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PRELIMINARY OPTIONS FOR METHODOLOGIES TO APPLY ADJUSTMENTS UNDER ARTICLE 5.2 OF THE KYOTO PROTOCOL

Preliminary options for methods to obtain revised greenhouse gas emissions estimates from the IPCC waste sector

Expert report

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RELATIVE SIGNIFICANCE OF SOURCE CATEGORIES

This technical background paper addresses the methodological options that could be used to obtain revised technical estimates of greenhouse gas (GHG) emissions from the IPCC waste source category. This source category consists of three sub-categories: solid waste disposal, solid waste incineration, and wastewater. Not all categories are equally significant as sources for GHGs and a prioritization of the major emissions will help focus on the most important sources. See Table 1.

Table 1. Approximate Global GHG Emission Estimates (Tg/yr CO_2 equivalent)

SOURCE	CO_2	CH_4	N_2O
Solid Waste	108	820	0
Wastewater	27	609	4 (10 selected Annex 1 countries)
Incineration	0.02 (Twelve selected Annex 1 countries)	0	3 (13 selected Annex 1 countries)
Total anthropogenic	26,000	7980	1,018 (Annex 1 only)

Source: DOE, 1998; Doorn et al., 1997. Doorn et al., 1999, UNFCCC Database.
Assumptions: landfill gas is approx. 50% CO_2 and 50% CH_4; wastewater gas is approx. 33% CO_2 and 67% CH_4. Global Warming Potential for CH_4 = 21 and for N_2O = 310 CO_2 equivalents.
Time frame: 1990 - 1995

Carbon Dioxide

Judging from Table 1, none of the three sources are large contributors to national and global CO_2 budgets. The 1996 IPCC Guidelines do not include methods to estimate emissions from MSW disposal or wastewater. In addition, CO_2 from solid waste and wastewater is typically biomass, so it is neutral in global warming terms.

No global estimates for CO_2 emissions from incineration were found, but many Annex 1 countries have submitted CO_2 emission estimates to UNFCCC. The average contribution of incineration to national CO_2 budgets is 0.5%, so it is justified to state that incineration is an insignificant contributor to national CO_2 emissions. Only Switzerland and Japan show emissions from this source category that are greater than one percent. The uncertainty associated with this gas and source category is relatively low (5% according to the draft Good Practice Guidelines). Therefore, maximum emissions from this source category will not be much higher than what is submitted by the Parties.

Methane

According to Table 1, methane emissions from municipal solid waste (MSW) disposal and wastewater are significant. Together, they make up about 18% of total methane emissions. Incineration produces no CH_4 due to its combustion nature.

Nitrous Oxide

The 1996 IPCC Guidelines include no methodology for N_2O from solid waste. But there is a methodology for estimating N_2O from wastewater from human sewage (domestic wastewater). The methodology is directly copied from the agriculture section and may, therefore, be less appropriate. The author is unaware of other existing methodologies. The draft Good Practice Guidelines also point to a lack of data and a possible over-simplification of the methodology (see footnote in Section 5.2).

A review of the emission estimates submitted by Parties indicates that this is not a large source of N_2O emissions (See Table 2). This is supported by other documentation in the literature (See Annex 1). For example, Czepiel et al. (1995) in Doorn, et al. (1997) estimated that for the United States N_2O emissions from conventional activated sludge WWT were 1,200 Mg/yr or 0.3 percent of national emissions. Schön et al., (1993) in Doorn, et al. (1997) estimated that German N_2O emissions from activated sludge WWT are about 0.2 percent of total emissions. On the other hand, one paper was found that suggests that wastewater discharged into rivers may be a significant source of N_2O emissions (See Annex 1).

Table 2. Total and Wastewater N2O Emissions for Ten Annex 1 Countries (Gg CO2 Equivalent)

	WASTEWATER	TOTAL	PERCENT
Canada	868	55,800	1.6
France	611	94,581	0.6
Germany	1,240	69,626	1.8
Latvia	84	6,984	1.2
Luxembourg	5	197	2.5
Netherlands	155	19,809	0.8
Portugal	908	4,340	20.9
Slovakia	62	3,875	1.6
Switzerland	19	3,565	0.5
United Kingdom	153	66,100	0.2
Total	4,105	324,877	1.3
Total (ex. Portugal)	3,197	320,537	1.0

1996 data

The 1996 IPCC Guidelines also do include a methodology for estimating N_2O from incineration and 13 Annex 1 countries have submitted emissions estimates which are included in Table 3. Incineration does not appear to be a large source of N_2O emissions; average 1.0% of national emissions. Only for Japan and Switzerland, annual N_2O emissions from this source are above one percent of total N_2O emissions. (Japan = 8%, Switzerland 1.4%). Switzerland incinerates all of its municipal waste and Japan incinerates 70%. *Note: The high Japan number may be an outlier. On the other hand, Japan may incinerate all of its sewage sludge, which is a nitrogen source, and Switzerland may not. Data on sewage sludge are not included in the documentation that has been reviewed.* According to the draft Good Practice Guidelines, uncertainties in N_2O emission estimates from incineration can be as high as 100%. Therefore, maximum emissions may be up to two times as high as reported numbers.

Table 3. Total and Incineration N2O Emissions For 13 Annex 1 Countries

(Gg CO_2 EQUIVALENT)	INCINERATION	TOTAL	PERCENT
Austria	3	2,030	0.1
Belgium	31	9,539	0.3
Canada	53	55,800	0.1
France	357	94,581	0.4
Greece	93	9,269	1.0
Italy	93	50,964	0.2
Japan	1,515	18,090	8.4
Luxembourg	2	197	1.0
Russian Federation	93	69,967	0.1
Slovakia	31	3,875	0.8
Switzerland	49	3,565	1.4
United Kingdom	115	66,100	0.2
United States of America	310	351,230	0.1
Total	2,744	735,206	0.4

1996 data

Recommendation

It is recommended that efforts to estimate or improve GHG emissions from the waste source category focus on CH_4 emissions from solid waste disposal and wastewater, because these sources account for an average of about 18% of total methane emissions on a country- or regional basis.

N_2O emission from incineration is a small source category (average 1.0% of national emissions) and, therefore, it is not recommended to review this source further. The uncertainties for this gas and source category may be as high as 100%. Uncertainties for N_2O from the wastewater category are expected to be even larger. Because not enough research has been done not enough information is available to develop any emission estimates for N_2O from the wastewater.

The average contribution of incineration to national CO_2 budgets is about 0.5%, so it is justified to state that incineration is an insignificant contributor to national CO_2 emissions. The uncertainty associated with this gas and source category is relatively low. Solid waste disposal and wastewater are negligible sources of CO_2.

METHANE FROM SOLID WASTE DISPOSAL: METHODS TO OBTAIN REVISED ESTIMATES

When a tonne of coal is burned for energy purposes, the source (geographic location, country, industry, or process) has little or no influence on the magnitude of the emissions. The amount of CO_2 released can be estimated accurately based on the amount of carbon in the coal and emissions are instantaneous. The efficiency of the energy conversion process will play a role if emissions are expressed per unit of energy, but even that is ultimately governed by principles of physics.

For solid waste the situation is very different. Many factors decide how much methane may be emitted from a ton of landfilled solid waste (including but not limited to: temperature, humidity, pH,

behavior of bacteria, type of waste, carbon content). This amount can vary between zero and a theoretical maximum based on total anaerobic conversion of degradable carbon. Another essential difference is that disposed solid waste will emit methane over time, whereas emissions from combustion are instantaneous. In addition, quantification of the tonnes of coal burned in a country is much easier than quantification of the tonnes of waste that were landfilled in year X, but also in previous years.

Except for OECD countries, it is difficult to find data on per capita solid waste generation and disposal. Solid waste disposal/treatment practices are economically and policy driven and can vary strongly from one country to another. For example, The Netherlands is phasing out landfilling in favor of composting and incineration, whereas the United Kingdom views landfilling as the best option. Yet, these countries are culturally and economically comparable and geographical neighbors.

Existing Methodologies to Estimate Emissions

The 1996 IPCC Guidelines provide two main methods to estimate methane from this source. The "First Order Decay Model" requires current and historical data and accounts for methane from solid waste that was disposed in the past. But often, these historical data are not available, so it is likely that most countries will use the "Default Methodology" which assumes that emissions are instantaneous. This is not an unreasonable assumption if there are only gradual changes in waste generation and management over time. Both the First Order Decay and the Default methodology in the 1996 IPCC Guidelines incorporate the following main parameters:

- Population
- Per capita municipal solid waste generation (MSW) generation
- Fraction of waste disposed in a landfill (as opposed to recycling, composting, etc.)
- Degradable organic fraction in the waste (available organic carbon content)
- Methane correction factor (Degree in which landfill is anaerobic and the methane is not oxidized in the top layers of the landfill)
- Amount of methane that is recovered for flaring or energy recuperation.

The waste data that are used in the methodologies refer to MSW. There are also other wastes that may be landfilled which should either be considered separately or ignored, e.g., construction and demolition debris, and industrial waste. MSW may be recycled, composted or incinerated, reflecting country government policies or cultural preferences. Per-capita-MSW data are collected by various organizations (e.g., at city level) because they are needed to plan waste collection and disposal.

The degradable organic fraction is calculated from the weighted average of the carbon content of various components of the waste stream (page 6.8 in the 1996 IPCC Guidelines).

The methane correction factor reflects the physical conditions of the waste disposal site. Shallow, uncovered dumps are unlikely to produce methane, whereas deep landfills are likely to be totally anaerobic and produce methane. Methane emissions are further affected by the presence and quality of a soil cover on the landfill. When there is no cover or when the cover has large cracks, the methane may escape unhindered. But in situations with a soil cover, the methane will have to travel through the soil where soil methanophages may convert it into CO_2. Ultimately, certain countries may have imposed regulations that require methane collection systems for landfills above a certain size, which obviously, impact the emissions to the air.

Methodologies to Revise Estimates

1. IPCC "Default" method using available data (from Party or external)

As long as a Party has provided adequate documentation, a quality check of the parameters used should be fairly straight forward. The entries for different parameters as submitted by the country can be compared with the defaults. The 1996 IPCC Guidelines include defaults for countries/regions and other parameters that are used in the methodology. Also, Doorn, et al. (1995) contains comprehensive defaults that were compiled from the literature and expert judgment. Furthermore, data are available from OECD reports (See Table 4) and the Good Practice Guidance Report provides further assistance in choosing default factors. The Good Practice Guidance Report also includes updated uncertainty information. Uncertainties range between ± 15% for countries with excellent data and may climb to ± 50% for other countries.

Country populations may easily be obtained and good per-capita-solid-waste generation data are available for OECD countries. Alternatively, default per-capita-solid-waste generation data may be used from the 1996 IPCC Guidelines. Waste disposal data are also available for OECD countries but for many other countries this fraction may be hard to compute.

The degradable-organic-fraction is a parameter with high potential uncertainty. This parameter pertains to the waste that was or is actually landfilled or dumped. As such, it is also dependent on the extent of waste disposal practices such as composting, that remove the organic fractions from MSW.

As mentioned earlier, the methane correction factor reflects the physical conditions of the waste disposal site. Expert judgment must be used to assign a value to this factor and the default values suggested in Table 6-2 in the 1996 IPCC Guidelines are deemed adequate for this purpose.

Table 4. Waste generation and disposal data, and income for OECD countries

	MSW (kg/cap/yr	RECYCLING/ COMPOSTING	INCINERATION	LANDFILL	GDP ($/cap)
Australia	690	**	**	**	22,689
Austria	480	38	14	48	23,985
Belgium	470	14	31	55	24,097
Canada	630	19	6	75	24,468
Czech Rep.	230	**	**	99	13,137
Denmark	530	23	54	22	26,280
Finland	410	33	2	65	21,659
France	560	9	32	59	22,091
Germany	400	29	17	51	22,835
Greece	310	7	**	93	14,463
Hungary	420	**	7	93	10,524
Iceland	560	14	17	69	26,296
Ireland	430	8	**	92	22,509
Italy	470	**	6	94	21,739
Japan	400	4	69	27	24,109
Korea	390	24	4	72	13,540
Luxemburg	530	28	43	28	34,536
Mexico	330	1	**	99	7,998
Netherlands	580	38	27	35	23,082
New Zealand	***	**	**	**	17,712
Norway	620	15	16	69	27,497
Poland	290	2	**	98	7,986
Portugal	350	12	**	88	15,266
Spain	370	12	4	83	16,740
Sweden	440	19	42	39	21,213
Switzerland	610	40	46	14	26,576
Turkey	590	2	2	81	6,720
UK	490	7	9	83	21,170
USA	720	27	16	57	30,514

Source: OECD Website (Environmental data). Waste data mid-1990, Income 1998

Usually the amount of methane that is flared on a national basis is unknown and must be estimated. A conservative value is appropriate, because methane emissions will still occur from leaks in the soil cover or from older landfills that are closed.

--Example
In the following example, CH4 emissions are estimated for Belgium for 1995. Use Equation 1 in the 1996 IPCC Guidelines.

Parameter	Value	Source
Population:	10,000,000	UN or OECD
Per capita MSW generation:	1.29 kg/cap/day	OECD. See Table 5
Fraction of waste disposed in a landfill:	55%	OECD. See Table 5
Degradable organic fraction in the waste:	Paper and textiles = 24%; Yard waste = 16%; Food waste = 36% Inerts = 24%. DOC = 0.4x24 + 0.17x16 + 0.15x36 = 18%	Waste composition from Doorn et al., 1995. Equation 2 and default DOC values from Table 6-3 in the 1996 IPCC Guidelines.
Fraction of methane in landfill gas:	50%	
Methane correction factor:	1.0	Table 6-2 from 1996 IPCC Guidelines
Amount of methane that is recovered for flaring or energy recuperation:	10%	Guess based on Doorn et al. 1995.

Thus, methane emissions are: $10 \times 10^6 \times 1.29 \times 365 \times 55\% \times 18\% \times 50\% \times 1.0 \times 90\% \times 10^{-9} = 0.21$ Tg/yr. The emissions reported to UNFCC by Belgium were 0.184 Tg/yr. Given the error margins associated with this source category, the two estimates are mathematically the same.

2. Estimation based on Annex I averages and driving factor
The OECD provides useful data for their member countries that include: per capita MSW generation, population, and fraction landfilled (See Table 4). A methodology to estimate methane emissions for country X by making use of averages across submissions from other countries could be as follows:

- List available methane emissions from other countries
- Determine average fraction landfilled (F) over last 10 to 20 years
- For each country, divide methane emissions by average fraction landfilled (F)
- This provides methane emissions in case all MSW would be landfilled (M)
- Determine Total Annual Waste Quantity (Q). If this is not available, compute it by multiplying Per Capita MSW Generation with Population
- Divide M by Q
- This provides methane emissions per kg of waste generated
- Take average of all countries weighed by population. (Multiply by the country's population divided by the total population of known countries)
- Multiply by Q for country X
- Multiply by F for country X.

Most parameters are available, either from the countries themselves or from 1996 IPCC Guidelines defaults. F, the average fraction landfilled over the last 10 or 20 years, may best be obtained from a country expert. Mathematically, this method is similar to computing the CH4 emissions directly. Therefore, the margin of error is also similar, i.e., 50% for most countries, 15% for countries that have very accurate emission estimates.

--Example
In this example the emissions for Belgium are estimated, based on data from three other North European countries. See Table 5 below. Note that values for the fraction landfilled are higher than the data from Table 4. This is because these fractions must reflect the historical as well as the present. Norway, Denmark, and the Netherlands have recently embarked on rigorous programs to divert waste from landfills in favor of composting and incineration. However, the waste in the landfills reflects, in part the historical situation when this was not yet the case. Therefore, F values in Table 5 are best guesses.

Table 5. Example Estimation of CH4 Emissions for Belgium (1995)

COUNTRY	UNIT	NORWAY	DENMARK	NETHERLANDS	BELGIUM
CH_4 emissions	Tg/yr	0.191	0.072	0.479	??
Fraction landfilled F	%	80	40	60	70
Max CH_4 emissions M	Tg/yr	0.239	0.180	0.798	*0.381*
Population	Million	5	5	16	10
MSW generation	kg/cap/yr	620	530	580	470
Total Waste Q	Tg/yr	3.1	2.65	9.28	4.7
M/Q	g/g	0.077	0.068	0.086	
M/Q	Weighed by population	0.015	0.013	0.053	Weighed average = *0.081*

The weighed average M/Q for the three known countries is 0.081. This is multiplied by $Q_{Belgium}$ and by $F_{Belgium}$: 0.081 x 4.7 x 70% = 0.266 Tg/yr. This is significantly higher than what was reported by Belgium to UNFCCC (0.184 Tg/yr). However, if one multiplies the M by a value for F that is lower, for example 50% instead of 70%, then the emissions are 0.19, which is within the same range 0.184 Tg/yr.

If this approach is to be used, several assumptions must be made. The main assumption is that landfills in different countries are similar, so that the waste will decompose anaerobically to equal degrees. For example, all landfills are sanitary landfills with proper soil covers, gas collection, and leachate management.

Another important assumption is that the Degradable Organic Carbon (DOC) content of the waste is the same for different countries, i.e., that a given amount of generic MSW produces the same amount of methane. This is not a good assumption because the composition of landfilled waste in different countries varies because of culture, composting and recycling policies and other measures that have an effect on the amount of degradable organic carbon that is landfilled. It is possible to adjust for DOC differences between countries by using defaults provided in the 1996 IPCC Guidelines. But one must realize that by introducing this step, it may be better to use Option 1 and recalculate the emissions altogether.

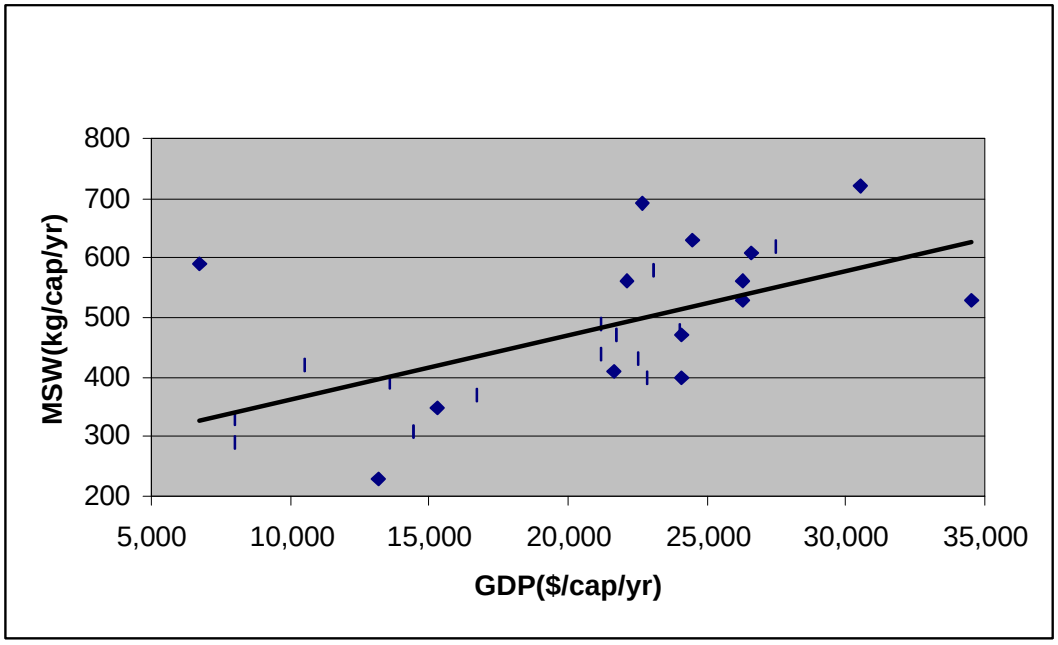
3. Extrapolation based on a driving factor

In the case that emission estimates need to be computed for a country, when only one or few data points are available, it may be possible to scale the existing data point(s) with a driver. The preferable driver would be the quantity of MSW that is landfilled. This parameter can be computed from the fraction landfilled, the per capita waste generation, and the country population. If this parameter is not available, a surrogate parameter must be identified. One possible surrogate parameter is income.

In Figure 1, per capita waste generation was plotted against annual per capita income for OECD countries. The line in the graph indicates there is a positive correlation between waste generation and income. Therefore, it appears justified to use per capita income as a driver to assess MSW generation changes. Although this was not researched in this study, it is likely that gross domestic product may also be used. Again, it must be assumed that for the different data points, there are only small changes in waste composition, as well as in waste management and disposal practices. The advantage of this method is that per capita income and GDP numbers are easily available in the literature.

This technique could be used for one country, to calculate emissions for missing years. In addition, this technique could be used to estimate emissions for one country based on data for another country. Again, one must assume that the other parameters, such as DOC and waste management and disposal practices are similar for the countries involved. Because of this assumption and because country-specific estimates already have a significant uncertainty associated with them, one may assume that the uncertainty here is larger than 50%.

Figure 1. Per capita waste generation and annual income for OECD Countries



4. Linkages of emissions between sources and gases

Obviously there should be a reverse link between incineration and solid waste disposal. But, incineration is the less significant category compared to solid waste disposal. So, it is not recommended to develop solid waste disposal data from incineration data. In addition, the link is expressed in the "fraction landfilled" versus "fraction incinerated". These parameters are easy to interpret and may just as well be applied within the separate methodologies. The author sees no other potential links between the solid waste disposal source category and other source categories.

5. Interpolation and extrapolation

When multiple data points for the same country are available, simple interpolation or extrapolation is an acceptable technique. Due to the fact that emissions from this source category take place over time, emissions will fluctuate little and only change gradually from one year to the next. The uncertainty associated with simple interpolation or extrapolation is small. Estimates computed with this method should have an uncertainty similar to the uncertainties of the available estimates.

Errors may be caused by sudden implementation of landfill gas collection systems on a large scale. This occurred in the United States where the "Landfill Rule" caused a reduction of emissions of 7% between 1990 and 1997 in spite of growing population and per capita waste generation.

METHANE FROM WASTEWATER: METHODS TO OBTAIN REVISED ESTIMATES

As with solid waste, the amount of methane emitted from wastewater may vary between zero and a theoretical maximum amount. Pertinent parameters reflect the amount of available organic carbon, as well as the presence of anaerobic and other essential bacteria, which depends on the wastewater disposal and treatment system (or lack thereof). Wastewater disposal/treatment practices are economically, culturally, and policy driven and can vary strongly between countries. Doorn et al., (1997) and Doorn and Liles (1999) provide further reading.

N.B. This paper focuses on emissions from Annex 1 countries, which are relatively small (Usually less than 1% of total national emissions). Some Annex 1 countries in Eastern Europe may have somewhat higher emissions. The largest emissions, and therefore, also the biggest potential errors are associated with populous developing countries, such as China and India, where the use of (anaerobic) latrines is widespread. The 1996 IPCC Guidelines do not address emissions from uncollected and/or untreated wastewater, although this may be a much larger source compared to wastewater treatment. (Doorn and Liles, 1999.)

Existing Methodologies

Existing methodologies to estimate methane emissions from wastewater typically differentiate between industrial and domestic wastewater. The 1996 IPCC Guidelines include methodologies for these source categories.

Country-specific methods for domestic wastewater generally include the following parameters:

- population
- per capita degradable organic carbon component (usually expressed in biochemical oxygen demand)
- maximum methane producing capacity which is a type of emission factor
- the degree to which the available carbon will decompose anaerobically ("methane conversion factor")
- fraction of the wastewater that is treated in a specific system.

The methodology for industrial wastewater includes:

- industrial output
- quantity of wastewater produced per ton of product output
- degradable organic carbon per cubic meter of wastewater
- maximum methane producing capacity which is a type of emission factor
- the degree to which the available carbon will decompose anaerobically ("methane conversion factor") which is dependent on the type of disposal/treatment system
- fraction of the wastewater that is treated in a specific system.

The methane conversion factor (MCF) is dependent on the type of disposal/treatment system. Some systems, such as anaerobic lagoons or latrines are fully anaerobic, whereas other systems are partially anaerobic or fully aerobic. Emission estimates are country, industry, and treatment system specific and must be summed to obtain total country emissions.

Methodologies to Revise Estimates

The wastewater source category consists of domestic and industrial wastewater. Interpolation or extrapolation across different years for the same country is probably possible.

Because of the specific nature of this source category, it is not likely that emissions can be linked properly with emissions from other source categories.

Given the above, a comprehensive recalculation of both domestic and industrial wastewater emissions may be the only way to review estimates that are under suspicion.

1. IPCC Method Using Available Data

A country that has submitted data for this source category to the UNFCC, is likely to have used the methodology provided in the 1996 IPCC Guidelines. Unfortunately, the IPCC methodology is sometimes hard to interpret and inclomplete. The draft Good Practice Guidelines aim to make the IPCC aware of this and suggest improvements. Therefore, it is strongly recommended to wait with review of wastewater emissions data until the Good Practice Guidelines have been published. Any attempt to use the 1996 IPCC Guidelines to develop new estimates should be in concert with the Good Practice Guidelines.

A detailed discussion of the 1996 IPCC Guidelines methodology to estimate emissions from wastewater is beyond the scope of this background paper. Because of the nature of this source category, as well as the confusion and possible errors associated with the 1996 Guidelines, it is not possible to adequately quantify uncertainties for this source category.

2. Alternative Method for Domestic Wastewater

The draft Good Practice Guidelines include an alternative method to obtain estimates for domestic wastewater for a country, the "Check Method". As the name implies, this method is a quick method that is intended to provide a general estimate. It also includes emissions from uncollected wastewater (septic tanks and latrines) which have previously not been addressed by the 1996 IPCC Guidelines. Hence, estimates via this method may be substantially higher than other estimates for countries that make extensive use of these types of systems. (This would not include many Annex 1 countries.) An example to estimate emissions using the Check Method is included in the draft Good Practice Guidelines. Until the draft Good practice Guidelines have been peer reviewed and the IPCC has accepted this method, it is not recommended to use this method to revise estimates.

SUMMARY AND CONCLUSIONS

Carbon Dioxide and Nitrous Oxide

The waste category consists of three source categories: solid waste disposal, solid waste incineration, and wastewater. Methane emissions from MSW disposal and wastewater are significant. Together, they make up about 18% of total methane emissions for Annex 1 countries. The three sources are negligible contributors to national CO_2 budgets and the uncertainties associated with CO2 emissions from these sources are small.

Also, N2O emissions from landfills are not considered by the IPCC and N2O emissions from wastewater and incineration are small. Uncertainties in N2O emission estimates from incineration can be as high as 100%. Therefore, maximum emissions may be up to two times as high as reported numbers. Uncertainties for N_2O from the wastewater category are expected to be even larger, because not enough information is available to develop adequate emission estimates for N_2O from the wastewater. N2O emissions are not considered further in this study.

Methane from Solid Waste Disposal

The best approach to develop revised estimates of CH_4 emissions from solid waste is a comprehensive assessment of the values and defaults that were used. Default values for most parameters are available, but quantification of some parameters will strongly benefit from expert judgment. Most default parameters are easy to interpret, but can have large margins of error associated with them. The Good Practice Guidance Report includes updated uncertainty estimates. Uncertainties range between ± 15% for countries with excellent data and may be as high as ± 50% for other countries.

Alternatively, simple scaling may be suitable to check or improve estimates for countries. Scaling factors that may be used are population or per capita income, both of which are readily available. Again, one must assume that the other parameters, such as DOC, waste composition, as well as waste management and disposal practices are similar for the countries involved. Because of this assumption

and because country-specific estimates already have a significant uncertainty associated with them, one may assume that the uncertainty here is larger than 50%. Because of the specific nature of the solid waste source category, emissions can not be linked properly with emissions from other source categories.

Methane from Wastewater

The wastewater source category consists of domestic and industrial wastewater. Simple interpolation or extrapolation across different years for the same country is possible and should not add significant additional uncertainty to the estimates. When no estimates exist for a country or the estimate is under suspicion, a comprehensive recalculation of both domestic and industrial wastewater emissions is the only alternative.

However, as the draft Good Practice Guidelines indicates, the 1996 IPCC Guidelines for this source category are sometimes hard to interpret. It is recommended to wait with review of wastewater emissions data until the Good Practice Guidelines have been published. Any attempt to use the 1996 IPCC Guidelines to develop new estimates should be in concert with the Good Practice Guidelines. Due to its nature, uncertainty for this source category is already large. Inconsistencies in the 1996 Guidelines, add to the uncertainties and any attempt to quantify the uncertainties is not considered useful at this point.

REFERENCES

DOE 1998. *Emissions of Greenhouse Gases in the United States.* Energy Information Administration. U.S. Department of Energy. Washington DC 20585. USA. DOE/EIA-0573(97)

Doorn, M.R.J. and D. Liles. 1999. *Quantification of Methane Emissions and Discussion of Nitrous Oxide, and Ammonia Emissions from Septic Tanks, Latrines, and Stagnant Open Sewers in the World.* Prepared by U.S. EPA, National Risk Management Research Laboratory, Research Triangle Park, NC, October, 1999. EPA-600/R-99-089.

Doorn, M.R.J., R. Strait, W. Barnard, and B. Eklund. *Estimate of Global Greenhouse Gas Emissions from Industrial and Domestic Wastewater Treatment.* Final Report prepared for U.S. EPA, Air Pollution Prevention and Control Division, Research Triangle Park, NC. EPA-600/R-97-091, September, 1997.

1996 IPCC Guidelines, 1996

Good Practice Guidelines, IPCC, 1999 (draft)

ANNEX 1: N_2O EMISSIONS FROM WASTEWATER

Below, two sections from Doorn, et al., 1997, pp. 21, 22, 23, 56, and 57.) are included that provide background information on N_2O emissions. The section entitled "N_2O from Rivers" is from a Good Practice background paper by John Hobson.

Nitrification and denitrification processes are an integral part of comprehensive wastewater treatment (WWT). Both processes are thought to be capable of producing N_2O, however, denitrification may be considered the dominant mechanism in N_2O formation (Debruyn et al., 1994). For both nitrification and denitrification a carbon source is required for cell growth and nitrification also requires oxygen. Nitrification ($NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$) is the first step in nitrogen removal and takes place in aerobic reactors such as trickling filters or rotating biological contactors, either separate or in combination with carbonaceous matter removal. Nitrifying bacteria are sensitive organisms and are extremely susceptible to a wide variety of inhibitors.

During denitrification ($NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$), N_2O is formed as an intermediate product and is usually consumed within cells, although some species excrete N_2O without further reduction (Hanaki et al., 1992). Denitrification is the second step in nitrogen removal and takes place under anoxic conditions. The presence of dissolved oxygen will inhibit the process, however, denitrification may not be described as an anaerobic process. The biochemical pathways are modifications of aerobic pathways (Metcalf and Eddy, 1991). As with nitrification, denitrification organisms are sensitive to changes in temperature and pH. Usually, an extra carbon source is required for cell growth.

Hanaki et al. (1992) researched N_2O emissions during denitrification from wastewater under steady-state, laboratory conditions. It was found that favorable conditions for N_2O production were a relatively low pH, a low COD/nitrogen (as NO_3) ratio, and a short HRT (i.e., less than one day). Knowledge acquired by Hanaki et al. indicates that N_2O production probably cannot easily be related to one single parameter of the wastewater, such as nitrogen concentration. N_2O is an intermediate product formed during denitrification and its formation and emissions are dependent on the incompleteness of various denitrification reactions that are governed by parameters that include pH, HRT, and feed concentrations.[1] Consequently, it will be difficult to develop accurate emission factors. The emission factor expressed by Hanaki et al. is 0.13 gram N_2O per gram nitrogen (as nitrate). Unfortunately they do not provide other wastewater data that allow for the development of more practical emission factors for estimating country-specific emissions (e.g., N_2O per COD or per capita).

In another study Czepiel et al. monitored N_2O emissions at an activated sludge plant in Durham, New Hampshire (Czepiel et al., 1995). As did Debruyn et al., and Hanaki et al., Czepiel et al. conclude that N_2O is generated in anaerobic sections of the WWT layout as an intermediate byproduct of denitrification. Potential sources are sewer lines, primary settling tanks, secondary clarification tanks, sludge holding tanks, and sludge transfer pipes. At the Durham POTW it was found that mechanical aeration (stripping) was a key release mechanism for N_2O. Czepiel et al. (1995) emphasize that they found no correlation between temperature and N_2O emissions. Emission factors derived from the

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1 Hanaki et al. concluded that N_2O production can be avoided by achieving complete denitrification by assuring high COD/NO_3-N concentrations, long HRTs, and neutral to alkaline pH.

Durham field tests include per capita emissions of 3.2 g N_2O/yr and flow based emissions of 1.6×10^{5} g N_2O/l of wastewater treated for an activated sludge system. Expressed per gram of SS, the emission factor is 0.14 mg/g SS.

Doorn et al., 1997 suggests the following emission factors to estimate N_2O emissions from WWT: 5.1 g/capita/yr for conventional[2] domestic WWT; and 0.09 g/g COD for anaerobic WWT that is either domestic or industrial. These emission factors are applied below.

Approximately 734 million people in the world are served by conventional WWT including aerobic and facultative lagoons. Consequently, global N_2O emissions from conventional domestic WWT are estimated at $5.1 \times 734 = 3{,}743$ Mg/yr (0.004 Tg/yr). Estimated global N_2O emissions from anaerobic domestic WWT are $0.09 \times 5.4 = 0.5$ Tg N_2O/yr. (The amount of COD in global domestic wastewater that is treated under anaerobic conditions is 5.4 Tg/yr).

Wastewater from the meat, poultry, fish, and dairy processing industries is expected to contain substantial amounts of bound nitrogen. The amount of COD in anaerobic wastewater from these industries is estimated to be 2.7 Tg/yr. Consequently, global N_2O emissions from this source category are estimated at $0.09 \times 2.7 = 0.24$ Tg N_2O per year. Czepiel et al. (1995) estimated that for the United States N_2O emissions from conventional activated sludge WWT were 1,200 Mg/yr or 0.3 percent of national emissions. Schön et al., (1993) estimated that German N_2O emissions from activated sludge WWT are about 850 Mg/yr or 0.2 percent of total German N_2O emissions. Debruyn et al., (1994) estimated that N_2O emissions from Belgian wastewater are 0.6 percent of total Belgian emissions, but provides no absolute figures. These estimates are associated with large uncertainties and are, at best, an indication of the relative significance of this source category.

N_2O from Rivers

Nitrogen in rivers comes from wastewater discharges as well as agricultural run-off. This source has not been previously addressed. Only one paper has been found covering this issue. A short synopsis is presented. McMahon and Dennehy (1999) investigated the South Platte river in Colorado. This river was heavily enriched both in nitrate from groundwater and ammonia from sewage effluent (9-800 μm) (groundwater in the region contained up to 3450 μm nitrate-N). N_2O emission rates ranged from 90 to 32,600 μg N/m^2.day. For the stretch of river in question overall emissions were 2 to 6 x 10^7 g/year as N (20 to 60 tonnes per year) depending on the time of year. Considering that 800 km out of over 100,000 km of N enriched rivers was studied, total annual emissions from this source in the US could be very much greater than those estimated by Czepiel from all US sewage treatment works.

McMahon and Dennehy (1999) Environ. Sci. Technol. 1999, 33, 21-25.
All other references in Doorn, et al., 1997

[2] Most conventional WWT is expected to be activated sludge WWT with nitrification/denitrification.