Advanced Methods for Estimating Uncertainty in National Greenhouse Gas Emission Inventories – the Case of Finland

Suvi Monni, Sanna Syri and Ilkka Savolainen
VTT Technical Research Centre of Finland
B.O.Box 1606
FIN-02044 VTT
Finland
suvi.monni@vtt.fi

ABSTRACT

This contribution presents the first comprehensive Tier 2 uncertainty analysis of the national greenhouse gas emission inventory performed in Finland. Reliable uncertainty estimates of national emission inventories have central role for the future verification of compliance with the Kyoto protocol requirements. Accurate emission estimates are also essential for emission trading. High-quality uncertainty estimates also give important information on the research priorities for the future improvement of the emission inventories.

All emission estimates contain uncertainty. Uncertainty can arise from, e.g., inaccuracy of emission monitoring, lack of knowledge in the emission factor and activity data estimates, or from bias in expert judgement. The quality of emission inventories for the most important greenhouse gas, CO_2, depends mainly on the accuracy of fuel use statistics. Some other sources of CO_2, e.g. emissions from agricultural soils, and the other greenhouse gases of the Kyoto Protocol, CH_4, N_2O, HFCs, PFCs and SF_6, are usually quite poorly known.

In this work, uncertainty estimates were based on available measurement data, domestic and international literature, expert judgement and the recommendations of the Intergovernmental Panel on Climate Change (IPCC). Uncertainty estimates of different sources are combined using Monte Carlo simulation, which allows the use of, e.g., asymmetrical distributions and a flexible handling of correlations.

In Finland, like in many countries, the most uncertain emission sources are N_2O emission from transportation, N_2O and CO_2 emissions from agricultural soils and CH_4 and N_2O emissions from the waste sector. The total uncertainty of Finnish greenhouse gas emission inventory is below ±7%.

INTRODUCTION

Climate change, due to increasing greenhouse gas concentrations in the atmosphere, can be seen as one of the most serious environmental risks facing humankind. Mitigation of climate change requires significant reductions of greenhouse gas emissions. The United Nations Framework Convention on Climate Change (UNFCCC) from the year 1992 can be seen as the first global effort to mitigate climate change. According to the Kyoto Protocol from the year 1997, industrial countries have to reduce their greenhouse gas (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) emissions on average by 5.2% under the 1990 level by the first commitment period 2008-2012. The current emission reduction target is not enough in order to stabilise atmospheric greenhouse gas concentrations but can be seen, however, a beginning of the emission reduction process. Negotiations of the second commitment period after 2012 will begin in a couple of years. European Union has a common emission reduction target of 8% below 1990 level. In the burden sharing of the European Union, Finland obtained a target of 0%, i.e. the emissions should be on average at the 1990 level between 2008 and 2012.

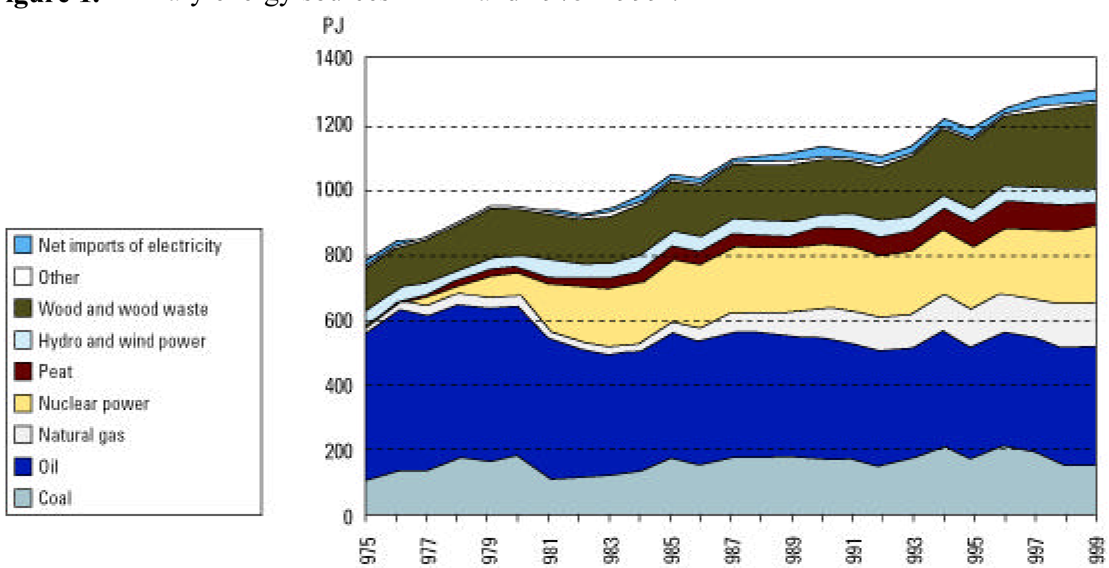
The implementation of the Kyoto Protocol and the forthcoming protocols need high-quality emission inventories to ensure an equitable treatment of all parties of the convention. Reliable uncertainty estimates are a tool for increasing the quality of national emission inventories. However, only a few industrial countries (so-called Annex I countries), namely Australia, Austria, Norway and the UK have performed a Tier 2 (Monte Carlo) uncertainty analysis of recent inventories. Canada has performed an uncertainty analysis for the year 1990 inventory. In addition to these, the Netherlands and the USA have performed a Tier 1 uncertainty analysis, as well as Finland. Rypdal and Winiwarter[1] have compared the uncertainty estimates of Austria, Norway, the Netherlands, the UK and the USA. Most countries, which have performed an uncertainty analysis, have end up with a level uncertainty of ±5-20%, and a trend uncertainty of around ±5%-points, which seem rather high uncertainties when compared with the reduction target. Accurate emission estimates are also essential for emission trading, and high-quality uncertainty estimates give important information on the research priorities for the future improvement of the emission inventories.

This study presents the first comprehensive Tier 2 uncertainty analysis of the national greenhouse gas emission inventory performed in Finland. In this work, uncertainty estimates were based on available measurement data, domestic and international literature, expert judgement and the recommendations of the IPCC. Uncertainty estimates of different sources and gases were combined using Monte Carlo simulation, which allows the use of, e.g., asymmetrical distributions and a flexible handling of correlations. Uncertainties in land-use, land-use change and forestry sector were not included to the assessment.

GREENHOUSE GAS EMISSIONS AND TRENDS IN FINLAND

Finland is a northerly-located country (a quarter of the country lies north of the Arctic circle) with a cold climate. The mean annual temperature is below 6°C in the southern parts of the country, and even less in the northern parts. This causes high heating requirements in the winter months – around one fifth of final energy is used for space heating. A large amount of energy is also used to produce export products, e.g. products of paper and metal industry. In total, industry uses half of the total final energy. Most of the primary energy fuels used in Finland are imported. Main domestic sources of primary energy are hydropower and biomass by-products from pulp and paper industry, together with peat. Peat production areas, as well as peat utilisation in energy production are significant and very country-specific greenhouse gas emission sources in Finland[2].

Figure 1. Primary energy sources in Finland 1975-1999[2].



Total primary energy consumption in Finland between 1975-1999 is presented in Figure 1. It can be seen, that about two thirds of primary energy comes from imported sources, mainly coal, oil, nuclear fuel, and with an increasing amount, natural gas. The use of oil has been steadily decreasing, and the use of coal decreased, when nuclear power plants were taken into use. The use of natural gas and wood-based fuels has also increased recently. In 1999, the share of renewable energy and the slowly renewable biomass, peat, was 28% of the total primary energy supply. However, peat is not treated as a renewable fuel in the emission inventories. The use of black liquor and wood wastes in pulp and paper industry has also been increasing[2].

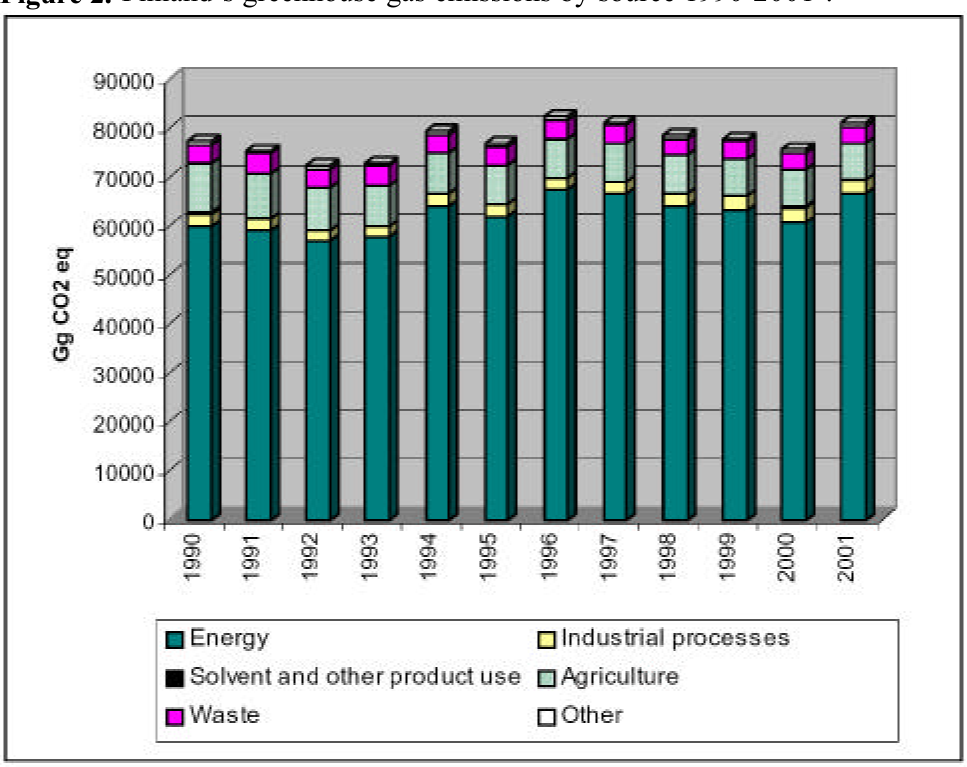
Fluidised bed combustion is also used rather widely in Finland. The advantages of this combustion technology are fuel flexibility (e.g. possibility to combust inhomogeneous low-grade fuels with variable particle size and energy content), low NO_x emissions and in-process capture of SO_2. Fluidised bed combustion has lower NO_x emissions, but rather large N_2O emissions compared with other combustion technologies.

Total greenhouse gas emissions (without removals) were approximately 77Mt CO_2-equivalents in 1990. However, in 2001 the emissions were 3Mt above the 1990 level. The total emissions have quite a fluctuating trend, mainly resulting from the economic fluctuation in the energy intensive industries[3], and availability of hydropower in the Nordic electricity market.

Energy sector, releasing CO_2, CH_4 and N_2O, covers some 80% of greenhouse gas emissions in Finland. Energy sector covers all emissions related to the production, distribution and consumption of fuels, including transportation. Finland's greenhouse gas emissions by source in 1990-2001 are presented in Figure 2. The variation in CO_2 emissions is mainly caused by variation in carbon dioxide emissions from the production of power, heat and steam. These emissions are highly dependent on economic trend and the energy supply structure, which is impacted by the availability of cheap hydropower in the Nordic electricity market[3], which varies considerably between rainy and dry years.

The second most significant emission source in Finland (10% of greenhouse gas emissions) is agriculture. Emissions from agriculture have decreased between 1990 and 2001 due to decreases in cultivation of organogenic land, nitrogen fertilisation and number of domestic livestock[3].

Figure 2. Finland's greenhouse gas emissions by source 1990-2001[3].

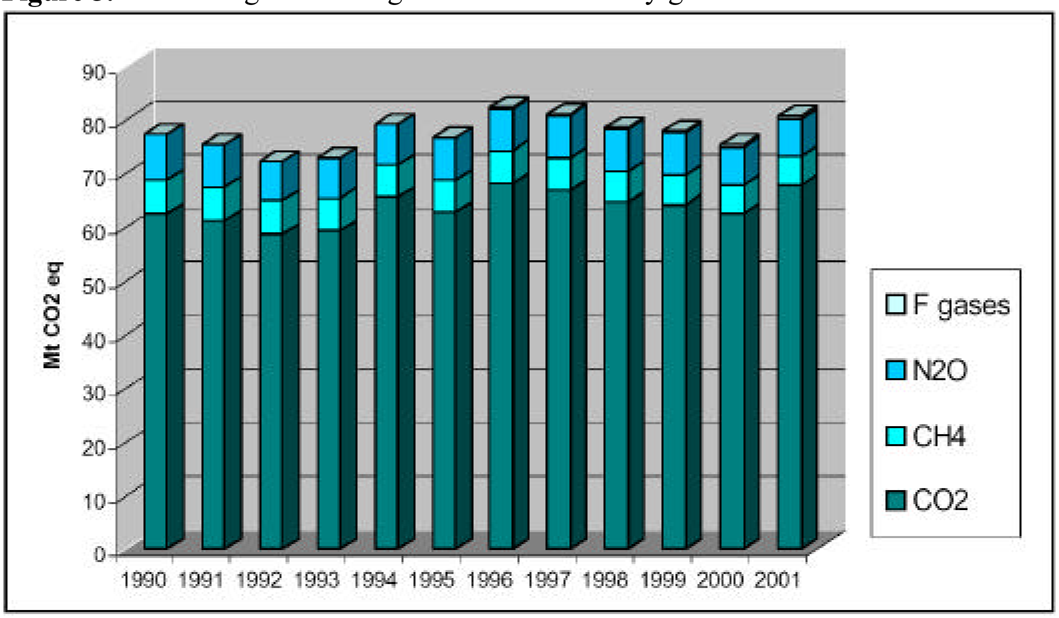


The emissions from industrial sector are around 4% of total greenhouse gas emissions in Finland. The emission level has not changed since 1990. The most important emission source in the industrial sector is N_2O emissions from nitric acid production[3].

Waste sector covers around 4% of Finland's greenhouse gas emissions. However, the emissions from waste sector have decreased some 20% since 1990. This is mainly due to the new waste law implemented in Finland in 1994. The CH_4 emissions from landfills are the most important emission source in the waste sector. After the implementation of the new waste law, the amount of municipal waste dumped in landfills has decreased significantly due to minimisation of waste generation, as well as recycling and reuse of waste material. In addition, some new waste treatment methods have been taken into use in landfills. These policies together have caused the significant reduction in emissions from landfills[3].

If Finland's emission trends are considered by gas (as in Figure 3), it can be seen that the emissions of CO_2 – the most important greenhouse gas in Finland - have increased some 8% since the year 1990. However, CO_2 emissions vary from year to year due to variation in energy sector, as described above. Nitrous oxide (N_2O) is the second most important greenhouse gas in Finland with a share of 10% of total emissions. The most important source of N_2O is agriculture. N_2O also has a very fluctuating trend, but the emissions were around 17% below 1990 level in 2001. CH_4 emissions have had a clearly decreasing trend over the 1990's, manly because of emission reduction in the waste sector. Instead, the F-gases (HFCs, PFCs and SF_6) have an increasing trend, though their share of total emissions is still very low (0.7 % in 2001)[3].

Figure 3. Finland's greenhouse gas emission trends by gas 1990-2001[3].



Only a few emission estimates can be based on direct measurements of emissions. Most emissions in the Finnish inventory are calculated using emission factors and activity data values. Some of the emission factors used in Finland base on plant-specific measurements, some are expert judgements and some are IPCC default emission factors. In the waste sector, a new dynamic model describing the degradation of waste in landfills has been taken into use for the year 2001 inventory[3].

In general, the quality of emission inventories for the most important greenhouse gas, CO_2, depends mainly on the accuracy of fuel use statistics. These are very accurate in Finland, and also the quality of commercially traded fuels is good, i.e. fuel density and carbon content are nearly constant. Some other sources of CO_2, e.g. emissions from agricultural soils, and the other greenhouse gases of the Kyoto Protocol, CH_4, N_2O, HFCs, PFCs and SF_6, are usually quite poorly known. In Finland, like in many countries, the most uncertain emission sources are N_2O emissions from transportation, emissions from agricultural soils and emissions from the waste sector. In addition, there are two highly uncertain sources very specific for Finland, namely fugitive emissions from peat production and N_2O emissions from fluidised-bed combustion. The share of peat of total primary energy consumption in Finland was around 6% in 2001[4].

METHODS

In most cases, for the purpose of uncertainty estimates, inventory calculations have to be simplified. In the Finnish uncertainty estimation, most emissions were calculated using activity data and emission factor in a coarser source category level than in the original inventory calculation. For example in Energy Industries, the uncertainties were estimated by fuel types but not divided into lower subcategories (public electricity and heat production, petroleum-refining etc). This is reasonable, because the uncertainties are lower at the upper level than at the lower level (total fuel consumption is better known than sectoral shares).

Uncertainties in Input Parameters

In general, the best basis for uncertainty estimates would be accurate measurement data. If there were enough measurement data, the variance in data could be used as an estimate of the random uncertainty. The effect of possible systematic error could be added based on knowledge of measurement instruments and procedures. However, accurate and comprehensive measurement data of the whole emission category are seldom available. Therefore the uncertainty estimates have to be based on, e.g., national and international literature, available measurement data, IPCC recommendations or expert judgement.

In the Finnish uncertainty estimation, all measurement data available was used. When there was lack of domestic data, international literature was reviewed, if emission sources studied were seen to be similar enough with those in Finland. If IPCC default values for, e.g., emission factors were used in emission inventory, then the IPCC default uncertainties were also used as a basis for uncertainty estimate in most cases. However, the suitability of these estimates in Finnish circumstances had to be ensured.

According to IPCC recommendations[5], the uncertainties were in the Finnish inventory expressed as 2.5 and 97.5 percentiles defined as percents relative to the mean value. Uncertainties lower than ±60% were assumed normally distributed in most cases. In the case of larger uncertainties the most widely used distributions were lognormal and gamma distributions, especially in the case of expert judgements. Empirical data was used in several cases, and the resulting distributions could have all possible shapes.

Treatment of Correlations

Correlations might have significant effect on the resulting overall inventory uncertainty. For example, total fuel use is often rather accurately known, but the sectoral shares of fuel use can be rather poorly known. When the use of same fuel type in several categories is correlated, the overall uncertainty can be kept at a lower level, because the uncertainty at the upper level is small. For example, the use of gasoline was assumed to be 100% correlated in the case of road transportation (both in cars with and without catalytic converters), waterborne navigation (leisure boats) and off-road machinery. When calculating trend, all emission factors were assumed to correlate between the years 1990 and 2001, whereas activity data is assumed independent in different years in most cases.

Combining Uncertainties

For the year 2001 inventory the Tier 2 method (Monte Carlo simulation) was taken at use to combine uncertainties. In Monte Carlo simulation, random numbers are selected from each distribution (for example from probability distributions of activity data and emission factors), and the total emissions are calculated, e.g. 15 000, times to obtain the probability distribution of total emissions. To obtain the total inventory uncertainty, different gases were weighted according to their

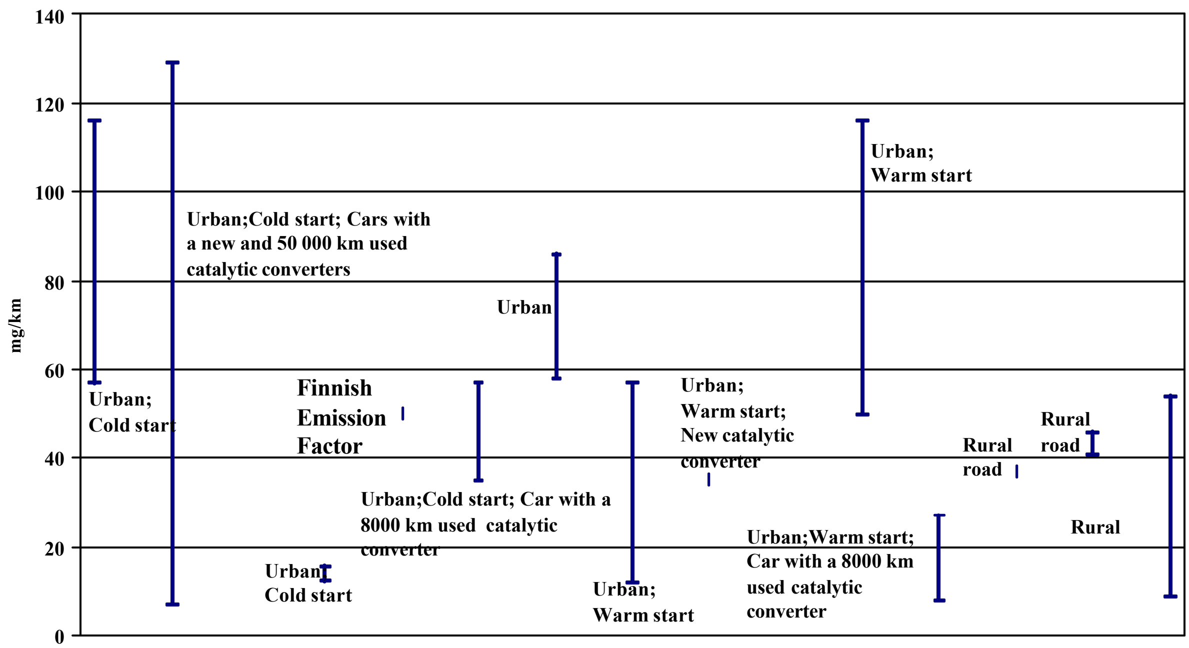
Global Warming Potential (GWP) values. Uncertainties of the GWP-values were not taken into account in uncertainty estimates, though they contain significant uncertainties[5], i.e. ± 35%[6].

SECTORAL UNCERTAINTIES

Energy (IPCC Source category 1A)

In the energy sector, uncertainties in activity data and in CO_2 emission factors are low in Finland. All fossil fuels used in Finland are imported, and the accuracy of fuel statistics is high. However, emission factors of CH_4 and especially N_2O are highly uncertain. These emissions depend strongly on process conditions, and these conditions are difficult to predict and model. Nitrous oxide emission factor depends strongly on combustion technology. For example, fluidised bed combustion has far higher N_2O emissions than conventional combustion technologies. Some measurements of CH_4 and N_2O emission factors on different combustion technologies have been performed lately[7,8] but more measurements are still needed to obtain accurate emission factors and thus, uncertainty estimates.

Figure 4. Measurement results of N_2O emission factors [mg/km] in different studies [9,10,11,12,13] and the emission factor used in the Finnish inventory.



In the transportation sector, available domestic and international measurement data was used to assess the uncertainties[9,10,11,12,13,14,15,16,17]. Much more measurement data is available of hydrocarbon and NO_x emissions than for CH_4 and N_2O emissions. Variation in measurement data of total hyrdocarbon emissions can to some extent be used to approximate the variation in methane emissions. Instead, the dependence between variation of NO_x and N_2O emissions is not so clear.

As an example, Figure 4 illustrates the differences between different studies of N_2O emission factor of cars with catalytic converters. The measurements have been performed with different cars and in different driving conditions (urban areas, highways etc.). These give, however, a picture of the possible uncertainty range of N_2O emission factor used.

Fugitive Emissions from Fuels (IPCC Source Category 1B)

Fugitive emissions from solid fuels in Finland arise from peat production. This contains preparation and profiling of peat soils as well as stockpiling of peat. This sector is very specific for

Finland, and hence very little international data of emission factors is available. In the Finnish greenhouse gas emission inventory, CO_2 emissions have been estimated for both peatlands currently used for peat production as well as for arable peatlands, which can be assumed to be reservoirs for future peat production. CH_4 emissions have been estimated only for currently used peatlands. The area currently used for peat production is rather well known, but the area of arable peatlands is more difficult to estimate. The emission factors contain even higher uncertainties. Some domestic measurement data of emission factors from arable peatlands is available[18,19,20,21], but the amount of measurement data from peatlands already in use is very small. Fugitive emissions have been reported under Energy sector in recent inventories, but will probably be moved to LULUCF (Land Use, Land Use Change and Forestry) sector in forthcoming inventories.

Industry (IPCC Source category 2)

There are only a few industrial greenhouse gas emission sources in Finland, and most uncertainties in this sector are rather low. Activity data is mostly obtained from industrial plants directly, and it is assumed rather accurate. There is one industrial source with national emission factors in Finland, namely N_2O from nitric acid production. The uncertainty in this was assessed based on national measurement data from industrial plants directly. The number of measurements was rather low, however. The uncertainty in emission factors was estimated based on variation between different measurement periods, variation within individual measurement series and information on measurement instruments.

Agriculture (IPCC Source Category 4)

In the agricultural sector, activity data is often well known. For example, the number of cattle can be calculated rather accurately, because all cattle in Finland have individual earmarks, and all births, deaths and slaughters are registered. However, the uncertainties in emission factors are high. In addition, even the natural variability of the sector is high. For example, the emissions from enteric fermentation and manure can vary a lot between individual animals. The most uncertain source, however, is N_2O emissions from agricultural soils.

Waste (IPCC Source Category 6)

In the Finnish greenhouse gas emission inventory, emissions from solid waste disposal on land are assessed using the Tier 2 method of IPCC Good Practice Guidance[5]. This method is a first order decay method (FOD), which takes into account the whole time series of waste disposal. 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.

In Finland, the historical waste amount is assessed beginning from the year 1900. The uncertainties in historical activity data are large, because estimates are based on current amount of waste and changes in Gross Domestic Product (GDP) and population. However, the amount of waste produced in the beginning of 1900's was rather small, thus reducing the significance of large uncertainties. The modelling of the decay of waste has many rather poorly known parameters. All the uncertainty estimates of the parameters were added straight to the FOD model, in order to take the dynamic behaviour of waste degradation into account also in the uncertainty analysis. The total uncertainty in CH_4 emissions from solid waste disposal on land is around ±30%. The parameters of FOD model, which have the strongest effect on uncertainty, are the faction of methane in landfill gas and the fraction of organic carbon dissimilated. In the wastewater sector, the uncertainties are very high due to the large uncertainties in the N_2O emission factor.

RESULTS

According to calculations, the total uncertainty of the Finnish 2001 greenhouse gas emission inventory is –5...+6%. Total uncertainties in other countries vary from ±4% to 21%[1]. The share of

CO_2 emissions from fuel combustion, which has low uncertainties, is large in Finland, thus resulting in rather low total inventory uncertainty, though some input parameters have very large uncertainties. The uncertainties by gas (resulting from the Monte Carlo Simulation) are presented in Table 1.

According to this study, the trend uncertainty in Finland is ±5%-points, when it is ±4-5%-points in Norway, the UK and Austria [1].

Table 1. Uncertainties by gas in the Finnish 2001 emission inventory.

Gas	Uncertainty
CO_2	-4...+6%
CH_4	–19...+20%
N_2O	-33...+40%
HFCs, PFCs and SF_6	–53...+32%

The uncertainty in CO_2 emissions from fuel combustion is low, but the uncertainties in CO_2 emissions from other sources, e.g. peat production, are higher. When compared with other countries (namely Austria, Norway, the Netherlands, UK and the USA), the uncertainty in Finnish CO_2 emissions is rather high, namely -4…+6%, when it is in other countries ±2-4%[1]. This is due to the fact that in Finland, CO_2 emissions occur also from peat production, which is a highly uncertain emission source.

The uncertainties in other gases than CO_2 are far higher, mainly because of the nature of the emission sources. The uncertainty in CH_4 emissions in other countries varies from ±17% to ±48%[1].In Finland, the uncertainty is estimated at –19...+20%. In the case of N_2O, the estimates differ a lot between countries. In other countries, the N_2O emission uncertainty varies from ±34% until 230%. In Finland, the uncertainty seems to be at the lower end, namely -33...+40%. Rather low CH_4 and N_2O uncertainty estimates in Finland occur for two reasons: firstly, the uncertainties in input parameters might be estimated lower as in reviewed countries. Secondly, a significant amount of these emissions occur in Finland in fuel combustion sector (e.g. in fluidised bed combustion), which is far better known, than for example N_2O emissions from agricultural soils, which might dominate the uncertainty in other countries.

The uncertainties by sector, which are also results of Monte Carlo simulation, are presented in Table 2. It can be seen that the uncertainties in the most important emission source, fuel combustion, are rather low. However, all other sectors contain far higher uncertainties, and the clearly most uncertain source is fugitive emissions from fuels.

Table 2. Sectoral uncertainties in the Finnish 2001 emission inventory.

Sector	IPCC code	Uncertainty in 2001 (%)
Fuel Combustion	1A	±3%
Fugitive emissions from fuels	1B	-59...+106%
Industry	2	-27...+43%
Agriculture	4	-37...+47%
Waste	6	-28...+30%
Total		-5...+6%

Key Sources

The key sources of the inventory, i.e. the emission sources, which affect the inventory uncertainty most, are defined using the Tier 2 method of the IPCC Good Practice Guidance[5]. 10 most important key sources are presented in Table 3. Peat production, as well as agricultural soils have very important role if uncertainty is to be reduced. Half of the 10 most important key sources arise from fuel combustion. This indicates also the effect of total emission level into the key source identification. Some highly uncertain emission sources (like N_2O from wastewater) are not identified as key sources, because the emission levels are low. Key source analysis can be used as a tool, when allocating the resources of inventory improvements to the most important sources.

Table 3. 10 most important key source categories in the Finnish 2001 ghg emission inventory.

Source category number	Gas	Key Sources
1B	CO_2	Arable peatlands
4D	N_2O	Agricultural soils
1B	CO_2	Peat production areas
1A4	CO_2	Other Sectors (commercial, institutional, residential, agriculture, forestry, fisheries,): Liquid Fuels
2B2	N_2O	Nitric Acid Production
6A	CH_4	Solid Waste disposal on Land
1A1	CO_2	Energy Industries: Other fuels
1A5	CO_2	Other (military etc): Liquid Fuels
1A3	N_2O	Road Transportation: Gasoline (cars with catalytic converters)
4A	CH_4	Enteric Fermentation

DISCUSSION AND CONCLUSIONS

The first Tier 2 uncertainty assessment was performed for the Finnish year 2001 greenhouse gas emission inventory. The most significant sources contributing to total uncertainty are CO_2 emissions from peat fuel production and N_2O emissions from agricultural soils according to key source analysis. Uncertainty estimates as a part of emission inventories are essential for the future verification of compliance with the Kyoto protocol requirements. All emission estimates contain uncertainty, which can arise from a number of reasons, and these reasons should be identified to increase the accuracy of emission inventories.

The total uncertainty of Finnish greenhouse gas emission inventory is rather low (-5...+6% in the case of level, and ±5%-points in the case of trend), because CO_2 emissions from fuel combustion, which are very accurately known (±3%), dominate the emission level.

In Finland, the most uncertain emission source by gas is emissions of HFCs, PFCs and SF_6. However, the share of these emissions is very low in Finland. The emissions of N_2O and CH_4 also contain high uncertainties, when compared, e.g. with uncertainties in CO_2 emissions. When compared with other countries, the uncertainties in N_2O and CH_4 emissions seem to be rather low. A significant amount of these emissions occur in Finland in fuel combustion sector (e.g. in fluidised bed combustion), which is far better known, than for example N_2O emissions from agricultural soils, which might dominate the uncertainty in other countries. This is clearly one reason explaining the rather low uncertainties in Finland.

Uncertainty analysis can be used as a tool for inventory improvements. Research priorities can be allocated to the most uncertain emission sources to increase the accuracy of emission inventories.

REFERENCES

1. Rypdal, K.; Winiwarter, W. "Uncertainties in greenhouse gas emission inventories – evaluation, comparability and implications", *Environmental Science & Policy. 2001,* 4, 107-116.
2. Sarkkinen, S.; Granholm, H.; Kolttola, L.; Kosonen, M.; Ojala, J.; Petäjä, J.; Pänänen-Landtman, A.; Roos, J.; Sourama, H.; Saari, R; Kuusisto, E.; Hämekoski, K. *Finland's Third National Communication under the United Nations Framework Convention on Climate Change;* Karisto Oy; Hämeenlinna, Finland, 2001. p 187.
3. Ministry of the Environment. *Finland's Report on the Greenhouse Gas Emission Inventory to the European Commission;* Ministry of the Environment; Helsinki, Finland, 2002, p 77.

4. Statistics Finland. *Energy statistics 2001;* Statistics Finland; Helsinki, Finland, 2002, p 148.
5. Penman, J.; Kruger, D.; Galbally, I.; Hiraishi, T.; Nyenzi, B.; Emmanuel, S.; Buendia, L.; Hoppaus, R.; Martinsen, T.; Meijer, J.; Miwa, K.; Tanabe, K. *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories;* Intergovernmental Panel on Climate Change (IPCC), IGES; Hayama, Japan, 2000.
6. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Houghton, J.T.; Ding, Y.; Griggs, D.J.; Noguer, M.; van der Linden, P.J.; Dai, X.; Maskell, K.; Johnson, C.A., Eds; Cambridge University Press; Cambridge, United Kindom and New York, NY, USA, 2001, p 881.
7. Korhonen, S.; Fabritius, M.; Hoffren, H. *Methane and nitrous oxide emissions in the Finnish energy production;* Fortum Power and Heat Oy, Helsinki, Finland, 2001, p 36.
8. Fabritius, M.; Korhonen, S.; Hoffren, H. "N2O and CH4 emissions from different power plant processes". In *Non-CO_2 Greenhouse Gases: Scientific Understanding, Control Options and Policy Aspects. Proceedings of the Third International Symposium, Maastricht, The Netherlands. 21-23 January 2002*, van Ham, J., Baede, A.P.M, Guicherit, R., Williams-Jacobse J.G.F.M, Eds; Millpress; Rotterdam, Netherlands, 2002, pp 67-72.
9. Potter, D. 1990. *Lustgasemission från katalysatorbilar.* Chalmers Tekniska Högskola and Göteborgs Universitet, Sweden, 1990; Rapport OOK 90:02.
10. Pringent M.; de Soete, G. *Nitrous Oxide N_2O in engines exhaust gases – A first appraisal of catalyst impact;* 1989. SAE Technical Paper Series 890792.
11. Becker, K.H.; Lörzer, J.C.; Kurtenbach, R.; Wiesen, P. "Nitrous Oxide (N_2O) Emissions from Vehicles", *Environmental Science and Technology.* 1999, 33, 4134-4139.
12. Perby, H. *Lustgasemission från vägtrafik. Preliminära emission faktorer och budgerberäkningar,* Statens väg- och trafikinstitut, Linköping, Sweden, 1990; VTI meddelande 629, p 21.
13. *Chemical and biological characterization of exhaust emissions from vehicles fuelled with gasoline, alcohol, LPG and diesel,* Egebäck, K.E.; Bertilsson, B.M., Eds. National Swedish Environmental Protection Board, SNV PM 1635, Stockholm, Sweden, 1983.
14. EMEP. *Atmospheric Emission Inventory Guidebook*. Co-operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe. 1999.
15. Korhonen, R.; Määttänen, M. *To solve the specific emissions of locomotive diesel engines, final report,* Kymenlaakso Polytechnic, Finland, 1999, p 46.
16. Sjöberg, K.; Lindskog, A.; Rosen, Å; Sundström, L. *N2O-emission från motorfordon*; 1989. TFB-meddelande nr 75.
17. Tarantola, S.; Kioutsioukis, I. *The JRC-IPCS in the ARETEMIS project: summary of the second year of activity.* Institute for the Protection and Security of the Citizen, Technological and Economic Risk Management, I-21020 Ispra (VA) Italy, 2001, p 32.
18. Nykänen, H.; Silvola, J.; Alm, J.; Martikainen, P. "Fluxes of greenhouse gases CH_4, CO_2 and N_2O on some peat mining areas in Finland", *Northern Peatlands in global climatic change*; The Academy of Finland, Helsinki, Finland, 1996. pp 141-147.
19. Laine, K.L.; Selin, P. ;Nyrönen, T. *The role of peat and peat utilisation in carbon balance. Peat memorandum.* 1998. p 11.
20. Selin, P. *Industrial use of peatlands and the re-use of cut-away areas in Finland (In Finnish) Turvevarojen teollinen käyttö ja suopohjien hyödyntäminen Suomessa;.* University of Jyväskylä, Jyväskylä, Finland,1999. p 239.
21. Maljanen, M.; Martikainen, P.; Walden, J.; Silvola, J. "CO2 Exchange in an organic field growing barley of grass in eastern Finland" *Global Change Biology.* 2001, 7, 679-692.

KEY WORDS

Emission Inventories
UNFCCC
Kyoto Protocol
Uncertainty
Monte Carlo simulation