

THE SHARE OF METHANE AND NITROUS OXIDE EMISSIONS OF THE TOTAL GREENHOUSE GAS EMISSION INVENTORY UNCERTAINTY

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In this contribution, the uncertainty in the sources of CH₄ and N₂O in greenhouse gas emission inventories under UNFCCC (United Nations Framework Convention on Climate Change) is considered using the uncertainty assessment of the Finnish National Inventory as an example. Though CH₄ and N₂O emissions represent less than a fifth of the Finnish greenhouse gas emissions, they have a significant impact on the total inventory uncertainty. According to estimates, the uncertainty in the total N₂O emissions in Finland is -30...+40% and that of CH₄ ±20%, whereas the total inventory uncertainty is around ±6%. In some emission categories the uncertainties are much wider.

The uncertainty in the Finnish Greenhouse Gas Emission Inventory in 2001 is estimated using the Tier 2 method (Monte Carlo simulation) following the IPCC Good Practice Guidance. Most of the CO₂ emission sources are well known, but CH₄ and N₂O emissions contain a lot of uncertainty. Of the 25 key sources in Finland (emission sources, which have a significant effect on the total inventory uncertainty), more than half are N₂O and CH₄ sources.

The uncertainty in CH₄ emissions from landfills are presented in more detail in this study. In the Finnish inventory, CH₄ emissions from landfills are modelled with a First Order Decay Model (FOD). The uncertainty in solid waste disposal is assessed by replacing the parameters of the FOD model with probability density functions describing the uncertainty. According to the study, the parameters affecting the uncertainty in FOD model most are the fraction of methane in landfill gas, fraction of organic carbon dissimilated and fraction of organic carbon in different waste composites. The total uncertainty in CH₄ emissions from landfills is around ±30%.

1. INTRODUCTION

According to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol made under it, the parties of the convention have to calculate their greenhouse gas emissions annually. It is also decided that parties have to estimate the uncertainties associated with their emission estimates.

All emission estimates contain uncertainty. In the simplest case, uncertainty is due to inaccuracy in emission monitoring, and the estimate can be based on the confidence level of monitoring instruments. In most cases, however, emission estimates cannot be based on monitoring. In these cases, emissions are estimated using emission factors and activity data, or by modelling the emission source (e.g. using a dynamic model for waste degradation in

landfills). Uncertainties can then arise from lack of knowledge of used emission factors and activity data, from errors in models or from biased expert judgements. Uncertainties can also be found in definitions, natural variability of the process and reference data (Penman et al. 2000). Though CO₂ emissions dominate the emission level in Finland and in many other industrial countries, non-CO₂ gases dominate the uncertainty. Sources of non-CO₂ gases are rather poorly known, and they can be highly variable in both space and time (Rypdal 2002).

The uncertainty in the Finnish Greenhouse Gas Emission Inventory was estimated first time using the Tier 2 method for the year 2001. This study is reported in (Monni & Syri 2003; Monni et al. 2003). This paper concerns the significance of methane and nitrous oxide emissions in the total uncertainty in Finnish greenhouse gas emissions.

2. METHODS

In greenhouse gas emission inventories, as well as in uncertainty estimates, the IPCC Good Practice Guidance (Penman et al. 2000) should be followed. The guidance gives advice on how to assess the uncertainties in input parameters, and also on how to combine uncertainties, e.g. by gas or by sector.

In the uncertainty estimate of the Finnish 2001 Greenhouse Gas Emission Inventory (Monni & Syri 2003), input parameter uncertainties were estimated using domestic and international literature, available measurement data, IPCC default uncertainties and expert judgements. Good Practice Guidance gives two methods to combine uncertainties. In the first method, Tier 1, rather simple error propagation equations are used to combine uncertainties. All uncertainties are assumed normally distributed, and the handling of correlations is rather limited. In the Tier 2 method, uncertainties are combined using Monte Carlo simulation, which allows the use of probability distributions of all possible shapes and widths, and the handling of correlations is very flexible. The latter method is used in the Finnish 2001 uncertainty estimate.

3. UNCERTAINTIES IN CH₄ AND N₂O EMISSIONS

In Finland, CH₄ emissions occur in all sectors (except solvent use): fuel combustion, fugitive emissions from fuels, industrial processes, agriculture and waste. N₂O emissions occur in fuel combustion, industrial processes, solvent and other product use, agriculture and wastewater handling sectors. The uncertainty in these sources comes from uncertainties in activity data, emission factors and other calculation parameters. In most emission sources, activity data is very well known when compared with other calculation parameters. Activity data includes, e.g., fuel consumption, industrial production and number of domestic animals. Relatively accurate statistics of all these exist in Finland, and therefore the uncertainties are rather low.

Emission factors contain far higher uncertainties. The formation processes of methane and nitrous oxide in combustion and in industrial processes vary a lot

according to process conditions, fuel type, combustion temperature etc. These processes are difficult to predict and model. In addition, new combustion processes have different emissions than conventional processes. For example, fluidised bed combustion, which aims at reducing NO_x emissions, causes more nitrous oxide than the conventional processes. There is seldom enough measurement data of all combustion technologies, which increases the uncertainty.

In the agricultural sector, the processes causing emissions from, e.g., enteric fermentation of domestic animals, or nitrous oxide formation in agricultural soils, are rather poorly known. In addition, the natural variability of the emission sources is large. The emissions from agricultural soils, for example, depend strongly on local conditions, like on soil type, climate, humidity and availability of oxygen.

According to the IPCC Good Practice Guidance, also the key sources of the inventory (i.e. emission sources, which have a significant effect on the total inventory uncertainty) have to be identified. Of the 25 key sources in Finland in 2001, 14 are N₂O and CH₄ sources, though these emissions represent only 15% of total emissions.

In Table 1, selected CH₄ emission sources in Finland in 2001 are presented, as well as their uncertainties. The uncertainties result from Monte Carlo simulation, and are expressed as upper and lower bounds of the 95% confidence interval, and presented as percents relative to the mean value.

Table 1. Examples of CH₄ emission sources and their estimated uncertainties in Finland in 2001 (Ministry of the Environment 2003; Monni & Syri 2003).

Emission Source	Emissions, Gg CO₂ eq	Uncertainty
Enteric fermentation of domestic animals	1 600	±30%
Manure management	200	-17...+16%
Landfills	2 900	-29...+31%
Domestic and commercial wastewater	110	-55...+109%

Examples of N₂O emission sources and their uncertainties in Finland in 2001 are presented in Table 2. The uncertainties result from Monte Carlo simulation, and are expressed similarly as in Table 1.

Table 2. Examples of N₂O emission sources and their estimated uncertainties in Finland in 2001 (Ministry of the Environment 2003; Monni & Syri 2003).

Emission Source	Emissions, Gg CO₂ eq	Uncertainty
Nitric acid production	1 300	-57...+99%
N ₂ O use	50	-34...+38%
Manure management	400	-82...+35%
Agricultural soils	3 300	-59...+76%
Domestic and commercial wastewater in densely populated areas	70	-92...+378%

4. SOLID WASTE DISPOSAL ON LAND

Methane emissions from solid waste disposal on land is one of the most significant non-CO₂ greenhouse gas sources in Finland. They represent more than half of the total methane emissions from Finland, and nearly quarter of CH₄ and N₂O emissions together, when expressed as CO₂ equivalents.

In the Finnish inventory, CH₄ emissions from landfills are modelled with a First Order Decay Model (FOD). This method takes also into account the emissions originating from waste disposed in landfills before the inventory year (in Finland, the first year of calculation is 1900). In the alternative calculation method, only the amount of waste disposed in landfills in the inventory year is taken into account. This method can either under- or overestimate emissions depending on the relative share of current and past amount of waste. The uncertainty in solid waste disposal is assessed by replacing the parameters of the FOD model with probability density functions describing the uncertainty.

Historical activity data (the amount of municipal waste) has been approximated using current annual amount of waste (in Finland, the year 1990 is used as a reference year) and the changes in gross domestic product (GDP) and population. However, there is no clear evidence of the correspondence between the amount of municipal waste and the above mentioned parameters. In Finland, GDP is estimated to be a more significant factor than population affecting the amount of municipal waste. Therefore the index for waste production is estimated by weighting GDP with 70% and population with 30%. In Finland, the increase in GDP has been very rapid in relation to the increase in population.

However, the resulting activity data values, if GDP or population would have been weighted by 100%, can be used as a basis for uncertainty estimates of historical activity data. The uncertainty estimates of historical activity data of the years 1900-1970 are based on differences between weighting of GDP and population. The uncertainty estimates of current amounts of waste are based on differences between different statistics, and also on expert judgement.

In the case of municipal sludge, the uncertainties also in current activity data are large. Therefore an uncertainty estimate -50...+100% is used for the whole time series based on expert judgement. In the other cases, activity data is far better known. Historical amount of industrial waste is estimated based on the volume of industrial production. This can be seen as a much more reliable estimate than e.g. the corresponding estimates of the municipal solid waste.

The other parameters of the FOD model contain even higher uncertainties than activity data. Uncertainties are mainly due to lack of knowledge of waste degradation process. It is also unclear, if the parameters of the model are suitable for the Finnish conditions. In Finland, climate is rather cold, which might have an effect on waste degradation. The uncertainties in other calculation parameters of the FOD model are estimated using measurement data, IPCC default uncertainties and expert judgement.

In some cases, however, Finnish uncertainties are estimated lower than in the IPCC Good Practice Guidance due to advanced knowledge. For example, in the IPCC Good Practice Guidance, an uncertainty estimate is given for the maximal default value of degradable organic carbon (DOC=0.21): -50...+20%. In Finland, different DOC values are used for different types of waste, and the uncertainty is estimated at $\pm 20\%$. Lower uncertainty estimate results from country-specific knowledge, because the DOC value is estimated based on measurements in 1990.

In the IPCC Good Practice Guidance, the uncertainty in methane recovery (R) is estimated to be “relatively small compared to other uncertainties if metering is in place” (Penman et al. 2000). In Finland, the amount of landfill gas recovered is obtained from the Finnish Biogas Plant register. This data is considered very accurate, and the uncertainty is estimated at $\pm 5\%$. An interesting note is that methane recovery describes the reduction of emissions compared with the situation where gas is emitted. In this case, the emission reduction is accurately known, though the total emissions contain high uncertainties.

5. RESULTS

The total uncertainty in CH₄ emissions in the 2001 inventory, resulting from Monte Carlo simulation, was -19...+20%. The asymmetrical distribution results due to some highly uncertain emission sources that are asymmetrically distributed.

The most important factors affecting the uncertainty in CH₄ emissions come from various sectors. The factor affecting the uncertainty in CH₄ emissions most is solid waste disposal on land. The next most significant factors to be considered are emission factor of enteric fermentation of dairy cattle, and the emission factor of biomass combustion in small point sources (e.g. residential, agricultural, forestry). The remaining CH₄ emission sources are only of minor importance in terms of uncertainty.

The total uncertainty in N₂O emissions in Finland is calculated at -33...+40%. The most important factor is the N₂O emission factor of direct emissions from agricultural soils. The following ones are emission factor of nitric acid production and the emission factor of cars with catalytic converters.

The resulting total emission uncertainty in solid waste disposal on land is -29...+31%, gamma distributed. It can be seen that the factor clearly affecting the uncertainty most is fraction of methane in landfill gas. The estimation of the uncertainty in this parameter was based on variation of data from selected landfills. However, the measurements might overestimate the uncertainty, because the uncertainty in measurements may be larger than the real uncertainty in the fraction of methane in landfill gas. The second most important factor is fraction of organic carbon dissimilated. The following most significant factors are related to fraction of degradable organic carbon in

different waste composites, and the fifth most important factor is the methane generation rate constant.

In Figure 1, uncertainty distributions of Solid Waste Disposal on Land and Wastewater Handling are presented, as well as the distribution of the sum. It can be seen that distribution of Wastewater Handling is clearly asymmetrical (lognormal), but emissions are relatively small. Distributions of solid waste disposal on land and total waste sector, in turn, are nearly normal (they are slightly positively skewed gamma distributions).

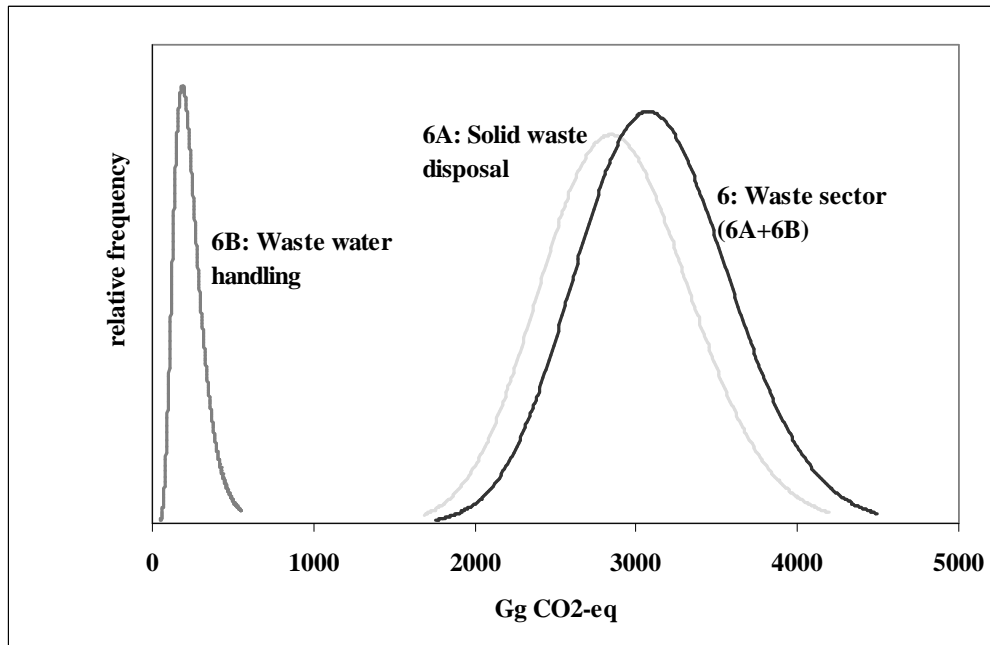


Figure 1. Uncertainty distributions of wastewater handling, solid waste disposal on land and the total waste sector. 6A and 6B denote the IPCC categories (Monni & Syri 2003).

6. DISCUSSION AND CONCLUSIONS

In this study, the significance of methane and nitrous oxide emissions as a source of uncertainty in national greenhouse gas emission inventories is presented, using the Finnish 2001 inventory as an example. In Finland, as in other industrial countries also, the most important greenhouse gas is carbon dioxide. However, methane and nitrous oxide emissions have a great effect on the inventory uncertainty.

In Finland, total uncertainty in CH₄ emissions in 2001 was around $\pm 20\%$, and that of N₂O -33...+40%. The most important sources affecting the uncertainty in CH₄ emissions are solid waste disposal on land and enteric fermentation of dairy cattle. Instead, the most important sources of uncertainty in nitrous oxide emissions are related to N₂O emissions from agricultural soils.

Uncertainties in some emission sources (e.g. in energy and industry) can be reduced with continuous measurement of emissions or at least by some measurements, on which the emission factors can be based. Instead, a large share of methane and nitrous oxide emissions come from agriculture and waste sectors, where the reduction of uncertainties is much more difficult. These emissions have a large natural variability, and therefore it is difficult to obtain good average emission factors. Reduction of uncertainties is important for the future climate conventions, and especially, if these gases will be subjected to emission trading in the future.

REFERENCES

Ministry of the Environment. 2003. Greenhouse Gas Emissions in Finland 1990–2001. National Inventory Report to the UNFCCC Secretariat. Helsinki: Ministry of the Environment. 95 p.

Monni, S., Syri, S., and Savolainen, I. 2003. Advanced Methods for Estimating Uncertainty in National Greenhouse Gas Emission Inventories – the Case of Finland. Conference paper for 12th international Emission Inventory Conference “Emission Inventories – Applying New Technologies”. San Diego, California, April 28- May 1, 2003.

Monni, S. and Syri, S. 2003. Uncertainties in the Finnish 2001 Greenhouse Gas Emission Inventory. VTT Research Notes 2209.

Penman, J., Kruger, D., Galbally, I., Hiraishi, T., Nyenzi, B., Emmanuel, S., Buendia, L., Hoppaus, R., Martinsen, T., Meijer, J., Miwa, K. & Tanabe, K. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Hayama: Intergovernmental Panel on Climate Change (IPCC). ISBN 4-88788-000-6.

Rypdal, K. 2002. Can we get rid of uncertainties in GHG inventories? In: Van Ham, J., Baede, A.P.M., Guicherit, R. & Williams-Jacobse, J.G.F.M. (eds.). Non-CO₂ greenhouse gases: Scientific understanding, control options and policy aspects. Rotterdam, Netherlands: Millpress. Pp 517-527. ISBN 90 7701770 4.