG		0 % - +10 %	
Half-life time ($t_{½}$) for various waste types	Half-life times are based on estimate composition and adjusted to Norwegian climate	Household waste: 9,5 years Non- household waste in MSW: 11 years Industrial waste 11 years	Household waste: 7-11yrs Non- household waste in MSW: 10-13 yrs Industrial waste: 10-15 yrs	÷ 25 % - +15 % ÷ 10 % - +20 % ÷ 10 % - +35 %	Summarised: ÷ 5 % - +10 %	
Content of CH_4 in LFG	Based on review of various sources and on undisturbed LFG samples	55%	50 - 60%	÷ 10 % - +10 %	± 10 %	Employed values in other sources in the range 50% to 62%
Oxidation effect	Relatively newly reported aspect. International agreement of using 10%	10%	5-30 %	÷ 50 % - +300 %	÷ 20 % - +5 %	Recent research indicate higher values, particularly when proper top cover
MCF	Incorrect estimates of effects of site conditions not favourable for CH_4 production. No field surveys referred to	0.9 i 1995	From 0.95 – 0.8 in 1995	÷ 25 % - +10 %	÷ 15 % - +5 %	
Composition of MSW	Lack of data on composition of non- household waste in MSW		± 20-30% for several fractions	For non- household waste in MSW ± 10 - 15%	± 10 %	Mainly uncertainty related to non-household waste in MSW
Historical quantities before 1970	Insufficient information on estimates and trends			± 30%	± 2-3%	Limited effect due to high degree of degradation today
Summarised effect					**± 30%**	**Many of the uncertainty factors will internally even**

2.3 Choice of activity data

2.3.1 The default method

MSW_T - Total MSW quantities

The default model only requires figures for the inventory years. Developed countries often have statistics on MSW generation and disposal quantities. Such figures may for many developing countries and countries with economies in transition be based on sample surveys being scaled up through multiplying specific figures (kg/capita/day) with the assumed urban population. Full-scale and full-time weighing of MSW is very often not implemented on a national basis in large regions of the world, not even in the developed countries. This clearly introduces a substantial uncertainty.

The World Bank has presented a comparison of the average MSW generation related to average GNP per capita. In Table 5 and Figure 6 this relationship is indicated. Many SW surveys have confirmed the validity of this. This may also be an indicative basis for assuming historical changes.

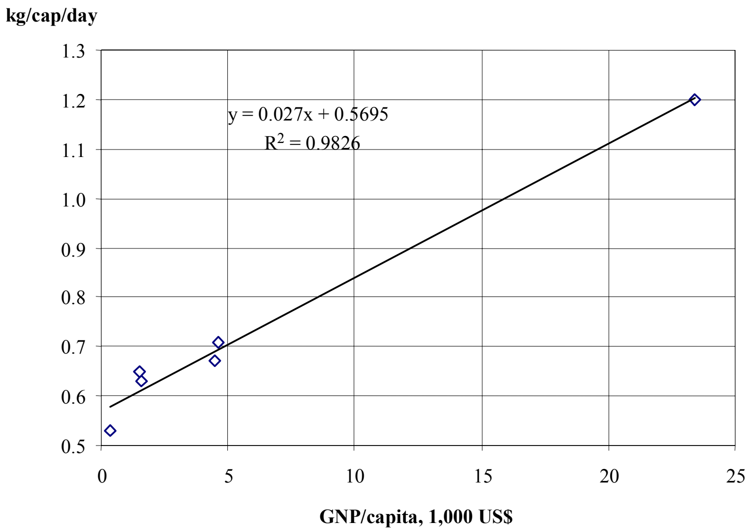
TABLE 5

CORRELATION BETWEEN INCOME LEVEL AND SPECIFIC WASTE GENERATION RATE FOR MUNICIPAL SOLID WASTE

	Average GNP per capita [1]	Average MSW generation [2]	No. of countries in statistics [1]
	US$/yr	kg/cap./day	
Low income	360	0.53	51
Lower-middle income	1,590	0.63	39
Jamaica	1,540	0.65	1
Upper-middle income	4,640	0.71	16
High income	23,420	1.20	24
World average	4,470	0.67	133

Sources:[1] World Development Report 1996. The World Bank [2] The Economics of MSW. The World Bank Research Observer vol. 2, 1995

Figure 6 Waste generation rates for municipal solid waste vs. GNP in various countries



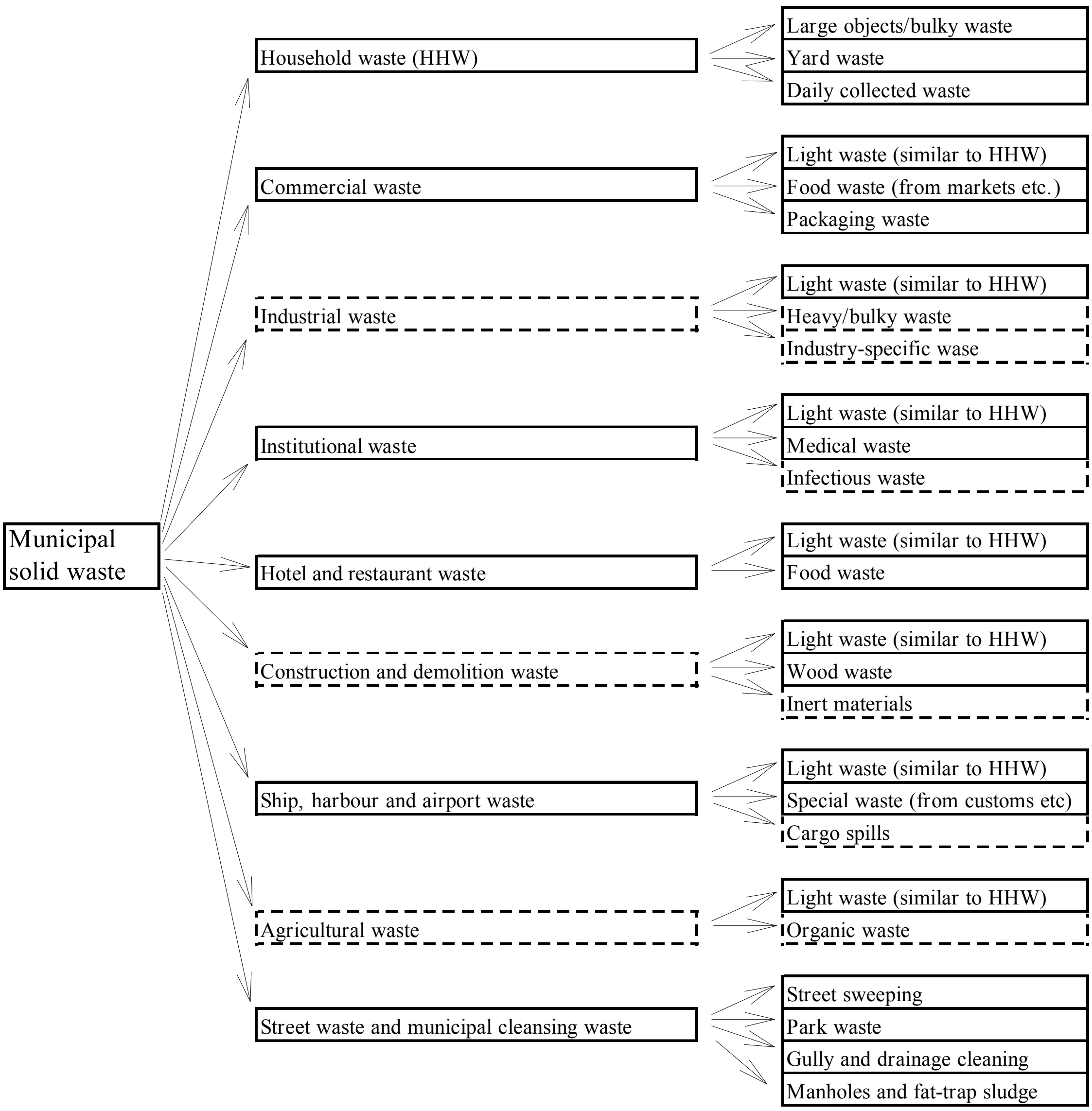
There is also a major concern of what types of waste to be included in these emission inventories. The IPCC workbook focuses on industrial waste as a potential LFG emission source in addition to MSW. The national inventories should, however, include all waste types, for example:

- agricultural waste (note: double counting with the CH_4 estimates from manure management in the agricultural sector must be avoided);
- building and demolition waste;
- ship/harbour waste;
- sludge;
- institutional waste (hospitals, municipal activities etc.), and
- other, not specified waste.

A presentation of SW types that may be included in the national inventories is in Figure 7.

Figure 7 Breakdown of major waste types in MSW

The waste types in dotted frames only partly enter the municipal waste stream.



The default values in the *IPCC Guidelines* do not include all these types, and national inventories must focus on establishing complete figures for the SW disposed in their country.

Another element with a substantial influence on the MSW_T figures is the split between urban and rural population, and if and to what degree the rural population should be included. Even in many developing countries, MSW from villages and townships is collected to some extent and brought to SWDS although their population is not included in the urban figures. Furthermore, many countries have limited updated information of their urban population.

Consequently, the figures for population to be used must be assessed and selected based on experience of the conditions in the country.

MSW_F - fraction to disposal

This fraction differs from MSW_T through:

EQUATION 10

$$MSW_F = (MSW_T \bullet CC) - MSW_{TREAT} - MSW_{REC}$$

Where:

CC: Collection Coverage (this figure may range from near 100 percent in many developed countries to 40-50 percent even in urban areas in many developing countries)

MSW_{Treat}: Registered or estimated MSW quantities to other treatment like incineration or composting

MSW_{Rec}: Registered or estimated MSW quantities to recycling

For many developing countries and countries with economies-in-transition the two last figures are relatively low, although an extensive recycling activity may be observed through scavenging and sorting both in the collection areas and in the SWDS.

R - Recovered LFG

Many countries have operative LFG extraction and recovery plants at present. The global number of plants is not known, but in 1995 some 270 plants with LFG recovery were reported worldwide (Doom and Barlaz, 1995). At present, the Scandinavian countries alone with a population of approximately 23 million have a total of more than 120 plants in operation, and UK have over 100 LFG recovery schemes, so the present world-wide figures should be higher than estimated by Doom and Barlaz for 1995.

Most modern LFG plants have a flare in operation when recovery for energy use is not in place, and normally a central flow meter with a counter would be installed. A flare will convert most of the CH_4 to CO_2. Thus the total extracted LFG quantities must be included in the figures for R under the condition that either flaring or recovery for energy use is implemented.

2.3.2 The FOD-model with supplements

In addition to the required input to the default model, the FOD-model requires historical figures or assumptions of change rates over time. Preferably these figures or assumptions should cover both quantities and composition of SW and disposal conditions.

There are international statistics and sources that may provide some of this information, presented in various publications from organisations such as United Nations (UN), International Monetary Organisation (IMF), World Bank (WB). These may be information on economic growth, urban population growth rates or MSW generation rates. Most countries have also available local surveys and supplementary information enabling estimates and/or assumptions of historical changes. As earlier mentioned, a historical period of 20-25 years would be appropriate for most countries in the tropical and sub-tropical zones, and relevant specific figures should be available based on various studies and surveys either in the country or in similar countries in the region.

2.3.3 Accuracy of activity data

The accuracy of activity data will vary fundamentally between the countries. For some developed countries, MSW quantities and composition are normally well documented and registered since the last 20-30 years, although the figures from the 1970's and earlier have more errors included. Probably the data on MSW generation and composition in countries with good data collection systems may have an uncertainty range of ±10-20 percent. In other countries, the uncertainties associated with MSW quantities and composition may be more than twice as large.

Even for most of the industrialised countries the figures on MSW_F and other SW disposal are more uncertain. This is especially true for data on industrial and other waste than MSW. The composition of other SW than MSW is also less well known and hence also the uncertainties associated with emission potentials larger. For instance, the waste emissions in the Norwegian inventory have been estimated to have an uncertainty of –80 to +50 percent., and that these emission figures have had an effect of –8 to +5 percent over time on the total national emission figures.

For many developing countries and countries with economies in transition, the inaccuracy will be substantial higher, with a multiple set of causes like:

- lack of weighing statistics;
- lack of updated figures for urban population;

- lack of information of collection coverage;
- lack of information of disposal conditions, and
- lack of information of management of SW outside the MSW.

Summarised, this may lead to inaccuracy in some countries of up to ±50% in the activity data.

2.4 Input to uncertainty workshop

Uncertainties associated with the emission factors (see text and Tables 3 and 4 in 2.2.4) and activity data (2.3.3) are addressed in the above chapters and ranges for the values are suggested. When assessing the total uncertainties of the emission inventories the uncertainties need to be combined. When using the FOD model the ability of the model to describe the timing of the emissions need also to be considered in the estimation of the uncertainties of the annual emissions. The uncertainties are, however, very dependent on quality of the country-specific data on the various input parameters needed in the calculations. The possibilities to produce figures on global and regional uncertainties in emission estimates will be explored at the Sao Paulo expert meeting.

2.5 Completeness

Completeness means that estimates should cover all sources and sinks, as well as all gases (included in the *IPCC Guidelines*) and other existing relevant source/sink categories which are specific to individual Parties, and therefore may not be included in the *IPCC Guidelines*. Completeness means also full coverage of sources and sinks of a Party to the UNFCCC (FCCC/SBSTA/1999/l.5).

Some factors that may, in addition to introducing uncertainty and inaccuracy, also result in the lack of completeness in the inventories, are identified:

- Rural population contributing to LFG and CH_4 emissions. The *IPCC Guidelines* assume that this population does not contribute to the emissions, while to some (though limited) extent they do, and
- Emissions caused by other SW types than MSW, particularly for countries using the specific generation figures and indicated default values given in *IPCC Guidelines*, might be missing entirely from the inventories. Although the Guidelines' workbook mention organic industrial waste as a source, no information on how to estimate emissions from this waste type is provided. For instance, Norway has a relatively wide definition of MSW, but still approximately 15 percent of the national emissions come from other SW types apart from MSW. In Finland the waste categories used in the calculation are MSW, industrial SW, construction/demolition waste, community and industrial sludge. MSW contributes 60 – 70 percent to the total emissions.

In the preparation of the inventories on GHG emissions from SWDS, Parties could use the following checklist to ascertain the completeness of their inventory:

- Activity data should cover all types of SW disposal (see Annex 7); if information on only MSW is used, this should be stated in the inventory;
- SW disposal may produce GHG emissions apart from CH_4, for example CO_2 from fossil waste, N_2O and NMVOCs. If information on these emissions is available, countries are encouraged to report them with descriptions and documentation on the emission estimation methods and emission factors, and
- Information on LFG recovery.

2.6 Baseline determination

The activity data available on SW disposal has improved considerably in many countries during the last decade and will continue to do so in the coming years. As activity data on 1990 cannot be improved afterwards, the consistency of the time series from 1990 onwards may suffer. Transparent reporting on how these issues are dealt with in the inventories is therefore very important.

3 REPORTING AND DOCUMENTATION

3.1 Existing reporting and documentation guidelines

IPCC Guidelines contain a sectoral table where emissions are to be reported and worksheets where all relevant information concerning the estimation of the emissions may be included. Documentation is required to enable review and comparison of the inventories (major assumptions, methodology, etc.) and to provide a basis for reconstruction of the inventories by a third party. The instructions also include an annex explaining how to manage uncertainties.

The UNFCCC Secretariat has prepared, in co-operation with the IPCC, new "Common Reporting Format" tables. The draft table for waste is very similar to the IPCC table on emissions from waste. The draft table on background data contains information on input values (activity data, emissions factors and other relevant information) used in the calculation. This new table clearly adds to the transparency of the reporting, but could still be improved.

Furthermore, information on the quality of the data used in the calculation is needed. The accuracy of the inventories is dependent on the collection systems for activity data being used, and the basis for the emission factors used. Information on how the activity data has been collected or estimated and the basis of the emissions factors and other variables used in the calculation is needed. This information will also enhance the transparency of the inventories.

When country-specific values are used they should be well documented and justified. As the factors influencing the emissions are very country-specific, determination of such values should, however, be encouraged.

3.2 Potential improvements

Some potential improvements on the current *IPCC Guidelines* are listed here. Some of them are already included in proposed Common Reporting Format – tables prepared by the UNFCCC Secretariat.

As the minimum supplementary information, the choice of method (default or FOD or other) should be presented. The tables should be modified accordingly.

For the method chosen, the selected type of data (default or country-specific or other) and emission factors should be presented, either in the national inventory or in attachments or cited documents.

For added transparency, as much as possible the following information should be attached:

- MSW_T and MSW_F and their basis (whether statistical data or default values are used, how the statistical data is collected and preferably a division in MSW and other SW types);
- Chosen DOC (data on waste composition) and $DOC_{F;}$
- Chosen OX;
- R-figures (LFG extracted/recovered, number of plants, etc.) and how the data is collected, and
- k value chosen if FOD-model used and how it is obtained (e.g. $t_{½}$ for different waste types).
- Major historical assumptions (how historical waste amounts are obtained (e.g. percent growth), change in MCF due to disposal practices, etc.) when using the FOD-model

3.3 Lack of Information

Many countries probably may lack established reporting requirements and routines, hence information may be available but is not automatically presented to the authorities or the inventory agency. This may be information of SW quantities in some regions in the country or information from LFG recovery plants, etc.

Thus, for all countries, improved reporting schemes should be encouraged and supported. As a minimum, all available information that may be available in the country should be collected. Normally, there should be no limitations in information availability due to commercial concerns or other private or official obstructions.

4 INVENTORY QA/QC

4.1 Introduction

Quality Assurance (QA) and Quality Control (QC) should be an integrated part of the inventory process. This will ensure a confidence in the inventory results among relevant parties.

The QA/QC process may be divided into an internal process and an external process. The internal procedure should ensure the accuracy, check for calculation errors and assure that the best available activity data and other information is used in the inventory. Inventory producers are encouraged to consult waste experts within the country. Externally, unbiased review and audit will enable identification of preparation errors and sources of incorrect inherent bias. Comparisons of emission factors with countries with similar conditions are encouraged.

4.2 Internal QA/QC items

Since the *IPCC Guidelines* introduce two methods for estimating emissions, national figures could be based on any of these. The reporting instructions may require countries to always report the potential emissions calculated with the IPCC default methodology and should encourage reporting of actual emissions also. The method used in the calculation should naturally always be reported.

4.2.1 Emission factors

The emission factors should be based on *IPCC Guidelines* and default values, or preferably on evaluations of and adjustments to local conditions. If the inventory agency does not have sufficient knowledge of the conditions, information may be collected from environmental authorities, institutes, consulting companies, etc. Some information may be collected from national statistics, for instance the status and number of SWDS.

Documentation of the factors, including both present and historical values, used in the calculation must be presented.

QA systems should be implemented in these decisions and a QC-form for verification and later review may be established.

4.2.2 Collection of activity data

When activity data is based on national statistics, it is important to use a QA system throughout the relevant reporting agencies. Information must be reported in a standardised form to enable transparency, and the reported figures should be checked by the inventory agency or others for completeness and correctness. When more simplified methods are used (like using specific figures multiplied with relevant population figures), the chosen values must be selected or verified by agencies with sufficient professional knowledge.

4.3 External QA/QC systems

This may include external reviews and audits, both during the inventory execution and after the draft figures have been presented. Some aspects to be reviewed are:

- Quality and appropriateness of emission factors in use;
- The use of the relevant equations, depending on the method;
- The correctness and validity of the resulting figures, and
- The QA/QC systems implemented in the inventory process

The external review should be implemented within certain intervals, not necessarily each year. As a minimum, initial review should be carried out when estimation method is changed.

External review may be carried through:

- Expert (peer) review by local or international experts;
- Third party audit; review by selected third parties;
- Review by stakeholders (government, official pollution agency, SW companies associations, etc.), and
- Public review (NGOs, etc.).

5 CONCLUSIONS

SW disposal is a significant source of CH_4 emissions in many countries. The CH_4 emissions from SW disposal have shown a declining trend in many industrialised countries lately, whereas the emissions from developing countries are expected to grow in the near future due to improved economy and improved landfill management practices.

The *IPCC Guidelines* give two methodologies for estimation of CH_4 from SW disposal – the IPCC default (a mass balance method) and the FOD (a first order decay method) methods. The emission estimates calculated with the two methods are not comparable. The mass balance method gives an estimate of the potential CH_4 emissions of solid waste disposed on land without consideration of the timing of the emissions. The FOD method takes the timing of the emissions into consideration and gives a more realistic picture of the actual emissions during for the inventory year in question.

Both the IPCC default method and FOD method have advantages depending on how the results are used. The IPCC default method gives an estimate of the total potential CH_4 emissions caused by disposal of a certain amount of SW, and the FOD method gives an estimate on how these emissions are realised in time. Changes in the amount of SW disposal are reflected immediately in the results of IPCC default method, whereas the FOD method responds corresponding to reality more slowly to the changes. The IPCC default method is easy to apply and the result are very transparent. The FOD method is more complicated and its use requires more input data and knowledge of the decay process at SWDS. As the emission estimates of the methods are very different, especially when changes in SW disposal are taking place, clear guidance on how the methodologies should be used in the preparation of national greenhouse gas inventories should be given.

The FOD is inadequately described in the *IPCC Guidelines* and default values for all parameters needed in its use are not given. Wider use of the method would require more information on how the necessary national input data can be estimated, as well as default values for the method parameters.

The uncertainties in the estimates on CH_4 emissions from waste are large, regardless of the method used. The data on composition and amount of waste disposed of at landfills is still often based on rough estimates and, when looking at past values, the lack of data is even greater. Statistics on both municipal and industrial waste management are currently improving in many countries, and future emissions will be based on more reliable data. Waste management and SW disposal practices, as well as the composition of waste, varies much from country to country. Data collection and choice of emission factors should therefore to the extent possible take national circumstance into account. Transparent and comparable reporting of the emissions is also important, as well as systematic evaluation and improvement of the accuracy and quality of the emission estimates.

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